PROCEEDINGS

First USAID/GOI Workshop on Alternative Energy Resources and Development

Coal Conversion and Biomass Conversion

Taj Palace Hotel
New Delhi, India

November 7-11, 1983

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FIRST USAID/GOI WORKSHOP
ON
ALTERNATIVE ENERGY RESOURCES
AND
DEVELOPMENT

COAL CONVERSION
AND
BIOMASS CONVERSION

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TAJ PALACE HOTEL
NEW DELHI, INDIA

NOVEMBER 7-11, 1983

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FIRST WORKSHOP
USAID/GOVERNMENT OF INDIA
COOPERATIVE PROGRAM
ON
ALTERNATIVE ENERGY RESOURCES DEVELOPMENT - COAL/BIOMASS CONVERSION

The First Workshop of this Cooperative Program was held at the Taj Palace Hotel in New Delhi, India on November 7-11, 1983. The intent of the Workshop was to provide a forum for a technical exchange between the U.S. and Indian specialists in specific areas of interest in coal/biomass conversion. The meeting also served the objective of acquainting each side with the present state-of-the-art and ongoing research and development activities in the areas of concern, as well as to conduct specific project-related discussions in order to develop and/or modify work plans for implementing the selected projects. Finally, at the end of the Workshop and subsequent discussions, site visits were made to assess the facilities and equipment, and also to meet the technical personnel available to carry out the proposed projects.

There are four areas selected for collaboration in coal conversion and three in biomass conversion. The four major coal areas are:

- Fluidized-bed combustion
- Gas cleanup and separation
- Coal-water mixtures
- Coal cleaning.

The three major biomass conversion areas are:

- Development of a village-level gasifier (5 hp for irrigation pumps based on charred agricultural residue)
- Utilization of producer gas in small (3 to 5 hp) engines
- Development and field implementation of small wood-based gasifier engine systems (5 to 30 hp)

The Workshop sessions included presentations by Indian scientists/engineers and by U.S. team members, followed by panel discussions. At the opening of the Workshop, representatives of the Government of India and its participating units, the USAID office in New Delhi, and U.S. DOE provided introductory remarks which emphasized the need and importance of the technology development in meeting India's energy needs. During the Workshop sessions, presentations covered the status of the above technologies in both the U.S. and India.

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WORKSHOP AGENDA

Monday, November 7, 1983

Morning Session

10:00 a.m. - 12:00 noon	**Introduction - D. Bienstock, DOE (PETC)** Presentations by the following organizations o USAID - W. Nachtrieb o DNES - B.N. Swarup o CFRI - B.K. Mazumdar o BHEL - M.K. Sridhar
12:30 p.m. - 1:30 p.m.	Lunch

Afternoon Session: Fluidized Bed Combustion, Session Chairman, Y.P. Abbi (BHEL)

2:00 p.m. - 2:45 p.m.	**Indian Presentation**, K.M.V. Malarkkan - BHEL/M.M. Sen (CFRI)
3:00 p.m. - 3:20 p.m.	**Overview of U.S. DOE FBC Program** - J.W. Byam, DOE, (METC)
3:20 p.m. - 3:45 p.m.	**Evaluation of Free Board Performance in a Fluidized Bed Combustor** - R.P. Krishnan, ORNL
4:00 p.m. - 4:15 p.m.	**Break**
4:15 p.m.	**Panel Discussion**

Tuesday, November 8, 1983

Morning Session: Coal Water Mixtures, Session Chairman, M.K. Sarkar (IIT)

9:00 a.m. - 9:45 a.m.	**Indian Presentation**, M. Chakraborty - CFRI K.M.V. Malarkkan - BHEL
10:00 a.m. - 10:45 a.m.	**Status of Coal Water Mixture Technology** - D. Bienstock, DOE (PETC)
11:00 a.m. - 11:15 a.m.	**Break**
11:15 a.m.	**Panel Discussion**
12:30 p.m. - 1:30 p.m.	**Lunch**

WORKSHOP AGENDA (cont'd)

Tuesday, November 8, 1983, (Continued)

Afternoon Session: Coal Cleaning, Session Chairman, B.K. Mazumdar (CFRI)

2:00 p.m. - 2:45 p.m.	**Indian Presentation**, A.K. Chakravarti (CFRI)
3:00 p.m. - 3:45 p.m.	**Status of Coal Cleaning Technology in U.S.** - A. Deurbrouck, DOE (PETC)
4:00 p.m.	**Break**
4:15 p.m.	**Panel Discussion**

Wednesday, November 9, 1983

Morning Session: Biomass Conversion, Session Chairman, O.P. Vimal (DNES)

8:30 a.m. - 8:55 a.m.	**Indian Experience in Gasifying Agricultural Residues** - P.D. Grover, IIT, Delhi
8:55 a.m. - 9:20 a.m.	**Small Internal Combustion Engines for Producer Gas Application** - H.D. Mathur, IIT, Delhi
9:20 a.m. - 9:45 a.m.	**Wood Gasifier Program** - Surendra Kumar, Jyoti Solar Energy Institute, Vallabh Vidjanagar
9:45 a.m. - 10:00 a.m.	**Technology Development Through Biomass Conversion** - M.K. Sarkar, IIT, Delhi
10:00 a.m. - 10:15 a.m.	**On the Combustion of Corncobs in Fluidized-Bed** - A.K. Drona, G.B. Pant, University of Agriculture and Technology, Nanital
10:15 a.m. - 10:30 a.m.	**Break**
10:30 a.m. - 10:55 a.m.	**Gasification and Pyrolysis of Biomass Fuels** - Virgil Flanigan, University of Missouri, Rolla, Missouri
10:55 a.m. - 11:20 a.m.	**State-of-the-Art of Agricultural Residue Gasifiers in the U.S.** - John Goss, University of California, Davis, California

Wednesday, November 9, 1983, (Continued)

Morning Session, (Continued)

11:20 a.m. - 11:45 a.m.	**Implementation of Wood/Biomass Energy Projects in Developing Countries -** Abu Talib, The MITRE Corporation, McLean, Virginia
11:45 a.m. - 12:00 M.	**Brief Review of Wood/Biomass Development Work by Pyrenco, Inc. -** Frederick Beierle, Prossor, Washington
12:00 M. - 12:15 p.m.	**Comments** by G.S. Sidhu, Director General, CSIR
12:15 p.m. - 12:30 p.m.	**Indian Biomass Conversion Experience -** R.C. Maheshwari, Head, Electromechanical Engineering Division, Central Institute of Agricultural Engineering, Bhopal
12:30 p.m. - 12:45 p.m.	**Development of Small (3-5 kW) Producer Gas Plant Running on Locally Available Waste -** Anil K. Rajvanshi, Director, Energy Division Nimbkar, Agricultural Research Institute
12:45 p.m. - 1:00 p.m.	**Concluding Remarks -** O.P. Vimal, DNES
1:00 p.m. - 2:00 p.m.	**Lunch**

Afternoon Session: Gas Separation and Gas Cleanup, Session Chairman, M.K. Sarkar (IIT)

2:30 p.m. - 3:00 p.m.	**Indian Presentation,** R. Rangan (BHEL)
3:00 p.m. - 3:30 p.m.	**Status of Gas Separation and Gas Cleanup Technology in the U.S.** - M. Ghate, DOE (METC)
3:30 p.m. - 3:45 p.m.	**Break**
3:45 p.m. - 4:15 p.m.	**Panel Discussion**

Concluding Session

4:30 - 5:15 p.m.	**Panel Discussion** M.K. Sridhar, BHEL

WORKSHOP AGENDA (cont'd)

Wednesday, November 9, 1983, (Continued)

Concluding Session, (Continued)

	Don Masters, USAID D. Bienstock, DOE, Moderator
7:30 p.m.	**Reception and Diner**

Thursday and Friday, November 10 and 11, 1983

Development of Work Plans-Refine, modify and finalize work plans where required, including initiation of projects.

9:00 a.m. - 12:30 p.m.	Project Managers will continue to develop work plans.
2:00 p.m. - 5:30 p.m.	Project Managers will continue to develop work plans.

Monday, November 14, Saturday, November 19, 1983

Individual Site Visits.

OPENING SESSION - MONDAY, NOVEMBER 7, 1983

INTRODUCTION - DANIEL BIENSTOCK

Good Morning, Gentlemen. My name is Dan Bienstock. I am with the Pittsburgh Energy Technology Center of the U.S. Department of Energy. It is an honor and a very deep pleasure for me to be associated with this progran and to have the opportunity to be at this initial Workshop of the Alternative Energy Resources and Development program between the governments of India and the U.S. The U.S. effort is under the auspices of the Agency for International Development.

The purpose of this Workshop is, first, to allow both sides to become aware of the technology development in their respective fields and, second, at the end of this Workshop to have completed work plans in the four areas of coal conversion--fluidized bed combustion, coal beneficiation, gasification and cleanup, and coal-water mixtures. The biomass conversion work plans have already been completed.

I would like to introduce representatives of some of the key agencies involved in this program. From U.S.AID, Robert Nachtrieb, Chief of the Office of Project Development at New Delhi. He is a tremendous asset to the program, and I am proud to be in association with him.

Mr. Nachtrieb....

ROBERT NACHTRIEB

Good Morning, All. I had asked Mr. Berry of U.S. AID to put together some figures for me on how important energy is to India and how important alternate energy is as a new source of energy. I got to thinking about it last night and I figured the last thing you people need is for a bureaucrat to tell you things you already know, so I won't. Rather, I will just say that we at AID are proud to have played a part in bringing you all together. I think this probably is not the first time something like this has happened, but it doesn't happen as often as it probably should.

ROBERT NACHTRIEB (cont'd)

I want to thank Dan Bienstock in particular for his part in organizing this, Secretary Swarup of DNES, Dr. Sridhar of BHEL, CSIR, IIT and Jyoti Solar Lab

I would like to extend, on the behalf of all of us at AID, our best wishes for a useful, productive and interesting Workshop -- and let's get down to the technical business at hand. Thank you very much.

MR. BIENSTOCK

Thank you, Bob. The next speaker represents the Department of Non-Conventional Energy Sources, who have the overall responsibility on the Indian side. Mr. Swarup will be speaking to us. Mr. Swarup has had a very distinguished career in the Indian government and, at the present time, is Secretary of the Department of Non-Conventional Energy Sources in the Ministry of Energy. Mr. Swarup.....

B. N. SWARUP

Friends. When the question of my participation in this Workshop came up, I had certain reservations because I thought that my presence among these experts might disclose my ignorance on the subject. But then I thought, because the subject is so important, I should at least present the wider perspective in which the further development of the program is seen, leaving it to the more distinguished scientists and technologists who are assembled here to see how those overall objectives could be achieved as fast as possible. So, first of all, I would like to say that we are indeed grateful for the effort U.S.AID has spent in arranging this Workshop here. I hope it will be possible for the interaction which will take place here to produce some worthwhile programs that can be taken up in the near future. Almost on an immediate basis. Now I say this, gentlemen, because it is common knowledge that, in a country like India where about 80% of the population lives in rural areas, the need for decentralized electrical systems is obvious. I am not going to take your time re-emphasizing it. As you are all aware, in our sixth plan, the level of public sector investment in agricultural development and rural development is of the order of 11 thousand crores ($US 11 Billion). Now, if this

MR. SWARUP (cont'd)

investment is to produce the desired results, the energy inputs which are necessary for agricultural production, irrigation and cooking are obvious, and that is why the Department of Alternate Energy Sources has been very keen to develop as fast as possible programs that can take care of the need for a sustained and cheap energy supply on a decentralized bas in the rural areas. With about half a million villages in the country, i will not be very easy to take into consideration all the areas of the country, even with the extension to the rural areas of the program. So any rural energy program will have to be predominantly a decentralized energy program, supplemented in time and where possible with the extension of the rural energy programs.

We are trying to attack this program on three fronts.

- The biogas program is a program for converting animal waste to useful energy. It is being organized on a national scale very fast, and there is a fair amount of interest in the rural development program.

- Energy from fuelwood-burning stoves.

- Conversion of crop residues. This program has not yet been taken up on as large a scale as possible, and I would like to know if there are technical problems which stand in the way of the development of this program, or if the economic calculations do not show much promise, or whether, at some stage when we take up this program, we will have to think in terms of whether or not it would be accepted by the villagers without too much resistance. Our villagers have a tremendous hardy common sense, and I think they have been found to be quite responsive toward accepting things which appear to further their interests.

While these technological discussions take place, we will have to give some thought to whether the economic parameters are satisfactory, whether the tech nological parameters are satisfactory, and whether the sociological parameters

MR. SWARUP (cont'd)

are satisfactory. If the answers to these questions can be evolved during the Workshop, the Department of Non-Conventional Energy Sources will not be found wanting in implementing or undertaking this program.

The other aspect of these programs is that there are tremendous amounts of social benefits available. Quite apart from benefiting agricultural production, a lot of importance is attached to improving the life and health of the rural people. Thus there is a human angle, the angle of improvement in the quality of rural life. This is why I am very anxious to see progress made in the next two or three days. Dan has evolved a very fine program and it will receive the maximum possible support from me and the Department of Non-Conventional Energy Sources. Thank you.

MR. BIENSTOCK

Thank you, Mr. Swarup. The next organization representative on the program is from the Council of Scientific and Industrial Research. Dr. Sidhu could not make it, as he had another commitment and, in his place, Professor Mazumdar from the Central Fuel Research Institute will speak to us. Prof. Mazumdar is internationally renowned in the field of coal chemistry and coal structure. In 1979 he won the First Coal Scientist Award and earlier, in 1969, he won the National Metallurgist Day Award of the Ministry of Steel and Heavy Engineering of the Government of India. I have asked Dr. Mazumdar, with the few minutes that he had to prepare, to give us his views on what he would like to see in this program. Professor Mazumdar.....

PROF. MAZUMDAR

Coal preparation is a must, and I am glad to see all the subjects which have been identified for collaborative and cooperative work between U.S. and Indian scientists in this forum. Then, again, we need to conserve oil and its use to every extent possible. Coal-water and coal-oil have been identified for the firing of industrial furnaces. For efficient combustion of coal for power, electrical heating and process steam, Fluidized Bed Combustion (FBC) is a very good technology ushered in in the last 10-20 years. It has come to stay in many countries, particularly the U.S., Japan and West Germany, but it has to

come in a big way in our country. This technology has to be advanced in a big way here, and I am glad that it is included in the current Workshop.

Gas cleanup and separation is important in any process of coal combustion and effective utilization of coal, and its inclusion and identification for discussion in this Workshop has been a very good chart. Thus we will have FBC, gas cleanup and separation, coal-water mixtures and coal cleaning. On the biomass subject, Mr. Swarup has already set the tone for what we should aim for and arrive at by the end of our discussions.

India is a poor country, no denying that fact, although we call it a developing country. We have developed considerably since independence but, because of the population explosion, the power of purchasing, etc. has not changed significantly. People in India are poor, and while we usher in the improvements in the technologies for coal to oil slurries and mixtures, or coa to domestic coke, does it as Mr. Swarup said change the lifestyles of the people in the villages? Village economies and purchasing power have to improve and then, and then only, can the benefits of development in technology reach the millions in the villages. Therefore, biomass conversion is an answer, be it undertaken by cooperatives or otherwise, and the interaction with the U.S. scientists could be very helpful.

Gentlemen, this is a golden opportunity, not only to derive additional knowledge but to utilize this knowledge in furtherance of our technology in coal conversion and biomass conversion.

MR. BIENSTOCK

Thank you, Professor Mazumdar Prior to coming here in May of this year, I had heard of Professor Mazumdar because he has an international reputation and when I met him in May at CFRI I was tremendously impressed by his personality and technical background. disagree with him, however, when he says that the U.S.

MR. BIENSTOCK (cont'd)

will have little to gain. think we have a lot to gain, because this is a collaborative project and you have prime laboratories here and we intend to work together closely. For those people who will be visiting the U.S. in the near future, we are making very strong efforts to make sure that they see, hear and learn from the best laboratories we have in their respective technologies.

Our next speaker was to be Mr. Puri from BHEL; however, he could not make it and Mr. Sridhar will take his place. Mr. Sridhar joined BHEL at Trich as an Assistant Works Manager in 1964, and was promoted successively to Works Manager, Deputy General Manager, General Manager and then Executive Director in 1980. Since October of this year, Mr. Sridhar is the Technical Director of BHEL. Mr. Sridhar .....

MR. SRIDHAR

Dan, Mr. Swarup, Dr. Mazumdar and all Distinguished Indian and American Engineers. In the month of May we had a meeting with DNES, CSIR and others. The two technologies of coal conversion and biomass conversion were selected as the highest priorities in the area of technology transfer which the U.S. team could give us. Accordingly, we have with us today Dan Bienstock, who has taken a very keen interest in this technology transfer, and other distinguished engineers from the U.S. who are assembled here to share their experiences in the coal and biomass conversion technologies. We in India have also done considerable work in this area at BHEL, CFRI and other institutions. This is a very good opportunity to exchange our experiences and we Indians will learn from the very vast experience our American friends have developed in this area and will provide us with.

I would like to share a few of my thoughts with my Indian colleagues. While our friends from America have developed considerable work, the purposes for which the technologies in America were developed are different from ours.

I will confine myself to coal conversion, with which I am more familiar. In the U.S.A. the coal conversion technology has been developed as a replacement for oil, because of the 1973 oil crisis and in the need for decreasing pollution in the environment. These are the two main criteria, if I am correct,

MR. SRIDHAR (cont'd)

which have led the U.S. engineering and research laboratories going for these technologies. In our country it is slightly different. As far as power generation is concerned, today 100% of it is coal-fired only. There is no oil-fired power generation equipment which needs to be converted to a coal base. On the other hand, we have a number of small industrial furnaces used by manufacturing units using oil. Hence our technology for use of coal should be more oriented toward converting these small oil-based energy sources, boilers, furnaces, etc. Similarly, the coal-water slurries -- one of the points mentioned in the agenda for this seminar. In the U.S. coal-water slurries development is seen once again for the conversion of the oil-based sources of energy to coal. In our country, as mentioned earlier, the thermal power stations are all coal-based. Coal-oil or water slurries could be more used for transporting the coal from the mining stations in remote places, converting the small oil-based furnaces and boilers to use coal.

So I would appeal to my colleagues, whatever the exchange of ideas in this Workshop, bear in mind what will be the ultimate use of this technology in India.

In the area of FBC, BHEL has done quite a good bit of work, and I am happy to inform you that, last week on the 28th of October, the first sizeable FBC (45 tons/hr or the equivalent of 10 megawatts) was successfully lighted up at Vizak (Hindustan Polymers). I also understand that steam blowing has been completed and, by the middle of November, we hope to put it into full-scale operation. This project should have been on stream in the first week of January 1984 but we have been able to do it ahead of schedule. From the 15th of November, when it goes on full steam, not only will the benefit go to the ultimate user -- a small chemical plant -- but we at BHEL have organized to make a number of studies on that boiler which will enable us to work on the next project of scaling-up of FBC to a 20-30 megawatt stage.

MR. SRIDHAR (cont'd)

In the area of FBC, apart from introducing the FBC for steam generation for chemical process industries, we find that the number of small users who have been using oil-based steam generators, or for a drying medium, have been asking us to retrofit the FBC, using coal and a variety of other combustible materials such as tar, wood waste, bagasse and paddy husk, all of which are available in plenty. This is another good area where tremendous potential is available in this country.

So FBC for our requirements in this country is

- for smaller-sized steam generator units up to 50-80 tons/hr,
- for conversion of oil-based boilers, dryers, etc.

In the area of utilities, we have appreciable plans to develop 20-30 megawatt FBC units. Here again the main competitition is from the stoker-fired boilers which are proven equipment, so they would like a very large adjustment of the advantage of the FBC before they change over. This is one of the subjects which we would like to discuss in this forum.

The FBC can also be built for a variety of other fuels -- tar, woodbase, husk. All these we have tried successfully in our facilities. We have a large amount of rejects coming from our ball mills, which are transported to the power region's from the mines only to be rejected -- a sheer waste of energy. Here again we find that mill rejects can be successfully used in the FBC. A number of power stations, especially in Maharashta where there are 210 megawatts, are asking us to see if we can supply FBC using their mill rejects generated within their plants; similarly the washery rejects which are lying as waste.

Tremendous scope is available both in the utility sector as well as industry for converting oil-based boilers and other energy sources to FBC. I am sure that in the next four days of deliberations with our American colleagues we can use their experience to be able to commercialize more of the FBC, bearing in mind the requirements in India.

In the area of coal-water slurry, BHEL wanted to take up a major project but there are some constraints. Most of the utility boilers are coal-fired so the need to convert to coal-oil slurry doesn't arise. There are some industrial boilers for process steam where oil is being used which can be converted to coal-water slurries. But the problem is moving the coal from the various mines to the end user by the railways, already facing tremendous bottlenecks in transporting the ever-increasing requirement of coal to various parts of the country. Hence, coal-water slurries may be used as a means to reduce the transport bottlenecks. In India water is a scarce commodity; the water to be used in preparation of these slurries at one particular place ultimately has to be used in another place, and it cannot be used from state to state. Hence, whatever technology we adopt the transport of water should be at a bare minimum. Otherwise it may not be popular since no state would be willing to part with its share of water. This must be borne in mind in whatever technology we develop.

In the area of biogas also, BHEL has done considerable work in our R&D complex in Vikasnagar and Hyderabad. We have developed a biomass petrol engine which we intend to sub-license to any Indian manufacturer who would like to take advantage of the tremendous energy potential available in our villages and make it. Most of our villages are quite remote from the main transmission lines. Here again it may take considerable time before the entire rural sector is electrified. The transmission is itself faced with a lot of bottlenecks, so the use of biogas energy for meeting the needs of the villages, especially those which are far away from the main transmission lines, is another very important and right subject selected for this forum.

I would like to thank Mr. Bienstock for organizing this seminar, where I am sure in the next four days there will be a very useful exchange of information. However, I would like to share some of my thoughts with my Indian colleagues here that, whatever we absorb in this four-day workshop, we should bear in mind the context in which the technology is to be used in India, which is slightly different from the purpose for which it was developed in the USA. Once again, thank you very much and all the best for the seminar.

MR. BIENSTOCK

We are running ahead of schedule, so I would like to make a suggestion that, if there are any questions you would like to address to our speakers this morning, please do. The floor is then open to any questions you might have or your own personal comments. Yes, Dr. Krishnan.....

DR. KRISHNAN

I am from Oak Ridge National Laboratory, and I would like to say a few things in light of what Mr. Sridhar said about fluid bed combustion. First of all, I want to say that I am very very fortunate to be involved in this U.S.AID program as a specialist in fluid bed combustion. When I came in 1981 to India on a similar assignment with the Department of Energy, one of the things was to identify an area for future work in fluid bed combustion We have had a very excellent working relationship with BHEL in this area and in 1981 when I left for the States, I was just hoping the work we did in the short period I was here in India would continue -- for two reasons. I found BHEL to be one of the international organizations in this technology and they had made tremendous progress in the short time they had to develop this technology. As Mr. Sridhar was saying, their purpose was slightly different from what we were doing in the U.S. I have been fortunate to be involved in this technology, thanks to the Department of Energy and the Tennessee Valley Authority, but when I came here I found that there really was something that we could learn from BHEL.

This goes back to what Mr. Mazumdar said about the quality of coal in India. It is something that we probably never will see in the U.S. and the coal is nothing we can compare with the Indian coal. So we had to start from scratch and find out how we could adopt this technology in an Indian context and, in that process, we thought we could learn something from BHEL and that was how we would design boilers. It would still be a hypothetical case because I don't think we are going to find coals of that poor quality in the U.S., but it is something our industry would be very willing to find out -- for two reasons.

DR. KRISHNAN (cont'd)

There is a big market in the developing countries for fluid bed technology, and the U.S. organizations that have been involved in this effort would like to share the market with other countries. So my friends in the U.S. representing various industries were particularly interested in what AID and the Department of Energy were going to do in this area with BHEL. I would just want to reemphasize what Mr. Sridhar said that the context in which we have to look at this one particular technology is very important because this is something we could take back and share with our industries there, and maybe with some good old American ingenuity they could come up with better ways to burn this coal.

I think we have had some programs through the Department of Energy to look at fluid bed combustion to burn low rank coals, primarily anthracite, and other things which my friend, John Byam of DOE, will talk about this afternoon. I don't want to take all the information that he wants to say and maybe he will be saying something in that area. But this aspect of the poor quality of coal is something we have to work together on to find out how to effectively use the mill rejects and some of the parent coal itself.

I came here on October 8. I was thrilled to see that the first BHEL boiler was commissioned in Vizagapatnam and immediately sent a cable to Dan and John saying please, make it a point to see this facility, because I think it is something very creditable for BHEL to have accomplished in a very short time. I really don't know how I am going to contribute to the already available expertise in this area. I personally feel we will benefit quite a bit from this transfer of technology in fluid bed combustion. In the process we would equip them with better instruments. One of the things Mr. Sridhar was addressing was the scaleup, and I think this is an area where the U.S. could make a contribution in terms of R&D and transfer of technology.

DR. KRISHNAN (cont'd)

Again, I consider it a unique privilege to be involved in this program. When I left in 1981 I shook hands with Ram there and said "I hope to see you in the future," and here I am, and I am really looking forward to working with AID and Dan and BHEL on this program. Thank you very much.

MR. BIENSTOCK

Thank you, Dr. Krishnan. For those of you who do not know Dr. Radha Krishnan and how serious we are about this collaboration, we have asked him to give up the soft life he leads in the United States to spend five months in India away from his wife and children, and he was willing to do this because he is so dedicated. He is also one of the leading authorities on fluidized bed combustion.

DR. SURENDRA KUMAR

I am Dr. Kumar from Jyoti Solar Energy Institute. I wanted to comment upon the fact that I did not visualize the benefit of Biomass technology to the U.S. by this collaborative process. I have in mind that, if we are able to develop a good reliable rugged gasifier which can be used in rural India, then certainly that type of gasifier can be sold to American farmers after it has been developed with the help of U.S. experts here. Mr. Swarup mentioned that our farmers are very choosy. They may appear to be very simple but they have sufficient common sense that, if it is economically useful, technologically useful and sociologically acceptable to them, then they will accept that type of technology. If we are successful, which I am confident we will be, in developing a gasifier useful for a small Indian farmer, that type of machine can certainly be useful in the U.S. where small areas are to be farmed. The U.S.A. is a big and advanced country and the requirement for such gasifiers is very small. No big manufacturer is going to enter into that area where requirements may be very small in number. Certainly then our country can come up and supply the gasifiers back to them that we have developed with their technical know-how. Thank you.

PROF. M. K. SARKAR (IIT, DELHI)

Gentlemen, I came here mostly to listen, but I find a unique combination of people from energy, coal and biomass which is a rare opportunity to see. I wish the petroleum and solar energy people were here also.

Now I would like to make some comments that the organizers will consider Probably they would be more appropriate for future workshops since the programs have been more or less made. As an energy scientist, the following thoughts come to mind.

Sometimes when we talk of energy we forget other things. For example, energy can be derived from carbon and non-carbon sources. Carbon sources can be fossilized as coal, oil and gas or it can be renewable. But, at the same time, there is an equally important feedstock situation which has to come from these carbon stocks. Occasionally when we talk of energy we completely forget that aspect. Consequently, I feel that future energy may come from non-carbon sources -- that means from solar energy, nuclear energy and other energy derived ultimately from the sun. While we talk about using fossil fuels and developing technology, or developing technology for renewable resources, we should not think in terms of only burning and producing energy, because future feedstocks also have to come from these renewable resources. So technology must keep this thought in mind. As, for example, the BHEL presentation. I would ask the question "Is it always good to burn coal, or only part of coal?" It was mentioned that it is very difficult to convince old power people to change to fluidized bed systems. But there are very convincing arguments. For example, even the more sophisticated boilers continuously keep on complaining that we cannot tolerate ash more than 25%. I would like it to be enforced that any future power plant should take coal which is not less than 50% ash, then the case for FBC becomes automatically apparent.

PROF. SARKAR (cont'd)

Number two, if we concentrate on the Indian situation we should see the supply on one side and the demand on the other. We will always have a shortage of petroleum over coal irrespective of how much oil we discover. Probably this discrepancy will remain for a long time. The power situation is also equally short. Therefore, any research plan should take into account our power needs, our feedstock needs and how much we can tap from hydroelectricity, how much from nuclear, how much from coal combustion, etc.

In that case another thought comes to mind. All carbonaceous fuels starting from coal up to biomass consist of so-called hydrogen rich part and the other part, which is coke or char. In the long-range program, I feel it is advantageous, particularly with an oil shortage, that any conversion processes take this into account. Why not make the balance this way? Take any combustible material. Today we know that fluidized bed technology is coming so consequently we should take it as a long-range mission that we burn only that part which cannot be used for any other purpose. That means that any hydrogen-rich part that can be taken out from any carbonaceous fuel in the form of, say, liquid should have preference in the program.

Number three, I liked Mr. Swarup's presentation and also Dr. Mazumdar mentioned that agricultural waste should go for making fuel. I think that is the best short-range view. If our villagers' lot is to improve from the things that they burn, we must find some high value products from it. I don't think that, only for burning, the villagers are much interested. They will always collect some materials to burn in their kitchens, and they would not buy your coke, neither will they buy them if you briquet them and sell them.

So, in the long range, we must see if, first, the same material which today is either gasified or briquetted to make fuel should be burned in more improved burners, etc. Second, can we further add to this program so that along with the fuel value we are getting at the moment, we can increase the value of the product from it and, third, can we then adopt this technology in the long-range future for rural development?

Thank you very much.

DR. GROVER (ITT, DELHI)

I am glad that Mr. Swarup mentioned two thrust areas -- one the biogas program and the other the wood burning program -- and glad also that he has taken a very active interest and put biomass conversion as a thrust area. I would like to mention that we have already done some work in the area of use of biomass effectively by briquetting after partial charring. Now more than 20 plants of 4 tons/day are working. These plants are not coming up very fast because, in this area, not many incentives have been given. So my request is, if we want to develop this technology further, could the Ministry of Energy come out with incentives which are given to other renewable sources? Thank you.

Mr. K.M.V. MALARKKAN (BHEL, TRICHI)

Regarding the coal-water slurry, there has been a lot of progress made in the U.S. from coal-oil mixtures to coal-water slurries. People have been able to make stable slurries, but then that is with very good coals -- not more than 10 to 15% ash content. We are trying to have a program with U.S. AID for application with Indian coals having not less than 30% and as much as 40-50% ash. Here coal washing would be essential, and coal washing down to very low levels of ash content may be necessary, possibly as low as 5% ash.

First of all, developing technology for such high-ash coals should be considered, and developing reliable burning systems for such high ash coal-water systems should also be considered. The other part is, when we make such an oil-replacing coal-water slurry, there is always another part with a larger percentage of rejects, and this may have to be burned in a different technology. What comes to mind is, again, fluidized beds for burning coal-water slurries. Therefore we should consider totally integrated programs in these deliberations.

Thank you.

DR. G. S. SIDHU, DIRECTOR GENERAL, COUNCIL OF SCIENTIFIC AND INDUSTRIAL RESEARCH:

I am indeed very happy to be here. When I received the program I found that I am one of the panelists this afternoon but, due to some breakdown in communications, this notice came a little bit late and I am committed for the whole of the afternoon with the Federation of Indian Chamber of Commerce and Industries, so I will miss the opportunity of taking part in the panel discussion this afternoon. So Dr. Bienstock was kind enough to ask if I could come at this time.

All I can say is that the development of alternate sources of energy for India is very important and the importance is realized from the fact that the Government of India has a separate department for this purpose. We in the CSIR have several research institutions which are involved in the development and conservation of energy. We were, for example, yesterday reviewing what CSIR as a whole has done and can do for the utilization of solar energy. We intend to have this review of our own work and the part it can plan in an internationally integrated development plan for the use and the conservation of energy. So this workshop is very opportune in that a number of my colleagues are participating and we are sure that we will benefit by the deliberations that are taking place in this seminar.

In many cases when one discusses these things the question of cost crops up. Whenever one thinks of an alternative, let us say the utilization of coal, then the question of cost must come in. On the utilization of solar energy through photovoltaics, the subject is raised that it is so many times more costly than petroleum or power generated by conventional means. Looking at it from a research and development angle, we have come to the conclusion that any cost calculations are premature until a substantially large demonstration unit has been built. And, after all, one of the purposes of research and development is not only to make a thing work but, after making a thing work, look at the cost reductions, and cost reductions always come. To rule out a development program on the basis of paper calculations has proved to be the wrong decision in many a case.

Moving away from the energy area, let us remember the cost of penicillin when it was first discovered and the way it was flown and refrigerated and could be given to only a few patients. If one looks at the literature at that time one would come across arguments that yes, these things will only remain a laboratory curiosity. And look at what research and development did -- today it is one of the cheapest antibiotics and it has opened up an era of antibiotics, and medicine has completely changed. So today we will look at solar energy and say that, unless the cost factor of photovoltaics is brought to 10% of what it is, it is not going to be competitive. I think that these developments will come if we realize their importance. That would be true of any other R&D in the field of energy. We in India have, in most of the regions, plenty of sunshine so we should be making a major effort to utilize and harness its energy. We have planty of agricultural wastes so we should also find out what are the optimal methods of utilizing these. And in that we must be benefited by the advice of people in commerce, economics, sociology -- because , especially with regard to the by-products of agricultur the bottleneck is not going to be in the development of technology, it will be in the collection and transport of material. The plant material which we will use -- let us say a hundred tons a day -- will have to be transported. Then one will have to look at the radius from the point where we put such a plant and the collection point, and the cost of transport of this lightweight materi to a central plant. Therefore it is germane to think of what should be the optimum size which will meet the requirements of a given community and which could be put where the transport of this very light raw material will not be uneconomic in itself.

The second thing which occurs to me in this particular field is that, when we take the cost of a raw material which is available today and is not being put to any organized industrial use, the moment you start doing that you have to put a cost which is many times more than when it is freely available. This will be true of rice husks, true of garden stalks, and true of anything you can think of. Therefore we must have a realistic picture during the development work in order to put some reasonable cost of that raw material which we do not always do in our calculations.

Another point I would like to make is that when we consider alternatives actually the word "alternative" itself means you have choice, that you are choosing between two alternates -- that is why we will use the term additional" sources of energy, not alternative sources of energy. You are not ruling out one and taking the other. If you are thinking of development, you do utilize every source of energy available and which can be optimally utilized in a given location. It may cost us say ten times more to generate a megawatt of power through photovoltaics but, if you put this at a location where we may have to take a transmission line a few hundred kilometers, and take into account also the transmission losses and the maintenance of this line and the staff that is engaged, maybe then it is more cost effective. So that is why we say, not alternative, but additional sources of energy, which will be utilized at a given time to the maximum possible. Another thing -- unfortunately there is a tendency to associate some of these technologies with a low level of development of technology. But I think the development that will be useful is the one that utilizes these additional sources at the highest level of technology and innovation and scientific thinking. Only then will we find solutions which are worthwhile and which can take us many steps forward in this direction.

So I thank you once again for giving me this opportunity of being here and I wish the delegations all success. We look forward to the recommendations of the various groups and seeing how far we can incorporate these in our own R&D programs. Thank you.

OVERVIEW OF FLUIDIZED BED COMBUSTION TECHNOLOGY

K. M. V. MALARKKAN

OVERVIEW OF FLUIDISED BED COMBUSTION TECHNOLOGY DEVELOPMENT AT BHARAT HEAVY ELECTRICALS LTD TIRUCHIRAPALLI, INDIA

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TIRUCHIRAPALLI

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ABSTRACT

This paper presents the status of the development and commercialisation carried out in the activities related to Fluidised Bed Combustion Technology (FBC) at Bharat heavy Electricals Limited,(BHEL). A brief review of the early work in FBC and a description of the FBC test facilities at BHEL is also presented. Future goals, research and development needs and the current FBC programmes underway are identified.

1.0 INTRODUCTION

Bharat Heavy Electricals Ltd (BHEL) is engaged in the development of Fluidised Bed Combustion (FBC) boiler for Indian coals since 1975. Fluidised Bed Combustion technology is presently recognised as a technology with significant potential in India to burn a wide variety of fuels such as high ash coals of all ranks and grades, coal washery rejects, middlings and municipal and industrial wastes and bio-mass.

Major Objectives of BHEL's intensified research and development are:

1. To design a boiler to burn low grade fuels in an efficient and environmentally acceptable manner.
2. To replace oil with cheaper energy resources such as coal, paddy husk.
3. To design less expensive and more efficient heat and steam generating systems.

It has been estimated that as much as 4.5 million tonnes of rejects from coal washery plants are generated per year. At the present rate of coking coal production, the average energy loss per year in the rejects at 2000 Kcal/Kg is 9×10^{12} Kcal or equivalent of the energy generated from a 500 MW plant. This figure is expected to rise to 1400 MW once all the 14 coal benefication plants go into operation. Fluidised Bed Combustion technology

is considered to be the only viable technology to burn these high ash content washery rejects for power generation.

While the major thrust in foreign countries particularly USA and JAPAN has been to utilise Fluidised Bed Combustion technology to combust high sulfur content coals in an environmentally acceptable manner, the emphasis in India has been to utilise Fluidised Bed Combustion for combusting the high ash, low grade coals and other fuels.

2.0 HISTORY AND BACKGROUND:

In order to carry out research and development in FBC, BHEL drew up development programme in 1975 and facilities were created at BHEL, Tiruchirapalli. Joint research work was also initiated with other National Laboratories and Institute of Technology. Areas where research and development activities were focused included the following:

1. Air distribution system.
2. Optimization of design and operating parameters.
3. Improvement in combustion efficiency and heat transfer.
4. Erosion, corrosion of in-bed tubes and material selection.
5. Ash removal system.
6. Development of start-up system and start-up procedure.
7. Dust loading and particulate removal system and method of load control and identification of special instrumentation needs.

Experimental test facilities were installed in BHEL and at other locations to obtain basic data in the above areas for design and scale-up to commercial size FBC units.

3.0 DESCRIPTION OF BHEL'S TEST FACILITIES:

The experimental test facilities available at BHEL, Trichy are as follows:

1. Prototype Fluidised Bed Combustion Boiler of 10 t/h capacity.
2. 500 mm x 300 mm Hot model test rig.
3. Coal feeding system development test rig.
4. Lighting-up system development test rig.
5. Erosion test rig.
6. Facilities at other locations supplied by BHEL.

3.1 The prototype unit capable of generating 10 t/h of saturated steam at 10 ata pressure was put into operation in 1977. Over 500 trials have been carried out so far. Coals from Singareni (30% ash), Chanda (40% ash), Middlings from Bhojudhi (50% ash) Rejects from Jamadoba (62% ash) Rejects from Kathara (72% ash) have been successfully fired in the prototype. Summary of the performance with different coals is given in Annexure-1. List of the fuels tested in this unit is given in Annexure-2.

The operating experience and test results from the prototype FBC boiler have been presented in the 6th International Conference on Fluidised Bed Combustion at Atlanta USA.

3.2 The 500 mm x 500 mm test rig is being used for preliminary investigations and testing the amenability to combust different fuels in FBC. Partial list of different fuels is provided in Table-1. This unit has been used extensively to study the bed design and operating parameters.

3.3 Coal Feeding System Development Test Rig

This rig was put up to study various methods of feeding coal into the combustor. Investigations till date have been limited to in-bed and side feeding systems. The rig can also be used to study the performance of coal feeding splitters which are required for large scale units.

3.4 Lighting-up system development test rig:

The light-up technique used at BHEL for start-up is a simple non oil/gas based technique. The start-up is achieved by having a thin layer of charcoal on the bed and sprinkling kerosene soaked charcoal. The chal coal is then lit with a swab soaked in kerosene. The bed is fluffed with fluidising air by controlling the fluidising

air until fire spreads uniformely throught the bed and the bed temperature is brought up to the ignition temperature of the fuel.

3.5 Erosion Test Rig:

Using the erosion test rig, the erosion characteristics of fly ash from different modes of combustion have been compared. FCB ash has been found to be less erosive than P.F. ash and significantly less erosive than stoker fired ash.

3.6.1: 12 t/h FCB at RRL, Jorhat:

This hot water unit having heat absorption equivalent to 2 t/h steam at 10 ata, is being used for testing sulfur retention capabilities of the fluidised bed while burning high sulphur North Eastern Coals along with local limestone. The results obtained using Bargolai coal containing 3% S and Chirapunji limestone are quite encouraging. Further tests on this unit are planned with different coals available in the region.

3.6.2: 2 t/h FCB at CFRI,Dhanbad:

This unit is similar to the above. It is being used for testing the combustion characteristics of different coals. So far experiments on Jaykay Nagar and Singareni coals have been conducted.

In addition to the above facilities, spedially set-up sophisticated manufacturing, quality control and chemical laboratories existing in BHEL are used for the development work.

4.0 Significant Achievements

4.1 Air Distribution System:

In the first generation design, BHEL adopted a multi-orifice type distributor. Eventhough the fluidisation performance was good, the long term reliability after many start-ups was not good. This necessitated extensive experimentation and development in this area. After testing several types of air distributors, BHEL has evolved a nozzle type distributor and finalised the material of construction and optimised the pitch of nozzles, nozzle heights, hole size and number of holes in the nozzle. With this design it has been possible to limit the distributor plate metal temperature very close to the inlet air temperature, thus eliminating problems of overheating, high differential temperature, warping, expansion provision etc. The World trend is also towards the nozzle type of distributors. BHEL has evolved suitable mechanical designs to support this air distributor (most critical component of the fluidised bed boiler) in the air box, (for very large

size units). Air pressure drop required across the distributor plate for satisfactory operation with many Indian coals, washery rejects and other fuels also has been established.

4.2 Operating Parameters:

Selection of suitable operating parameters is most important. Optimum parameters depend on the primary objective of going in for fluidised bed combustion. Thus we cannot simply choose the parameters adopted by others whose primary aim is on sulphur retention. These parameters, to some extent, depend on the fuel also.

4.2.1: Bed Temperature:

The minimum limit of the temperature is decided by stability of combustion and the maximum limit is decided by the initial ash deformation temperature. By extensive experiments the minimum stable temperature for the worst fuel (washery rejects) have been determined. With this as the minimum limit, the capability of burning other fuels at this limit has been established. From the test data available with different fuels, it has been established that with almost all the fuels the bed can be operated in the temperature range of 700°C to 950°C.

4.22 Fluidisation Velocity:

Experiments have been carried out over a wide range of velocity (1.8 to 4 m/s) and it has been established that it is quite satisfactory to operate in the range of 2 to 3 m/s.

4.2.3: Excess Air:

Many experiments have been carried out with excess air ranging from sub-stochiometric to 100% excess air. The results confirm that with most of the fuels 10-15% excess air would be sufficient to achieve reasonably good combustion efficiency.

4.2.4: Bed Height:

Experiments have been carried out with varying bed heights and it has been established that shallow beds would be sufficient for most of the fuels.

4.3 Choice of Bed Material:

Crushed refractory as initial bed material has been found to be satisfactory. When the fuel contains ash above 25%, even after many hours of operation, the bed stability was not a problem; ash in the coal more than compensates the loss of crushed refractory by elutriation.

4.4 Combustion Efficiency:

Combustion efficiency of over 90% has been achieved

with most of the fuels. With few coals combustion efficiency as high as 97% also has been achieved. Trials to establish the parameters to achieve high efficiency with other coals are in progress. The main reason possible for low combustion efficiency have been identified as low free board height and too much of cooling of the gases in the free board. In the designs being offered presently large free board is being provided. Other modifications being made include provision for admitting overfire air and recycling of the fly ash into the bed. The effects of these on improving the combustion efficiency will be known soon after the 45 t/h FBC Boiler at Hindustan Polymers, Vizag goes into operation.

4.5 Heat transfer Coefficient to the in-bed tubes:

By operating the prototype boiler as a hot water unit, many trials have been conducted. over a wide range of operating parameters. From the data collected, a correlation has been developed for estimating the heat transfer coefficient to the inbed-tubes.

In the first generation design, there was some apprehension to adopt natural circulation for thd in-bed tubes, because of the anticipated high heat transfer coefficient. Separate test loops were installed in the prototype boiler and the metal temperature of the tubes was studied, with

varying circulation ratios and fluid velocities. These trials have confirmed the feasibility of adopting natural circulation in the in-bed tubes. Similarly the feasibility of immersing superheater tubes in the bed and associated erosion/corrosion effects have been studied.

7.6 Coal feeding arrangement & sizing of fuel particles:

Air assisted in-bed feeding of coal has been found to be satisfactory and trouble-free from the experience gathered over 9000 hours of operation of 12 t/h FBC boiler at Trichy Distilleries & Chemicals Ltd (TDCL). Both at TDCL and in the prototype boiler, it has been possible to operate with half the number of coal feed points. The number of coal feed nozzles for the 45 t/h boiler has been provided on this basis. Further reduction in the number of nozzles and optimization will be possible once the experience at Vizag, with reduced number of feed points is available. While this information, will help in cost reduction, this is not an essential information for scale-up.

Similarly use of minus 6 mm coal particles and rotary airlock feeder with a mixing nozzle for the air assisted coal feeding have been found tobe quite satisfactory and trouble-free.

4.7 Ash removal System:

Ash removal by continuous over-flow to maintain constan

bed height with intermittant ash removal from bottom to remove oversize particles have been found to be satisfactory with most of the fuels. However, in order to recover part of the sensible heat loss in the ash while firing high ash coals and rejects, an auxiliary fluidised bed for ash removal has been develop ed and tested.

4.8 Development of start-up procedure:

Start-up system using charcoal and kerosene as fuels have been developed and perfected. More than 1000 start-ups have been made without any difficulty.

4.9 Method of Load Control:

Load control by slumping part of the bed has been demonstrated repeatedly.

4.10 Operation of the Boiler:

Start-up, operation and identification of abnormal conditions during operatin have been made with the experience gathered in the 9000 hours of operation of the 12 t/h FBC boiler at TDCL and over 500 start-ups of the prototype unit.

4.11 Dust Loading:

Dust loadingof the flue gases and the particle size distribution of dust with different coals have been quantified with a small free board. When the free board is made larger, the dustloading of the flue gas will further

reduce. This reduced dust loading information with large free board will be available in the next six months.

4.12 Identification of special Instrumentation needs:

The operating experience at TDCL and prototype boiler reveals that no special instrumentation is necessary for FBC Boiler. The only area of little concern in the early days of development was in the measurement of bed temperature. The in-bed thermocouples were breaking often. The cause has been identified as improper sheath material. This has been rectified and presently there no problems.

5.0 COMMERCIAL ACTIVITIES IN BHEL:

Based on the experience gained so far on the 10 t/hr prototype FBC boiler and other test rigs described earlier, and the experience available at BHEL, Trichy on boiler design BHEL is offering FBC Boilers for the following applications:

1. Industrial steam generation.
2. Utility power generation.
3. Conversion of oil/stoker fired boiler to FBC.

BHEL has developed designs of FBC Boiler upto 30 MWe (150 t/h steam) The status is as follows:

5.1 The 12 t/h FBC Boiler at Trichy Distilleries & Chemicals Ltd., Trichy has been in operation, since Oct'81 and has so far logged over 9800 hours with an overall availability of 88%.

The steam demand by the Customer is 9000 Kg/h for most of the time and the boiler is delivering this quantity at rated pressure temperature without any difficulty. It is also possible to operate at 7500 Kg/h steam flow (62.5% MCR) without resorting to segmental bed operation, which is normal practice when the load is reduced below 70% MCR The boiler is designed to burn coal having an ash content of 27% and heating value of 5400 Kcal/Kg. Coal having an ash content as high as 35-40% and heating value of 4000-4100 Kcal/Kg has been burnt without any difficulty. The design parameters for the boiler are given in Table: Bagasse and leco fines have also been fired in combination with coal for shorter durations.

The predicted efficiency of the boiler is 79%(with a combustion efficiency of 90%) while operating at 100% MCR load. Actual efficiency obtained was 82%(with a combustion efficiency of 92%) even while operating with coal inferior to the design coal at 75% MCR load. Further details and operating experience of this boiler can be found in Ganesh et.al.

The start-up method envisaged at the design stage has further been simplified and the boiler has been started from cold conditions over 75 times since commissioning, and the start-up has been very smooth.

5.2 A 45 t/h steam boiler has been supplied to M/s. Hindustan Polymers, Visakhapatnam. The boiler has been commissioned in October, 1983 and is now undergoing shakedown. Certain improved design features based on the feed-back from the operation of prototype & 12 t/h FBC boiler have been incorporated in this boiler.

The design parameters are:

Temperature	:	$363^{o}C$
Pressure	:	18 Kg/cm^2
Flow	:	45000 Kg/h

5.3 BHEL is currently working on several orders from Industrial and Utility industrial customers. A partial list of the orders received is presented in Table: In addition, BHEL has also submitted offers to other customers for utility boilers as well as conversion systems.

6.0 R & D ACTIVITIES:

The current Research & Development activities are concentrated in the following areas:

1. Testing of different fuels in the conventional FBC.
2. Design of fire tube FBC boilers.
3. Conceputal design of circulating FBC boiler.

7.0 FUTURE GOALS:

The future R & D efforts are concentrated in the following areas:

1. Scale-up problems related to coal feeding, ash handling systems, dust collection systems, fly ash recycle etc.
2. Fuel flexibility, combustion characteristic and enhancement of combustion efficiency with low grade fuels.
3. Free board design and performance.
4. Bed response to load changes.
5. Erosion/Corrosion of heat transfer surfaces.

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Annexure: 1

SUMMARY OF PERFORMANCE WITH DIFFERENT COALS

Type of Coal tested		Singareni	Chandamine	Bhojudhi Middlings	Jamadoba Rejects	Rejects	Bargolai (N.E.Coal)
Proximate Analysis:							
Fixed Carbon	%	40.30	34.83	24.92	16.78	12.3	48.57
Volatile matter	%	27.05	24.99	19.22	17.75	14.2	39.50
Ash	%	25.80	35.55	54.61	64.57	72.6	9.23
Ultimate Analysis:							
Carbon	%	51.70	43.33	34.89	23.94	19.9	70.00
Hydrogen	%	3.21	2.87	2.56	1.77	1.58	5.00
Sulfur	%	0.49	0.19	0.56	0.59	0.19	2.26
Nitrogen	%	0.87	1.00	1.05	0.31	0.66	1.12
Oxygen	%	8.76	8.88	5.12	7.92	5.63	9.69
Higher Heating Value, Kcal/Kg		4392	4340	3140	2150	1900	7188
Particle size	mm	0-6	0-8	0-6	0-6	0-6	0-6
Performance:							
Overall Efficiency	%	76.8	73.21	Not available	70.72	70.58	**
Excess Air (On fuel fed basis)	%	11.2	12	-do-	17.83	28.82	44.28
Exit gas temp	^{o}C	257	280	-do-	200	198	320
CO_2	%	15.00	14.4	-do-	14.6	13.00	12.00
O_2	%	5.70	4.5	-do-	4.9	6.5	6.8
SO_2	%	*	*	*	*	*	50 ppm (0.07 g/m^3 at STP)

* Undetectable. ** Purpose of the test was to demonstrate the feasibility of combustion.

Annexure: 2

LIST OF FUELS (OTHER THAN COAL) WHOSE FEASIBILITY OF COMBUSTION HAS BEEN DEMONSTRATED IN FLUIDISED BED COMBUSTION AT BHEL, TRICHY:

1) Bagasse.
2) Rice Husk.
3) Spent Liquor.
4) Bark.
5) Wood Chips.
6) Paper Sludge.
7) Oil.
8) Spent Bagasse.
9) Leco Fines.

-ooOoo-

ACTIVITY PROFILE OF BHEL

POWER SECTOR

PRODUCTS

TURBOSETS & AUXILIARIES
STEAM GENERATOR & AUXILIARIES
HYDROSETS & AUXILIARIES
NUCLEAR POWER EQUIPMENT
MOTORS
SWITCH GEARS
TRANSFORMERS
PUMPS
HEAT EXCHANGERS
SEAMLESS STEEL TUBES
PORCELAIN / CERAMICS etc.

SYSTEMS / SERVICES

POWER SYSTEM, TURNKEY POWER STATIONS
ERECTION & COMMISSIONING CONSULTANCY

TRANSPORT SECTOR

PRODUCTS

DIESEL ELECTRIC GENERATORS
TRACTION MACHINES

SYSTEMS / SERVICES

URBAN TRANSPORT SYSTEM
UNDERGROUND RAILWAY
ELECTRIC TROLLEY BUSES
TRACTION SYSTEM FOR RAILWAYS

INDUSTRY SECTOR

PRODUCTS

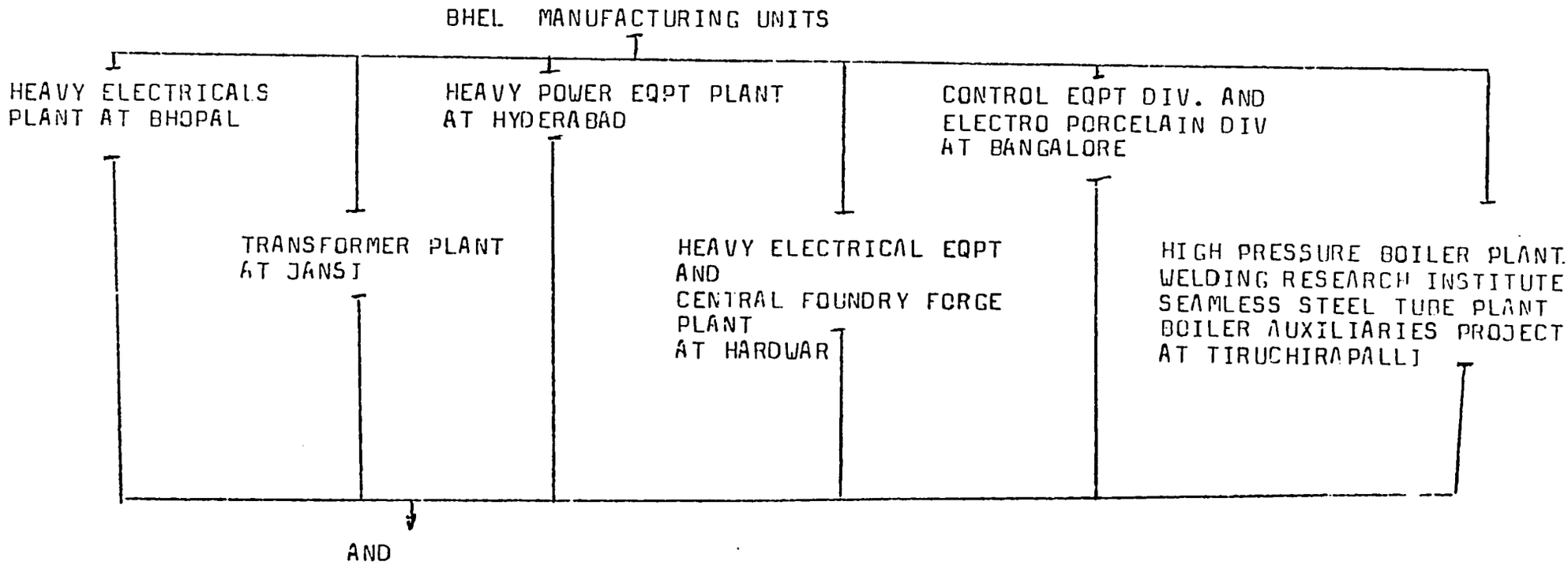
BOILERS
VALVES
T G SETS
COMPRESSORS
MOTORS
CONTROL GEARS
OILRIGS etc.

SYSTEMS / SERVICES

PROGRAMMABLE CONTROL SYSTEMS

PROCESS CONTROL-INSTRUMENTATION

ERECTION & COMMISSIONING



TOTAL NUMBER OF EMPLOYEES = 70,000

TURNOVER FOR YEAR 1982-83 = RS. 1170 CRORES ($ 117 MILLION)

BHEL, TIRUCHIRAPALLI

Mr.M.K.SRIDHAR

EXECUTIVE DIRECTOR

GM HPBP	GM ESG	GM SSTP	GM PA&F	GM MHD	GM VALVES	GM SPECIALIST

ENERGY SYSTEMS GROUP
(Dr.A.GOPALAKRISHNAN)

SPECIALIST / ESG
(Mr.K.M.V.MALARKAN)

FLUIDISED BED BOILER GROUP
- COMMERCIAL DESIGN & PROPOSAL
- OPERATIONS & SITE SUPPORT
- CONTROLS & INSTRUMENTATION
- REASEARCH, DEVELOPMENT & NEW CONCEPTS

18 ENGINEERS

10 DIPLOMA ENGINEERS &

30 TECHNICAL SUPPORT STAFF

BHEL, TIRUCHIRAPALLI

MAN POWER

DOCTORATES, POST GRADUATES & GRADUATE ENGINEERS	-	408
DIPLOMA ENGINEERS	-	463
SUPPORT TECH STAFF	-	323
TOTAL STRENGTH	-	14,000

BHEL'S FLUIDISED BED BOILER DEVELOPMENT

* INITIATED IN 1975
* PROTOTYPE UNIT (22000 lb/hr) LIGHTED UP IN 1977
* RELIABILITY RUN (EXCEEDING 100 hrs) CONDUCTED IN 1979
* FIRST COMMERCIAL FCB (26400 lb/hr) COMMISSIONED IN 1981
* SCALED UP COMMERCIAL FCB (99000 lb/hr) PUT IN TO SERVICE IN 1983
* FOUR ORDERS ON HAND FOR CONVERSION TO FCB (UP TO 44000 lb/hr)
* PROTOTYPE FLUIDISED BED SHELL BOILER (16500 lb/hr) ERECTED IN 1983
* FBC TECHNOLOGY TRANSFER TO SMALL BOILER MANUFACTURERS
* DEVELOPMENTAL WORK ON CIRCULATING FLUIDISED BED COMBUSTOR IN PROGRESS

OTHER FUELS TESTED IN BHEL - FBC FACILITIES

1	LIGNITE	5040	Btu/lb	(2800 Kcals/kg)	
2	WASHERY REJECTS	3600	"	(2000 ")	
3	BOWL MILL REJECTS	6480	"	(3600 ")	
4	BAGASSE	8038.8	"	(4466 ")	- DRIED
5	SPENT BAGASSE FROM FURFUROAL CHEMICAL FACTORY	3600	"	(2000 ")	
6	RICE - HUSK	5040	"	(2800 ")	
7	BARK	3780	"	(2100 ")	
8	PAPER SLUDGE	4500	"	(2500 ")	
9	WOOD CHIPS	10800	"	(6000 ")	- DRIED
10	SAW DUST	11647.8	"	(6471 ")	- DRIED
11	FURNACE OIL	18615.6	"	(10342 ")	
12	SPENT WASH FROM DISTILLIARIES	4841	"		
13	SPENT LIQUER FROM VISCOSE RAYON MANUFACTURING FACTORY	8712.8	"		
14	NEYVELI LECO FINES	12420	"	(6900 ")	

BHEL'S FBC BOILER COMMERCIALISATION

* INDUSTRIAL
* UTILITY
* CONVERSION

FBC BOILER ORDERS RECEIVED

TRICHY DISTILLAARIES & CHEMICALS	26400 lb/hr (12000 kg/hr) OPERATIONAL SINCE OCT 1981
HINDUSTAN POLYMERS LTD	99000 lb/hr (45000 kg/hr) COMMISSIONED OCT 1983
SREE VINDHYA PAPER MILLS	33000 lb/hr (15000 kg/hr) CONVERSION OF MARINE OIL FIRED BOILER TO FBCB
DALMIA CEMENTS	27.8×10^6 Btu/hr (7×10^6 kcal/hr) HOT GAS GENERATOR
SHIMBHOLI SUGARS LTD	44000 lb/hr (20000 kg/hr) CONVERSION FROM DUMP GRATE FIRED BOILER TO BAGASSE FIRED FBCB
PAMANI FERTILIZERS	31.4×10^6 Btu/hr (7.92×10^6 kcal/hr) RICE HUSK FIRED HOT GAS GENERATOR

SOME APPLICATIONS OF TECHNOLOGY
IN FLUIDIZED BED AREAS
OTHER THAN STEAM GENERATION

M. M. SEN

NOTE: THIS PAPER AVAILABLE FROM THE AUTHOR

OVERVIEW OF U.S. DOE FBC PROGRAM

J. W. BYAM

FLUIDIZED BED COMBUSTION
WHERE TO NOW

WHEN CONSIDERING NEW AND/OR REPLACEMENT ENERGY SOURCES-WHY FBC

— VERSUS OIL

- USES INDIGENOUS COAL SUPPLY
- FUEL PRICE STABILITY
- LOW PRICED FUEL

— VERSUS CONVENTIONAL COAL COMBUSTION

- NOT FUEL QUALITY SENSITIVE
- ABILITY TO MEET VARYING SOx RESTRICTIONS WITHOUT CHEMICAL SCRUBBERS
- LOW NOx
- SIMPLE OPERATION
- MAX CONFIGURATION FLEXIBILITY

FBC AS AN ALTERNATE ENERGY SOURCE

— FBC VS CONVENTIONAL COMBUSTION

- ECONOMICS
- RISK
- EMISSIONS
- MECHANICAL COMPLEXITY

— ADVANTAGES

- FUEL FLEXIBILITY
- REDUCED EMISSIONS
- COST OF POWER

FBC PROGRAM OBJECTIVES

— EXPANDED DATA BASE

— IMPROVED PERFORMANCE

— CHARACTERIZATION OF ADVANCED CONCEPTS

DOE FUNDED COMMERCIAL UNITS

ATMOSPHERIC FLUIDIZED BED

— GEORGETOWN UNIVERSITY

- 100,000 POUNDS/HOUR STEAM
- BITUMINOUS COAL
- OVER 4,000 HOURS OF OPERATION

— GREAT LAKES NAVAL STATION

- 50,000 POUNDS/HOUR STEAM
- BITUMINOUS COAL
- IN START-UP PHASE

— SHAMOKIN AREA INDUSTRIAL CORP

- 20,000 POUNDS/HOUR STEAM
- ANTHRACITE CULM FUEL
- START-UP JULY 1981

ADVANTAGES OF PFB AS COMPARED TO AFB

- HIGHER PROJECTED PLANT EFFICIENCY
- LESSER NO_x EMISSIONS
- GREATER SULFUR CAPTURE

PRESSURIZED FLUIDIZED-BED COMBUSTION
PROGRAM STRATEGY

TO PROMOTE COMMERCIAL ACCEPTANCE

- Develop technology in the commercial sector

TO OFFSET RISK

- DOE funding of staged development up to pilot plant
- DOE cofunding with commercial sector of demonstration units

TO MAXIMIZE POTENTIAL BENEFITS

- Develop systems for several applications in parallel through pilot plant stage

- PFB ISSUES
  - — TECHNOLOGY BASE (GOVERNMENT)
  - — SYSTEMS INTEGRATION (INDUSTRY)
  - — ADVANCED CONCEPTS (GOVERNMENT)
  - — ENVIRONMENTAL PERFORMANCE (GOVERNMENT/INDUSTRY)
  - — MARKETS AND ECONOMICS (GOVERNMENT/INDUSTRY)

PRESSURIZED FLUIDIZED-BED COMBUSTION

- CURTISS-WRIGHT 13 MWe PILOT PLANT
- IEA GRIMETHORPE COMBUSTION TEST FACILITY
- TECHNOLOGY BASE
  - Curtiss-Wright Small Gas Turbine/PDU
  - National Coal Board (NCB)/Leatherhead Test Unit
  - General Electric
  - Hot Gas Cleanup
  - Argonne National Laboratory (ANL)
    Laboratory Scale Test Unit

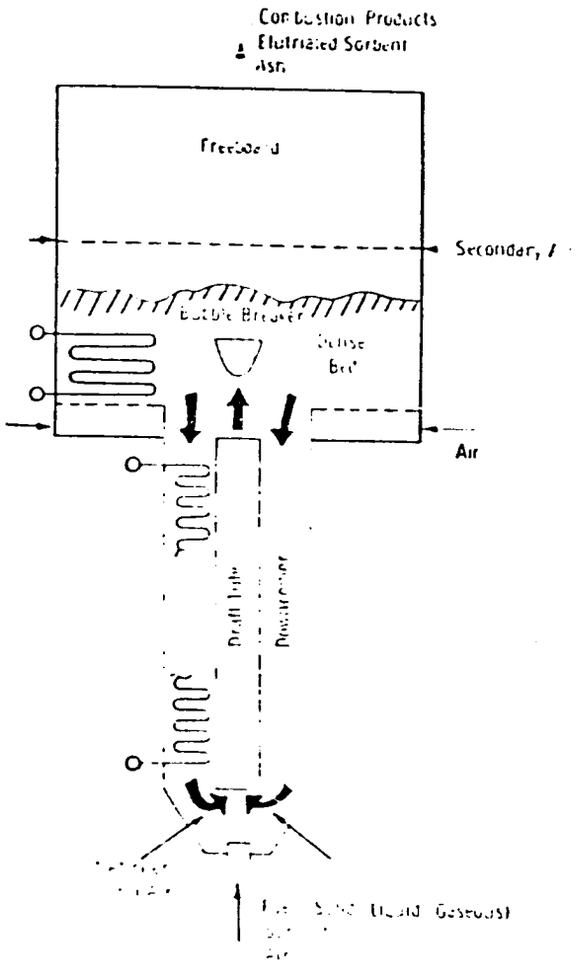
- ADVANCED FBC OBJECTIVES
  - DECREASE NO_X EMISSIONS TO 0.1 LB/MM BTU OR LOWER
  - DECREASE SO_X EMISSIONS TO MEET STANDARDS WITH MORE EFFICIENT SORBENT USE ($Ca/S < 1.5$)
  - INCREASED VOLUMETRIC HEAT RELEASE ABOVE 0.5 MILLION BTU/HR FT^3
  - SIMPLIFY FUEL FEEDING TO HANDLE AS-RECEIVED COAL WITH MINIMUM PREPARATION
  - INCREASE BOILER THERMAL EFFICIENCY TO 90+ PERCENT
  - DECREASE CAPITAL AND OPERATING COSTS OVER CONVENTIONAL AFB
  - IMPROVED TURNDOWN TO APPROACH 8:1 RATIO
  - EXTEND FUEL FLEXIBILITY RANGE

- STUDY DELIVERABLES
  - SUPPORT DATA FOR CONCEPT
    - BACKGROUND
    - PROCESS DESCRIPTION
    - POTENTIAL BENCH-SCALE PROGRAM
    - APPLICATIONS ASSESSMENT
  - DEFINE PROGRAM THROUGH TESTING AT LARGER SCALE TO DERIVE CONFIDENCE IN SCALE UP DATA
  - RECOMMENDATIONS ON A GOVERNMENT MULTI PURPOSE PDU

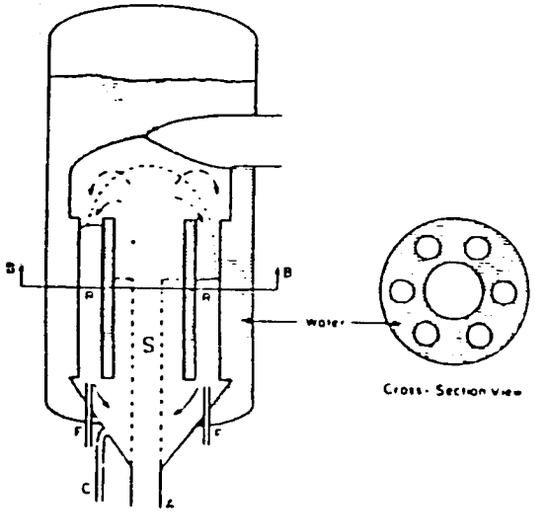
BED DYNAMICS

- PROPOSED ADVANTAGES
  - HIGHER VOLUMETRIC HEAT RELEASE
  - CONTROLLED FUEL/SOLIDS RESIDENCE
  - COARSE FUEL SIZE - LOWER FUEL COST
  - COMBUST AGGLOMERATING FUELS
  - HIGH SORBENT UTILIZATION & NO_X REDUCTION
  - NO CYCLONE RECYCLE
  - LOW CAPITAL COSTS
  - WIDE FUEL QUALITY ACCEPTABILITY
- TECHNICAL CONCERNS
  - HEAT TRANSFER, REMOVAL
  - BOP EFFECTS OF HIGH FREQUENCY VIBRATION
  - FEED SYSTEM BACKPRESSURE
  - NO_X REDUCTIONS

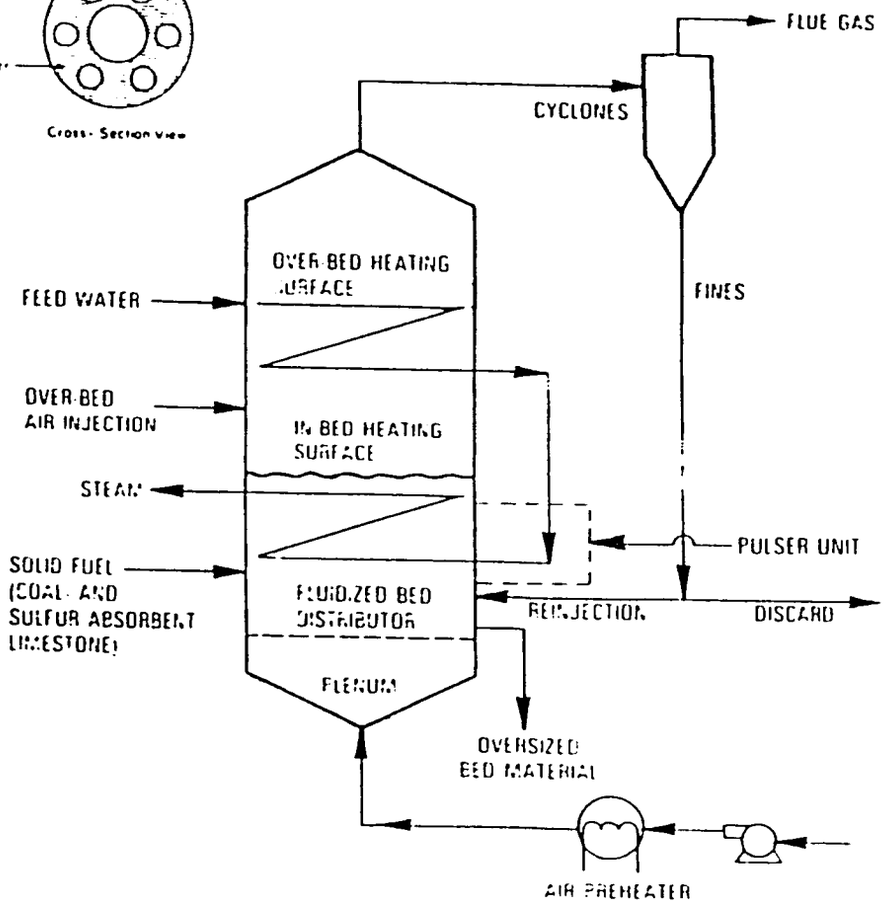
BED DYNAMICS



WESTINGHOUSE - DRAFT TUBE



BATTELLE - SPOUTED

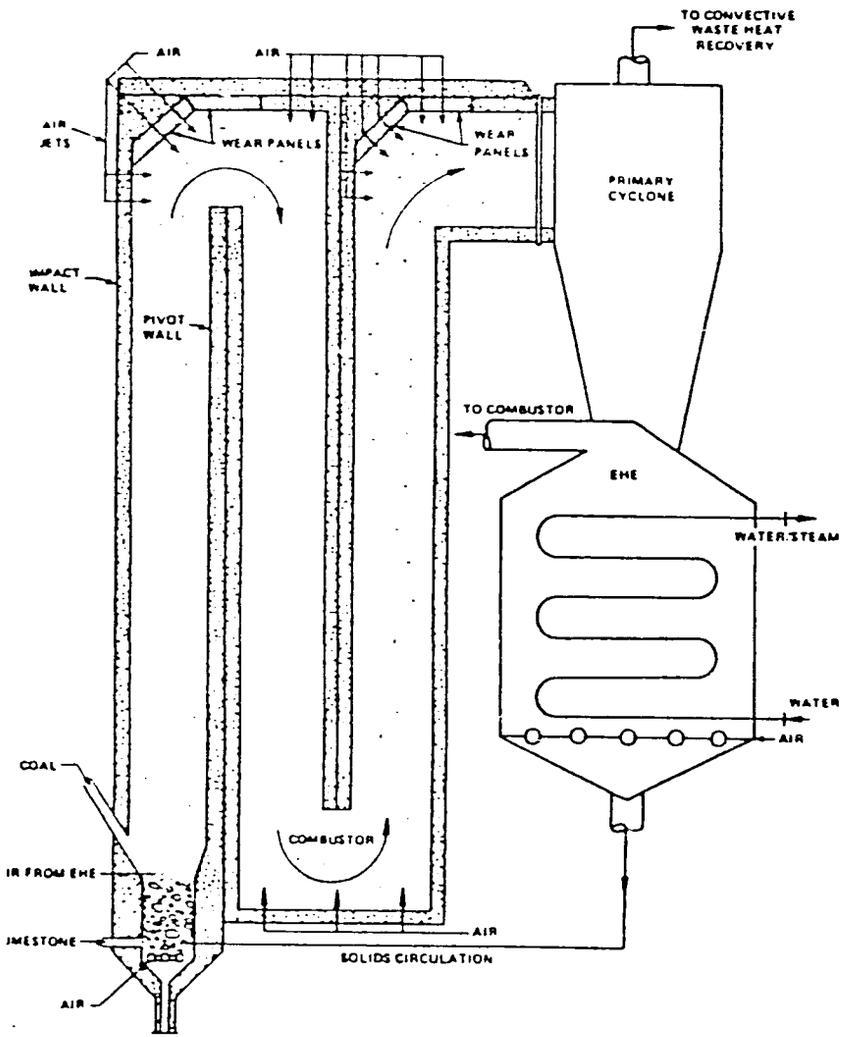


A.D LITTLE - PULSED

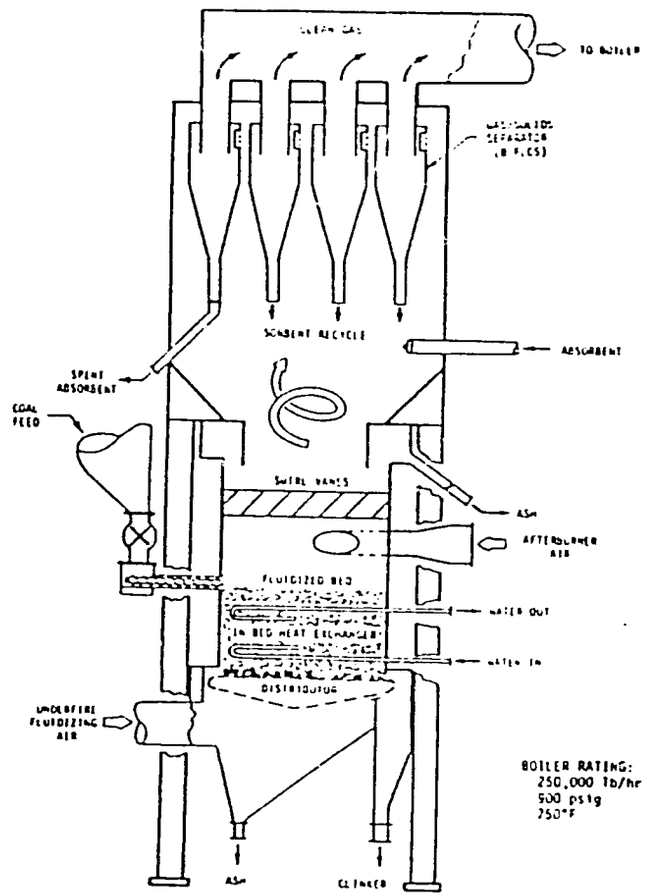
CIRCULATING BED

- PROPOSED ADVANTAGES
  - EXTENSION OF MULTI-SOLIDS FBC
  - HIGH VOLUMETRIC HEAT RELEASE
  - STAGED COMBUSTION - LOW NO_X
  - FUEL FLEXIBILITY
  - SINGLE POINT FUEL FEED
- TECHNICAL CONCERNS
  - EROSION
  - SOLIDS BACKMIXING AT HIGH VELOCITY
  - LARGE REACTOR SIZE
  - NO IN-BED TUBES
  - CAPITAL COST
  - CYCLONE SIZE

CIRCULATING BEDS



BATTELLE - ULTRA HIGH VELOCITY

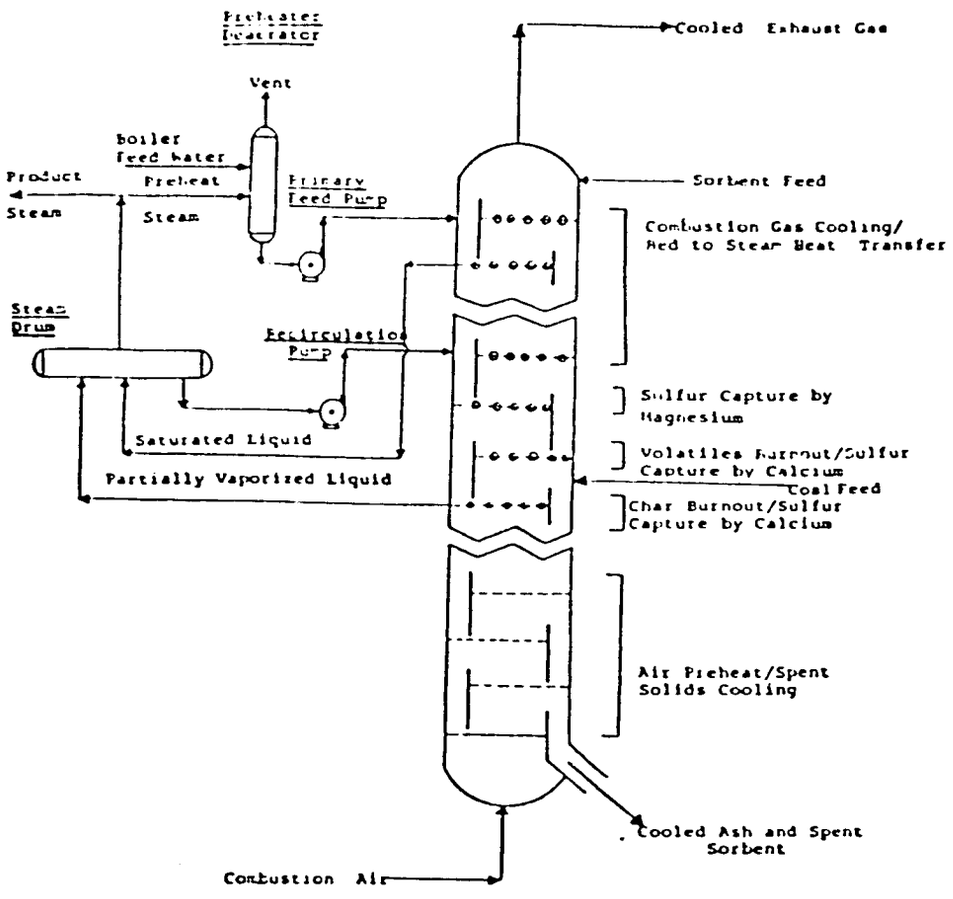


AEROJET - UNIVERSAL ADVANCED

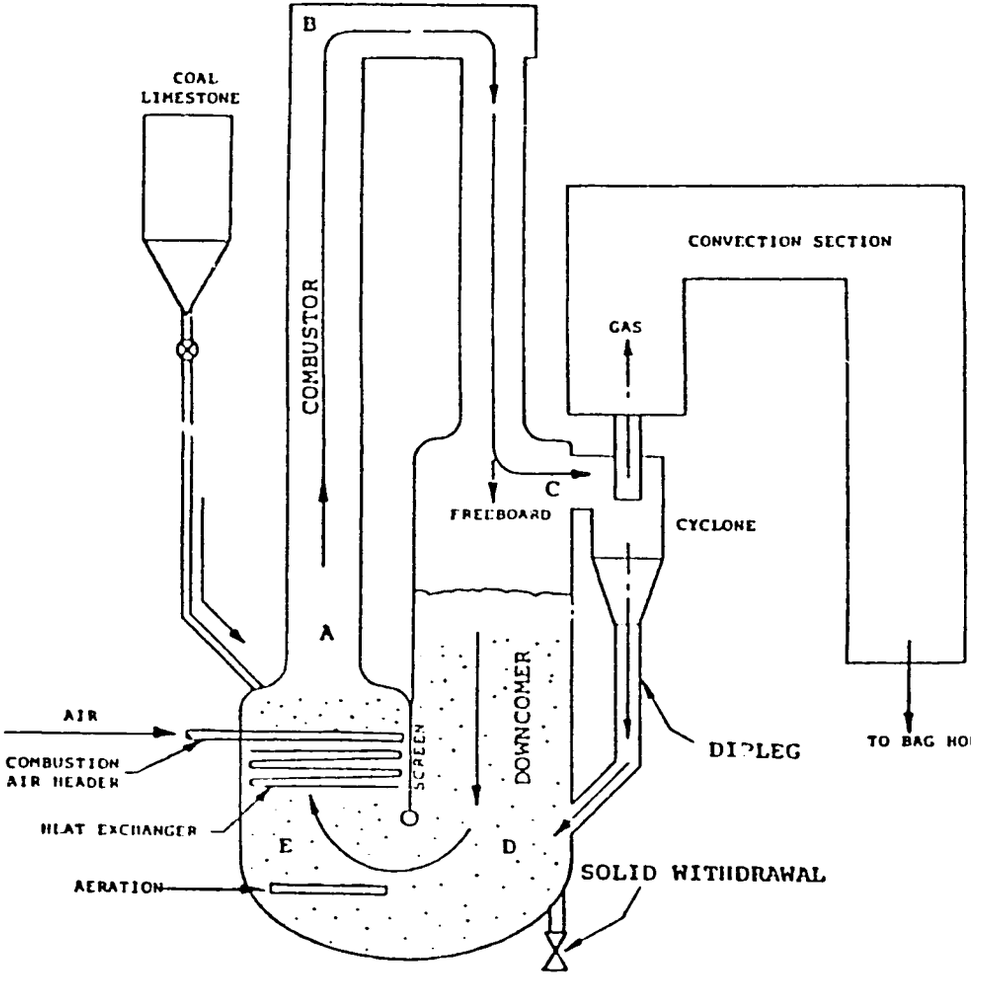
STAGED COMBUSTION

- PROPOSED ADVANTAGES
  - OPTIMIZED COMBUSTION/DESULFURIZATION
  - SO_X, NO_X REDUCTION
  - IMPROVED SORBENT UTILIZATION
  - GRAVITY FUEL FEED
  - POTENTIAL HIGH IN-BED HEAT TRANSFER
  - LOW CYCLONE LOADING
- TECHNICAL CONCERNS
  - COMPLEX FLUID DYNAMICS
  - SYSTEMS CONTROL
  - CAPITAL COST
  - FUEL SIZE; SMALL SIZE HIGH COST

STAGED COMBUSTION



E³I - STAGED CASCADE



KELLOGG - STAGED COMBUSTION

THE FUTURE OF FLUIDIZED BED COAL COMBUSTIO

FUEL FLEXIBILITY

— FBC'S CAN HANDLE LOCAL FUELS

REDUCES FUEL SUPPLY CONCERNS

EMISSIONS

— LOW SO_X AND NO_X

FUTHER PLANT CAPITAL INVESTMENT NOT RQD

IMPROVED PERFORMANCE

— SIMPLIFIED MATERIAL HANDLING

— NOVEL COMBUSTION

— CO - GENERATION

DOE ROLE

CHARACTERIZE HIGH RISK TECHNOLOGIES

DEVELOP STRONG TECHNOLOGY BASE

— DATA DEVELOPMENT .

— TECHNOLOGY TRANSFER TO INDUSTRY FROM SINGLE POINT SOURCE

INDUSTRY ROLE

HARDWARE DEVELOPMENT

PROCESS DEMONSTRATION

EVALUATION OF FREE BOARD PERFORMANCE IN A FLUIDIZED BED COMBUSTOR

R. P. KRISHNAN

NOTE: THIS PAPER AVAILABLE FROM THE AUTHOR

PANEL DISCUSSION - P.M., NOVEMBER 7, 1983 - FLUIDIZED BED COMBUSTION

Q: Dr. Sen has given a presentation on the generation of hot gas through fluidized bed combustion. In his presentation he has said that there are tubes in the bed through which air is passed and heated up. I wonder if the requirement is, ultimately, the hot gas and not particularly the hot air. Why not do the combustion under excessive air conditions and further dilute the gas to the required temperature after the purification of the gas to the required amount?

A. Thank you very much, Mr. Chandon, for raising a very important point -- that we could burn the gas and dilute the flue gas with inert air. But, in that case, the drying air would be contaminated not only with dust and carbon particles but also water vapor, which will retard the rate of drying. So, if you use hot air, you get a clean medium for drying and the efficiency of the drying will be better. But, where the presence of ash and dust particles is not harmful, we can use the flue gas with dilution with air. In fact, in our combustor system we have two heat exchangers, one convective heat exchanger and one immersed tube heat exchanger. We are getting clean air, but the flue gases are leaving at 350°C and there is still a lot of it so, if a little dust is permissible, we can use this flue gas at that dilution for preliminary drying, and final drying can be carried out with hot air generated in the heat exchanger.

A. I would like to add some information on these hot gas generators. In the two hot gas generators that BHEL has contracted, we have simply increased the quantum of fluidizing air, combustion air, and we are able to really get the air to the right temperature. In another system, over and above this increase in fluidizing air we have also added cooling air over the beds so this is all found to be adequate. Of course, as Dr. Sen has pointed out, the moisture content in this hot gas is more. In many industrial applications this is satisfactory, but in other applications requiring a very low moisture content it may not be.

NOTE: Q = Question, A = Answer, C = Comment.

C: I particularly raised this question because, if most of the requirements are for the hot gas, and not normally for very pure air -- and especially when you are doing air-to-air heat transfer -- the metal temperatures are high and you have to go for premium materials and, to the extent possible, we must avoid using premium materials.

Q: I have a question for John. In his presentation he described the circulating fluidized bed as well as pressurized fluidized bed development work going on in the U.S. My question, has a comparative study been made, a sort of assessment, and if a choice is available of these two, which would he recommend? To be very specific, both the circulating and pressurized aim at the reducing of feed points or, in terms of megawatts/M^2, we end up with a smaller area for the same megawatt. So I am asking, has a comparative assessment been made and what is your recommendation?

A: If I understand it right, your question is has there been an assessment of the square footage with the circulating vs. pressurized fluid beds. In circulating, it is generally felt that you need only one feedpoint. There is no square footage restriction at all, primarily because there are no heat transfer tubes within the primary bed. Consequently there is plenty of residence time for your coal to mix before you hit the tubes and therefore there is no worry about the size of the reducing zone. With regard to pressurized fluidized beds, we have run three feedpoints at Grimethorpe. Originally there were nine feedpoints which we cut to three and there was no erosion noted in the bottom of the tube bundles, so they feel that at that pressure, operating at 10 atmospheres, you still have a small enough reducing zone so that you are below the bottom of the bundle. The bundle is 600 mm off the distributor plate so it is a fairly small area. During the next test series on U.S. coals, due to begin in January, we intend to put a zirconium probe into the area just above the distributor plate to measure the exact boundary layer of the reducing zone, with the minimum number of feedpoints. I forget how many square feet we have in Grimethorpe but, basically, three will do it and it is possible we may be able to go below that. One of the things

they are looking at, however, is the effect on combustion efficiency when you get down to that few number of feedpoints.

Q. This is not a question -- I seek some information regarding pressure combustors. I understand that, six or seven years back, BHEL had a program of 10 atmospheres fluidized bed for combined cycle power generation. Today I know that BHEL has a program for MHD as well as a pressure gasifier, which is also going for combined cycle power generation. The two alternatives are special combustion combining gas turbine and conventional steam and special gasification then combustion of the gas. Then, with or without MHD, meaning, if the temperature is very high you can go MHD, then gas turbine, then conventional. Has anyone made an assessment of the future probabilities of these, particularly combined cycle through the gasification route and combustion cycle route? Is there any information?

A. The National Coal Board is in the process of doing a study right now where they are looking at 250 MW modules and they are assessing the PFB air cycle, PFB steam cycle, AFB air cycle, AFB steam cycle, a pulverized coal cycle and combined cycle gasification. Of these, the highest performance they are getting is from the Steam Cycle PFB so, if they can overcome the higher particulate loading, it is felt that the PFB cycle will give better results than the combined cycle, from both an economic and a performance standpoint.

A. I would just like to add, because his particular reference was to BHEL's work, we in BHEL are putting up a combined cycle demonstration plant of 6MW capacity for electric generation. Initially we are basing it on pressurized fixed bed coal gasification, but we have the facility to later on add pressurized fluidized bed combustion also, which we are working on separately, and putting up a small testery. Now, where most of the scientists all over the world are bogged down in the pressurized fluid bed system is the cleaning up of the hot gas under high temperature and high pressure conditions. When we have the presentations tomorrow on this subject we will know more about it. Here again we are trying to interact with the U.S.

scientists to see how we can best make use of the expertise and facilities available in the two countries. As John has pointed out, thermodynamics studies show that the combined cycle power generation through pressurized fluidized bed combustion is definitely more economical, and will ultimately give rise to higher efficiency. But gas cleaning is the major factor bogging us down in the present state of knowledge. Naturally, for immediate application, the focus is on gasification where the state-of-the-art is definitely better as compared with that of cleaning of the high-temperature high-pressure gases.

C. Just a small point to add to that with regard to the NCB in the U.K. They do have certain site-specific applications. As you know, the present economic turndown in Europe has led to a vast reduction in steelmaking. Consequently, where oxygen-blown steelmaking facilities have been installed, there is frequently an excess of pure oxygen available. There is in existence at the moment one 30 MW electrical oxygen-blown slagging gasifier installation, the gas being burned in an Olympus gas turbine producing approximately 30 MW, with a waste heat boiler on the back end and a steam cycle. If you look at this cycle in the context of the capital required in the oxygen-making process -- in other words, if it is not pre-existent and you debit the cycle with the cost of the oxygen plant -- it just does not come up with an economic equation. That is just a point of interest.

Q. One of the speakers mentioned a combustion temperature for the small testery -- the one meter square testery -- which was pushed up to a temperature of about 950°C.The reason given was that the coals were not very reactive. I obviously do not know sufficient about Indian coals, since the coals I have crossed in India have always been particularly reactive. Could any member of the panel please explain the geographical variations throughout the Indian sub-continent and the variation in reactivity, geographically -- just in general terms?

A. In India, the coals that we have are mostly bituminous with some sub-bituminous coals -- coals of the Bengal and Bihar region. 75% to 80% of the coal being raised comes from this area. Petrographically, these are as good as the coals of America and Europe. Previously, before our Institute came into being, it was thought the Indian coals were dull coals, petrographically speaking. Later coal studies by microscopy indicated a petrographic composition -- particularly of the Bengal coals, the low-rank, high moisture, highly volatile, non-coking coals -- with a carbon content mostly between 79 and 84. These are very good power coals. The moisture content ranges from 7-8-10% to 4 or 5%. Volatility on a pure coal basis is around 40%, plus/minus 5%. Except for the high ash content of 15-20%, these coals are in my opinion as good as the British bright coals. The correlations we have developed in our laboratories based on the coals of Bengal apply to British coals with equal precision. If the petrographic composition had not been the same as the British bright coals, the correlation would not have applied with the same precision, with actual petrographic studies in 55-57 laboratories. In Jharia, Bihar, coal from the Jharia coal fields have a carbon content, on a pure coal basis, ranging between 85 to 91-92. As you know, the coking coals have a narrow spectrum of carbon content between say 87.5 to 90.5. All these coals we have in the Jharia coal field are as good as the Durham coals, British bright coals or Pennsylvania coking coals, except for the high ash content. But, petrographically again, it is very often found that 75-80% of the coal is vitrinite. These can compare very well with American coking coals or British coking coals, or any good coking coals in the world. We have another big coal field in Janot, Kalanpuria, Bihar. These are all high-moisture, highly volatile, non-coking coals, but petrographically highly anomalous. There are a lot of inertinites -- about 30-40%. In terms of fusinites or semi-fusinites, the content may be anything from 10 to 20%. These coals are rather peculiar. By and large, you don't have such coals either in England or in America. Then we have lignite; some patches in South Arkot with about 2000 or 3000 million tons. This is very good lignite -- as good as North Dakota lignite. The ash content is 5-6-7% and it is I think a very standard lignite, not a Colorado

or Saskatchewan lignite. In Assam we have a peculiar coal with low moisture, high volatility, high sulphur, and high coking qualities; except for the high sulphur this would be a very good blending component for coke-making but the sulphur stands in the way.

Rounding up, I might say that our total reserves as indicated so far amount to 112 thousand million tons, of which 75% is of the non-caking variety. About 25% is caking to coking coal. Wherever you have a wide spectrum of coal as you have in the U.S.A. or in England you will see that 75% is non-caking coal. That is true of American coals, true of English coals and, I suppose, true of Indian coals. That is roughly the picture.

Dr. Radha Krishnan was mentioning about the fluid bed combustion of high sulphur coals releasing the sulphur in the bed itself to avoid atmospheric pollution or utilize it without any corrosion or erosion, but we have a substantial deposit of high sulphur, low moisture, high volatility caking coal in Assam; however, the production is not picking up. Hardly one-sixth of a million tons. Because it is a mountainous region, mining is difficult and transportation is difficult. In this Northeastern region the industries are lagging behind for various reasons. But we have to mine more Assam coal and then possibly this fluid bed technique will be very very helpful.

C. Thank you, Mr. Majumdar, for coming to the rescue of the panel by answering this question. Now, Dr. Krishnan was mentioning a high combustion temperature in fluidized bed, 950-1000°C. I have been very close with Dr. Krishnan in the initial design of this test facility. The reason for going to higher temperature is as follows. We find that a lot of our coals have a very high ash melting point and, from our studies of fluidized bed combustion we have found that temperature is the best governing factor for the combustion efficiency. It is very temperature sensitive. When the initial deformation temperature of our coal ash is close to 1200-1250°C we thought we must try to go to the highest possible temperature in fluidized bed combustion itself so that we will be able to get to a higher level efficiency. Krish, would you like to add something more to this?

C. With regard to temperature, from the standpoint of U.S. coals the limitation is definitely the sulphur. There is no question but that, if you go to higher temperatures, you lose out on sulphur retention. We plan to test high-sulphur coals in this testery, so that explains why we have to keep the temperatures low. When you swing to the other side and look at the higher temperatures, there is enough evidence to say that you have better combustion efficiency as you increase the temperature. I should say that I am not a coal scientist but a chemical engineer but, as a designer or engineer, when you look at getting higher combustion efficiency, it is definitely worth it if you can raise the temperature and get a few extra points in efficiency. This also implies that the combustion mechanism is definitely an aspect to consider in terms of how you select your operating temperature. If there is a lot of attrition in the bed and you generate a lot of fine particles, say less than 150 microns, you are in a regime which we call the chemical kinetic regime, where undoubtedly an increase in temperature is going to improve your burning rate. We just finished some very basic fundamental work at Oak Ridge, and we have found that there are distinct particle sizes where higher temperatures would enhance combustion efficiency. Now, people have speculated that in fluidized bed the particles are large so it is the diffusion regime, so you don't really have to worry about chemical kinetics. When you do an experimental investigation, as we are proposing here, we want to keep a whole range of temperatures and sort of get a plot, an Arrenius type of plot, and basically prove why we get higher combustion efficiencies as we go to higher temperatures. With the Indian coal you really don't have any reason not to go to higher temperatures and that is why we have decided that we would look at higher temperatures. In the U.S. we would like to but are not able to because of our sulphur constraint.

I hope that answers your question. Thank you.

Q. My question is partly answered because I was more concerned about the fusion temperature of the ash. But BHEL has worked also on biomass where the fusion temperature is really very low. In one of their presentations they mentioned rice husks with 20% ash and a lot of alkalis. I would

like to know from their experience about the slagging of the ash in the FBC they use especially for biomass.

A. We necessarily have to use lower temperatures with biomass. There is every chance of getting this kind of fusion and we have been tending to keep it on the lower side, not the high side, of the range of 800-950 for both biomass and rice husks.

Q. I am not an expert and I don't have any knowledge on fluid bed combustion but I wanted to make sure on one point from Dr. Radha Krishnan, Dr. Abbi and John Byam. For higher temperatures, will there be a concern of tube erosion because, with different metallurgies, there are certain temperature regimes? If we are talking about 200-300°C more than normal metallurgical concerns can handle, would you have any enhanced erosion problems because of high temperatures?

A. It is not a matter of your combustion temperature -- it is a matter of your tube metal temperature. So, if you increase the combustion temperature, all you have to do will be to increase your water flow and your steaming rate, and that would keep your metal temperatures down. We found at Grimethorpe that they have the best example in the valves. When you take a valve to 750°C or higher and try to operate it, even a stainless steel valve, over many cycles you will find that very quickly it will seize up and you'll lose it. They also had an instance where the tertiary cyclones were operating in an environment of 830°C and they had been designed for 750°. They were 1/8" stainless steel and they experienced a 500 millibar pressure differential and collapsed. So it is true that, if you are up at that range above 750°C, you are going to have a metal strength problem but, within the boiler proper, it is not a problem because of the low metal temperatures.

A. There is another point here. As John mentioned, you have the flexibility of increasing the water flow and getting the water temperature to the point where you will not have any tube failures. This is primarily due to thermal fatigue and cycling. Erosion, in my opinion and as I understand it,

is not truly related to temperature and, when you go to uncooled wall supports in a bigger unit, there you have a problem because you have the wall supports which are not cooled and if you get high enough in temperature then they may fail because of thermal stresses. The other aspect is the cycling. If you cycle from low to high temperatures, there is only so much it can take. So the concern is more on the uncooled wall supports than the tubes. We have been, at least in the TVA design evaluation, more concerned about this uncooled wall support and what the bed temperature would do to that than the case of the tubes themselves because, as John said, we have some control so far as limiting the wall temperatures.

A. We have recognized this problem of uncooled supports having to face higher erosion or even mechanical damage, so we tend to completely avoid such uncooled supports and believe in water cooling and nothing else -- water-cooled tubes and supports.

Q. I have a question regarding the environmental aspect of fluidized bed combustion. We are told that the NOx reduction takes place in the fluidized bed combustion. I would like to know, number one, how much is the reduction in NOx? Is it substantial or is it nominal? Number two, normally I understand that NOx formation is primarily a high temperature combustion phenomenon. Now, if you are using high temperatures with fluidized bed combustion, then perhaps NOx formation might increase. Number three, out of NOx we have NO_2 and NO. They have different roles to play in photochemical formation and, when we are instrumenting it for NOx measurement, I wonder if you are taking care to measure each of these separately?

A. The NOx emissions normally refining in the fluidized bed are about half the limits. I know the numbers are 300 to 400 ppm in atmospheric and 200 to 300 in pressurized. Don't ask me what the limit is in ppm. The limit is .6 pounds of NOx allowable emissions, and normally we run around .3. On the second question, you are right -- it is directly temperature-dependent and that is why the NOx is lower -- it is purely because in a fluidized bed you are running at a combustion temperature of 1550F rather

than the 2200-2900°F you get in a pulverized coal boiler. There are some catalysts being looked at which enhance the NOx reduction, but it is preliminary work in those areas. One thing has been found to help and that is to use secondary air feed to the boiler, which enhances the reaction and produces more NO_2 than NOx.

C. At that high temperature I don't think NO will exist. It will go to higher oxides of nitrogen so there is no question of detecting NO at combustion temperature.

Q. As a general rule of thumb the people in the fluidized combustion area feel that only the nitrogen which is present in the coal itself as inherent nitrogen will give rise to the NOx emission in the FBC. Even excess air does not have much effect in the formation of NOx in the fluidized bed system. Is that the general understanding?

A. Yes, that is true. The source of NOx is the fuel-bound nitrogen and not the nitrogen in the air.

A. This is a very interesting question and what we have to go by is the development in Japan. Their target is zero ppm NOx, and they are going to fluidized bed combustion. But I want to point out that the design of the fluidized bed in Japan is unique. As John mentioned, on this business of secondary air they are looking at staged combustion. Primarily, you operate the bottom portion of the bed as a gasifier. Now, there is a problem with the tubes but the CO acts as a catalyst in doing something to this NOx. Professor Beer at M.I.T. and Kurasawa and Kuni at the University of Tokyo have done fundamental work on NOx reduction. We at Oak Ridge have formulated a simulation computer model and one of the problems we have is getting the kinetics. If I recall correctly, when we did this the last time we had eight competing reactions, nine different rate constants and different values reported by different people. That just says that no one is quite clear as to what it is. But there is something The NOx you get is very much dependent on how you operate the bed and, in some cases, you may want to look at completely new concepts like the two-stage combustion where you operate the bed as a gasifier with sub-stoichiometric air at the bottom, and then go up and fire the additional

secondary air above the bed to get your combustion efficiency up. It's a very gray area but I think the directions are well-defined and, as John was saying, we know what the bad actors are and what we have to look for. In terms of coming up with actual numbers and data, we would have to do more experimenting. Here again what you would find as an isolated tubular reactor type of experiment in the laboratory will not necessarily be extrapolated to a fluid bed combuster, where the hydrodynamics are different from when you have a fixed static bed. There you have to worry about diffusion coefficients, mass transfer coefficients, and this would depend on what you would propose as the rate equation for NOx reductions. I think if you will follow up the Japanese work and keep up with them -- I find it hard to keep up with them -- but if you can you will get something on NOx.

Q. Do you have any provision for overbed feeding in the test facility?

A. When we designed this initially, we looked at underbed system because there is enough information and state-of-the-art available. The only reason you would want to go to an overbed system is if you have the high particle sizes like those mentioned -- 1-1/4" top size. Then we have the option of having a site injection for overbed feeding, and John Byam pointed out that that is something we definitely have to have -- the flexibility of overbed feeding. We have not identified it as a last bed system -- the underbed is the only thing we would use -- but we had to get enough information and data from the underbed feed system to see if it is a viable system. For example, if you go to overbed feed system with the coals I have seen in Trichi with so many fines, you may want to double-screen your coal and then it may not be an economical way to go if you have no control of the fines. On the B&W data, the last one I saw in August, they were just getting points on the graph. I think they had three and were trying to get a couple more. They feel the underbed system definitely has better combustion efficiency.
I would be cautious in extrapolating this data, and here is the problem. If you have a lot of fines and you don't want to go into double-screening of coal, you may want to do a lot of experiments on the underbed feed system itself rather than just do overbed feed system as a parameter. We have not closed the lid on this and would certainly consider it if the situation would warrant such a feed system for the test facility.

Q. I would like to ask Dr. Krishnan one simple question -- sort of an inquiry rather than a question. In what way does a circulating bed differ from a spouted bed? In a spouted bed we have also a lot circulation and definite geometry of the bed and the diameter of the pipe. We have a central core and a lot of mixing takes place in that bed also, so how are these two beds different?

A. I think we have a simple answer to that, and I hope I am saying the right thing. A circulating bed is primarily a transport reactor. The velocities are very high. You never see a spouted bed used primarily for drying wheat, grains and that sort of application. You have a draft tube in the middle and then you use high velocity and the solids fall down. But, in the circulating bed, the solids don't fall down; they travel as pockets and go up. In engineering terms, what it amounts to is that you may be looking at bed voidages in the circulating bed as a highest point, .883, and in a spouted bed you may have very much less than that. I think in a typical bubbling bed the bed voidage is roughly 0.45 and a spouted bed will not be anything more than that. It is very deceptive to think that voidages are higher in a spouted bed. So there is a definite regime, a fluidization regime, where you go from a static bed to an expanded bed and to a bubbling bed and then, after that, you have a transport reactor. So basically what you are doing is pneumatic conveying of solids. As a second point, in a circulating bed you are talking about particles 75 to 100 microns and, in a spouted bed, if you look at drying of large particles like wheat and rice, you know your particles are in a different regime so your terminal velocities are much much higher for the spouted bed. So there is a distinct difference between a spouted bed and this relates to voidage and the velocities. You have to go up to high enough velocities because, remember, you have one feedpoint so, in order to get high through-puts, you have to churn those solids at very high velocity. I think they run about 30 to 35 in some of the circulating beds they have used in Germany, Lurgi and in Finland.

Q. I have a question for Dr. John Byam. He was explaining about a number of advanced fluidized bed combustion systems, particularly circulating fluid bed. I want to know whether this is applicable for very high ash coals, whether erosion problems will inhibit such a technology in being considered for Indian coals -- high ash, high abrasive coals. Also, I would like him to highlight on the advanced fluidized conbustion technology which holds the most sense as compared with the others.

A. I think some of the advanced concepts will be more applicable to the high ash coals similar to the Indian coals than the others. I don't think the circulating concepts with very high velocities would fit. I think that perhaps the spouted bed concept might be applicable, as well as the Kellog approach. We are currently in the process of doing a final evaluation of the initial studies of all the different approaches, and I don't believe we have focused in to say that one is better than the other as yet. The intent is to develop a data base on those which we feel have the most promise for the largest market penetration, as well as those that have the highest potential to achieve the objectives I laid out in the presentation -- also to go forward with two or even three of the approaches to get enough bench scale data to allow industry to make its final determination.

CONSIDERATIONS FOR THE DEVELOPMENT OF COAL-WATER MIXTURE AS AN ALTERNATIVE FUEL

T. K. BHOWMIK and M. CHAKRABORTY

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A B S T R A C T

Coal-Water mixture is a low-cost liquid fuel which holds significant potential to replace oil (and gas) used for combustion in boilers and furnaces, with minimum modification and investment. The desired properties of coal-water mixture fuel are pinpointed. The slurry should have high coal content(about 70%) as well as sufficient fluidity and stability to ensure smooth storing, pumping, transportation and atomization. Typical characteristics of a coal-water slurry developed by DE/AFT (USA) is presented.

General characteristics of Indian coals are reviewed. Otherwise suitable, high ash content in Indian coals would pose problems. Demineralisation would be necessary in order to make the coal-water slurry fuel to a reasonable extent comparable with residual oil.

The principles involved in imparting appropriate fluidity and stability to highly concentrated coal-water mixture by manipulating and controlling particle size distribution and incorporation of surfactants are broadly discussed. Major steps of the slurry preparation process are also schematically shown.

Indian status of work on coal-water mixture is presented. CFRI and BHEL have already initiated work on slurry preparation and combustion studies, respectively. The preliminary results already achieved, are encouraging.

A Brief plan of work with tentative time schedule is proposed.

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1.0 INTRODUCTION

One of the main disadvantages of coal, apart from high ash content, is that it is solid in form which poses considerable difficulties in its industrial use. Concentrated coal-water mixture if suitably prepared behave more like a liquid and can be a low-cost potential substitute for residual fuel oil and gas with minimum of alteration and investment.

Allthough the concept is not new, interest in coal-liquid mixture technology in different combinations has recently been resurfaced and countries like U.S.A., Sweeden, Canada, and West Germany have already made remarkable progress towards its commercialisation.

In India, the principal coal deposits are located in eastern and Central regions. A considerable number of utility boilers and industrial furnaces in rest of the country are oil fired. Due to certain historical reasons, a few power stations viz., Dhuvanran, Trombay, Barauni and Chandrapur (Assam) have been based on fuel oil as the principal fuel and the requirements are of the order of about one million tonnes of oil (1). In order to conserve petroleum products, the replacing of oil by coal which would be sufficiently available for a few centuries to come, has been recommended by various committees including Fuel Policy Committee. Concentrated coal-water mixture which in some respects behave like fuel oil can be stored, transported pumped, atomized and burnt. It would hence be a coal based low-cost alternative fuel to replace fuel oil and gas under appropriate conditions. Coal-water slurry is also conveniently used as fuel in modified Texaco pressure gasification systems.

In hydraulic transport of coal, drying of the fines at the receiving ends poses a formidable problem. Direct use of concentrated coal-water mixture for combustion, if established, would make pipeline transportation of coal which is proposed to be installed in the country, economically more attractive.

In the context of this background, CFRI initiated a project to develop a pumpable concentrated coal water mixture for direct combustion. Considerations made in this development which is in progress, has been discussed in this presentation.

2.0 DESIRED PROPERTIES OF COAL-WATER MIXTURE

Since water would cause loss of heat and other problems, the primary objective is to develop a coal-water mixture having minimum quantity of water. In other words, the content of combustibles in the mixture should be as high as possible in order to achieve high heat value and stable flame. The mixture should nevertheless be sufficiently fluid for pumping, transporation and atomization. The fluidity however, decreases sharply with the decrease in water content. A pulverised coal (particle size below 75 micron) - water mixture containing 30% water would appear very thick under low shear condition and have very low fluidity unless specially prepared and chemically treated. A balance between fluidity and water content is to be finally achieved depending on the nature of coal, particle size distribution, surfactants incorporated, etc.

Although for concentrated slurry fluidity i.e., viscosity is more important, the coal-water mixture should also have reasonable stability i.e., resistance to settling. The static and dynamic stabilities are likely to ensure smooth storing and transportation.

The main aim being replacement of oil, the mixture should resemble this fuel to the possible extent. As the mineral matter content in fuel oil is practically nil, this cannot be significanbly achieved unless coal is drastically demineralised to bring down the mineral matter content in the slurry as low as tedhnologically and economically possible. Apart from reducing the heating value of the mixture, mineral matter would cause boiler tube deposition, erosion, resistance to heat transfer and other associated problems which do not usually exist in oil or gas fired systems.

Micron size uniform particle size of coal though desirable for uniform combustion, would adversely affect the fluidity of concentrated mixture. Here again a balance between contradicting factors has to be achieved.

It is obvious that coal should have higher content in volatile matter to facilitate ignition and to have longer flame.

The desirable properties of concentrated coal-water slurry for use as fuel may be summarised as follows :

a) Low water content
b) Sufficient fluidity
c) Reasonable stability
d) Low ash content
e) coal having high V.M.

The optimum values of these properties can best be established by actual experimental investigation with the particualr coal and set-up.

One typical specification of coal-water slurry as prepared and used by combustion Engineering/Advanced Fuels Technology is presented below (2).

Coal - water slurry properties (CE/AFT CWS Specifications)

Particle size	100 % minus 100 Mesh (150 microns)
Viscosity	less than 2800 Centipoise at 100 Sec^{-1} and 25°C (Haake Method) Newtonian or Psuedo Plastic Behaviour.

AFT Coal - Water Slurry Analysis

Total moisture, %	31.0
Solids content %	69.0

	'AS RECEIVED'	'MOISTURE FREE'
Proximate analysis %		
Moisture	31.0	-----
Volatile matter	27.0	39.3
Fixed Carbon	40.1	58.1
Ash	1.8	2.6

	'AS RECEIVED'	'MOISTURE FREE'
Ultimate Analysis%		
Moisture	31.0	
Hydrogen	3.8	5.5
Carbon	56.1	81.3
Sulphur	0.6	0.9
Nitrogen	1.1	1.6
Oxygen (diff.)	5.6	8.1
Ash	1.8	2.6
Gross Heating value		
BTU/lb	10,170	14,740
K cal/kg	5,650	8,190

In short, one typically desires a liquid with 65-70 weight per cent of solids viscosity of the order of 10^3 centipoise resistance to sedimentation and shear degradation (3).

3.0 RELEVANT CHARACTERISTICS OF INDIAN COAL

The predominant part of Indian coals are non-caking having relatively high moisture, volatile matter, and ash. Properties of typical non-caking coals are as follows :

Moisture	:	4 - 8 %
Volatile matter	:	25 - 34%
Ash	:	15 - 40%
Fixed Carbon	:	35 - 50%
Ash fusion range in mild reducing atmosphere	:	1100 - 1300°C

Calorific value generally varies from 3600 to 6000, K cal/Ks.

The properties are found to vary largely from mine to mine and even from seam to seam. It is therefore difficult to have consistent supply of uniform quality of coal for a reasonable period of time. The high V.M. and non-caking nature of Indian coals would be beneficial for combustion.

It is apparent that high ash content in coal would pose problems in crushing and grinding it to fine particle size as required for the preparation of coal-water mixture. Unfortunately, washability characteristics of Indian coals are also generally very poor, as the mineral matter is intimately mixed with the coal matrix. The washability indices of Indian coals are between 15 and 40 whereas for British, German and American coals it ranges between 45 and 76 indicating that they are comparatively much easier to wash (4). It was hardly possible to reduce the ash content of Indian coal ~~over~~ by 50% of the original value by conventional washing techniques without substantial decrease in recovery.

In this context, it is worth mentioning that oil agglomeration and chemical demineralisation techniques developed by our Institute could play a vital role. It has been observed that by the Chemical method involving alkali treatment of coal under specific condition, demineralisation to the extent of over 90% has been achieved with 100% recovery (9). A 3- tonne per day pilot

plant for this process is to be commissioned soon. In view of particular nature of Indian coals, it would probably deserve careful considerations to integrate chemical demineralisation technique with preparation of coal-water mixture.

The cleaning of fine coals by heavy medium cyclone which would be dealt with in another presentation of this workshop, is probably a [illegible] possibility for effective demineralisation of difficult coal.

Incorporation of demineralisation step would also be helpful in producing coal of consistent quality which would be required for the preparation of standard coal-water mixture fuel.

4.0 PRINCIPLES AND PROCESS STEPS INVOLVED IN PREPARATION

4. PRINCIPLES

The requirement and role of fludity and stability of concentrated coal-water slurry on its use has already been discussed. These properties can largely be manipulated by the use of different particle-size distributions of the powdered coal and by the selection of surfactants of specific characteristics and concentration.

The fluidity is a function of rheological properties of concentrated slurry. To achieve the desired properties, it is necessary, in addition to incorporation of surfactants, to have a very carefully selected distrubution of particle sizes, its optimisation and control. The theory of rheology of a suspension is very complex and dependent on many factors of the system. A-part from size and distribution of particle sizes and particles concentration, particle shape and surface charges also influence rheological properties.

The minimum viscosity, hence maximum fludity is closely related to sizing of particles for maximum packing density of powder beds, the latter being inversely proportional to slurry viscosity. It means that miximum bed density will result in minimum slurry viscosity for a specified particle concentration (5). In simplified terms, another way of viewing this limit is to consider the flow of coal-water slurry as motion of larger particles over one another as being "lubricated" by the motion of the smaller particles in the interstices (3). A typical particle size distribution (6) is : per cent less than 200 mesh (75 microns) : 63 - 78, and mass mean diameter : 44 - 60 microns depending on type of coal and system parameters.

The viscosity of concentrated coal-water slurry also depends on shear rate (i.e. rate of agitation). Its viscosity is well above 10,000 centipoise at low shear rates of 0.3 sec^{-1} and below, and it is lower than 2000 cp at shear rates above 100 sec^{-1} indicating that the slurry will resist settling

when at rest and will pump readily (7). If the shear rate is increased further, there is little variation in viscosity behaving more or less like Newtonian fluid (2).

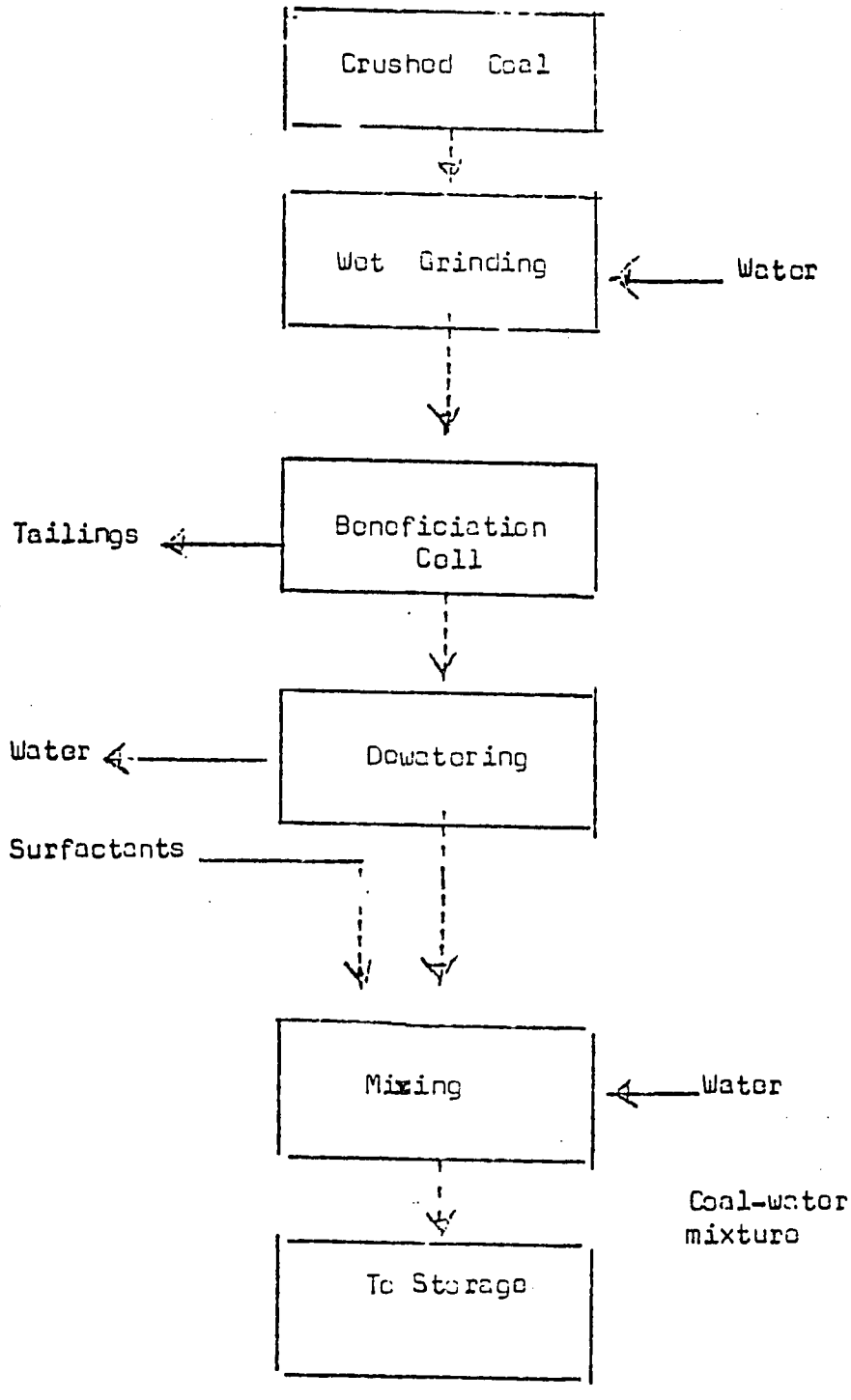
The role of surfactants on the fluidity and stability is important. It is believed that they lower the surface tension of the water, keep the coal particles from flocculating, promote suspension and provide good flow properties (7). Surfactants used are generally ionic and nonionic, and concentration required is usually less than 1.0 %. They are absorbed at solid surface and hinder close particle approach, ionic surfactants do so primarily by electrostatic repulsion and nonionic surfactants by steric hindrance. The nonionic surfactants are usually compounds of macromolecules which are anchored at the solid surface only through the end of the long chain, while the chain is free to move around. As a result, the particles tend to remain apart and this is manifested as repulsion and stability (8). Under that condition a balance among attractive, repulsive, hydrodynamic and gravitational forces is probably established.

Other additives like anti-foam agents and water soluble resins (gums) to increase viscosity can also be used if required (7). It may be mentioned that Coals respond to chemical additives in a variety of ways. It has been observed in coal-oil systems that some additives which stabilize particualr slurry worsen stability if second coal is substituted (11)

4.1 PROCESS STEPS

The process for the preparation of concentrated coal-water mixture is simple and straight forward.

It is better to beneficiate coal, as discussed earlier, if the ash content is high. Whether coal is beneficiated or not it is to be crushed to have desired size consist. One way of obtaining desired particle size range is by wet grinding a part of the feed to a particular size range and mixing the dilute slurry thus produced with the remaining part of feed of different size range produced by dry grinding. Dewatering would be required if only wet grinding is adopted. The process steps are schematically shown below :-



The process steps would however depend on the method of beneficiation used.

5.0 INDIAN STATUS

5.1 PREPARATION

Having realized its relevance to the country, CFRI has initiated a project for the development of concentrated pumpable coal-water mixture for direct combustion as a substitute for fuel oil. Non caking coal from Samla seam in Raniganj field was used for exploratory investigations. The proximate analysis of the coal sample used : Moisture - 4.2 %, Ash - 11.2 %, V.M.-33.0%, F.C. - 51.6 %.

The coal without any beneficiation crushed to below 200 mesh (75 microns) ~~and~~ was used in the study.

A number of surfactants were tried. Water soluble polycarboxylic acids prepared for other purpose by the oxidation of coal with HNO_3 (10) was found to be effective for reducing viscosity. Other large molecular compounds having functional groups were also successfully employed for this purpose. It was possible to prepare a sufficiently fluid coal-water slurry containing 60% coal on dry basis . Settling of coal up to 3 days was not appreciable, under laboratory scale experimental condition.

The rheological properties could not be systematically studied as yet. Shear thinning properties of the slurry was however observed. Facilities for large scale preparation and characterisation of slurry are being installed. It has been proposed to utilize the facilities existing at Central Glass and Ceramic Research Institute (CGCRI) Calcutta, for the characterization of the slurry.

Regional Research Laboratory, Bhubonswar, another CSIR unit, has been working on dilute coal-water pipeline slurries. This is however distinguished from highly concentrated, stable fuel slurries. A few other Institutes are also conducting studies on hydraulic transport of solid in laboratory scale primarily with academic objectives .

5.2 COMBUSTION

It has been reported that BHEL, Tiruchi, is engaged in developing a combustion system suitable for heavily-loaded coal water slurry. Detailed cost benefit analysis for using different coal-liquid mixtures in Indian context has also been made by them. It is hoped that participants from BHEL would present more information on their part of work at this workshop.

CGCRI has also expressed interest in conducting test on ignition and combustion of coal-water slurry fuel at their existing oil-fired furnaces after appropriate modification. It would also undertake design of suitable furnace and burner including abrasion resistant refractory lining for which the institute has reportedly sufficient expertise. Preliminary work has already been initiated in this direction.

6.0 WORK PLAN

Tentative plan of work for the preparation of coal-water slurry fuel is proposed. Combustion part of the work is not included in this report. Programme for communition and beneficiation of coal is also not considered here.

Major activities involved in the preparation part of the work, and estimate of time required for their completion are as follows :-

Activities	Time, Months
1. Effect of particle size distributions	18
2. Role of type of coal	18
3. Search for less expensive surfactants and their optimisation	12
4. Rheological studies	8
5. Stability and studies on other characteristics	8
6. Coal-Water slurry mixing kinetics and mixer scale-up studies	18

7. Studies on actual pumpability and pressure drops in experimental loop 10

8. Studies on erosion 12

Some of these activities at least in part could be conducted simultaneously. A period of three years is estimated to be the total time requirement for the completion of the project. It is merely tentative. The major activities would be further broken-up to sub activities and represented in the form of Bar or PERT Chart after discussion modification and finalisation of the plan at the end of this workshop

The time proposed would be effective after the procurement and installation of instrument and equipment and having obtained adequate fund including foreign exchange, and appropriate manpower. It is needless to mention that the support of all concerned sections and organisations and prompt availability of infrastructural facilities would be essential to maintain time schedule as in any work plan of industrial importance.

7.0 CONCLUSION

i) Coal-Water mixture is a low-cost liquid fuel which can be used under appropriate condition as a potential substitute for oil and gas with minimum modification and investment, and hence it is a fuel of immediate relevance to the country.

ii) In order to make it to a reasonable extent comparable with petroleum based oil, the slurry fuel should contain minimum quantity of water and mineral matter, and have sufficient fluidity and stability.

iii) Typical Indian coals would be suitable for the preparation of slurry fuel in view of their non-caking characteristics and relatively high V.M. content. But high ash in Indian coals would pose

problems and beneficiation would be necessary for the preparation of slurry fuel near -equivalent to oil.

iv) Sufficient fluidity and stability of concentrated slurry can be achieved by manipulating the particle size distribution of coal and incorporating suffactants of appropriate type and concentration.

v) Characteristics of coal-water slurry fuel would also largely depend on the nature of coal used which would make it necessary to establish the optimum process parameters for each particualr coal.

vi) CFRI has initiated work on the development of coal-water slurry fuel; preliminary experiments have already showed some encouraging results.

vii) BHEL and CGCRI have taken up combustion studies including design aspects.

viii) Major activities involved in the slurry preparation part of the work are identified and tentative time schedule proposed. This will be discussed, modified and finalised in separate session of this workshop.

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DEVELOPMENT OF COAL-WATER SLURRY COMBUSTION TECHNOLOGY: BHEL'S VIEWPOINT IN THE INDIAN CONTEXT

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NOTE: THIS PAPER AVAILABLE FROM THE AUTHOR

HISTORY AND DEVELOPMENT OF COAL-LIQUID MIXTURES

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HISTORY AND DEVELOPMENT OF COAL-LIQUID MIXTURES*

In this discussion I would like to present, briefly, the history and development of coal-liquid mixtures focusing initially on coal-oil-mixtures and then coal-water-mixtures.

Coal-liquid mixtures have emerged as viable alternative fuels to displace fuel oil and/or gas in both the utility and industrial sectors. Although fuel oil costs are presently low with oil supplies abundant, the concern for depending on a fuel with an uncertain future both in price and availability, especially for importing countries, makes the CLM technology very attractive.

COAL-OIL-MIXTURE DEVELOPMENT

The interest in the use of COM rose and fell as the supply of oil either was threatened or became readily available over the years. In 1974, one year after the oil crisis of 1973 the General Motors Corporation initiated a COM project funded by a consortium of 26 companies. Similarly, after the oil embargo the Japanese government decided to reduce its dependence on petroleum. A government-subsidized COM program was initiated in 1976 with the Electric Power Development Company becoming the lead organization.

In May 1978, the U.S. Department of Energy sponsored the First International Symposium on Coal-Oil Mixture Combustion. The purpose of this symposium was to bring together the international community of users, manufacturers, and researchers interested in and active in COM. In five years, the annual COM symposium had been expanded to include coal-water mixtures, coal-alcohol mixtures, and other forms of slurry fuels. The fifth symposium, in April of this year, attracted more than 700 attendees from major industrial and developing nations.

COM replaces only a portion of the energy provided by oil. A 50 wt% of coal in COM replaces about 40-percent of the energy of the oil; the remaining 60-percent of the energy is still supplied by oil. In 1977, the price differential in the U.S. between COM and oil was only $\$0.36/10^6$ Btu, which had to cover the COM processing cost, the additional transportation cost, the incremental boiler operating and maintenance costs, capital charges for conversion, and a profitable return on investment. The price differential in the States today is 3 1/2 times this figure. As the price of oil is expected to increase at a faster rate than that of coal, this differential should increase correspondingly.

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* The expanded written version by D. Bienstock and O.K. Foo is available by writing to the author.

UTILITY BOILER DEMONSTRATIONS

Figure 1 summarizes experience with COM combustion in utility boilers. An observation revealed by this table is that, despite the more favorable economics of coal-water mixture, there are still several important projects aimed at converting utility boilers to COM. In Japan, the Electric Power Development Co. plans to convert an oil-designed 350 MWe boiler to COM during the 1984 to 1985 time period, and Tokyo Electric Power plans to convert at Yokosuka two 265 MWe units to COM in 1984. Whether these full scale COM projects will continue to multiply will depend on COM technology development in the next few years. Potential trends in COM fuel development may make it a more competitive fuel for utility boiler application. These are the possibilities for higher coal loading, 60-70% coal (on a H_2O-free basis) and the balance oil, and the use of coal cleaning to reduce the ash content substantially.

In 1980, the Florida Power and Light Company converted a 400-MWe oil-designed boiler to COM firing. Long-term, continuous boiler operation with virtually no derating was achieved with 42-percent of coal in the COM. The significance of this project was that it was the first COM conversion of an oil-designed utility boiler, which is the largest segment of the potential COM market in the United States.

The first permanent COM conversion of a utility boiler is now in its second year of operation. Florida Power Corporation converted the 120-MWe Bartow Unit No. 1 to COM, under a five-year COM supply agreement with COMCO. The burning of COM in this unit has been highly successful.

INDUSTRIAL BOILER EXPERIENCE

COM was burned successfully in industrial boilers as shown in Figure 2. Boiler efficiencies achieved with COM firing in industrial boilers approach that obtained in residual oil firing. Given the current economic conditions and the prices of coal and oil, COM conversion appears attractive only to a limited number of industrial boiler users.

COM PREPARATION PLANTS

Major COM preparation plants in the world are listed in Figure 3; the preparation techniques include dry-grinding and mixing, wet-grinding, ultrafine coal grinding, beneficiated coal, and coal-oil dispersion.

Dry-Grinding and Mixing

The dry-grinding and mixing COM preparation process involves grinding the coal and then mixing of pulverized coal in heated oil, usually with additives. This approach is sufficiently simple so that Florida Power and Light Company was able to design, build, and start to operate a 10,000 barrels per day COM preparation plant in six months. Coaliquids, Inc., produces a COM by mixing pulverized coal, oil, and water into a slurry, which then passes through an ultrasonic dispersion system.

Wet-Grinding

Wet-grinding combines the grinding and mixing steps into one operation so that handling and storing of pulverized coal is not required. Wet-grinding of coal is regarded as safer than dry-grinding. A wet-grinding process developed by the Electric Power Development Co. in a pilot plant involves coal and oil pulverized and mixed simultaneously in a ball mill. It has been successfully scaled to a 10-ton/hr plant at the Takehara Power Station and a 20 ton/hr plant at Sumitomo Metal Industries, Ltd.

Ultrafine Coal Grinding

Ultrafine coal with an average coal particle size of 10-30 microns was used to make COM by General Comminution Inc. in Canada and COMCO and ERGON in the United States. Advantages of ultrafine coal are stability without the use of additives, improved combustion efficiency, and less ash deposition in the boiler. These advantages help to offset the higher cost of ultrafine coal grinding.

Beneficiated Coal

In the preparation of beneficiated COM, additional steps are required for the removal of ash and pyritic sulfur. The use of beneficiated coal will add a premium to the price of COM, but will reduce downstream costs when the cleaned COM is burned in a boiler originally designed for oil-firing.

Coal-Oil Dispersion

The British Petroleum Company (BP) developed a coal-oil dispersion process. A 100,000-ton/year plant at West Thurrock had been planned for late 1981 but is now postponed.

UTILITY BOILER PERFORMANCE WITH COAL-OIL MIXTURES

Boiler Efficiency

At the Sanford Station of Florida, Power and Light, boiler efficiencies obtained with COM were 0.7 to 1.5 percent lower than those obtained with 100-percent oil. The slightly lower efficiencies were attributed to the higher excess-air requirements to burn COM.

Ash Deposition and Slagging

Florida, Power and Light found that ash deposition on the furnace walls became significant after 30 wt% concentration of coal in the COM was reached. To overcome the accumulation of ash, wall blowers were added to the furnace walls.

Derating

Derating of boilers with coal-firing capability is very small as indicated by the Florida Power experience at Bartow Station. The maximum load carrying capacity of this unit was essentially unchanged. The rating before

conversion was 115-MWe which has been attained repeatedly after COM conversion and even exceeded at times.

The only COM experience with an oil-designed boiler was obtained by Florida Power and Light in its Sanford Station. As the percentage of coal was increased to 50-percent, handling of COM became more difficult. It was sometimes necessary to derate the unit from 400 MWe to 355 MWe to keep temperatures within the desired limit, due to inadequate fan capacity for combustion air. However, no derating was required with a 42-percent coal in the COM.

There is no COM experience with a compact-type oil-designed utility boiler. Engineering analyses indicate that substantial derating could result. In the final analysis, testing may be required to resolve questions of derating with regard to specific boilers.

FUTURE COM DEVELOPMENT

Three major areas are identified for future COM developments; beneficiated COM, a compact oil-designed boiler demonstration test, and a highly loaded COM.

A low-ash, low-sulfur COM is still an attractive fuel for utility and industrial users. Oil-agglomeration (Australia, Canada, and Japan) and froth frotation (Sweden and U.S.) have been incorporated into the COM preparation process. However, there is a need for long-term operation of larger facilities.

Compact oil-designed boilers are a large share in the potential COM market. COM conversion of this type of boiler has been considered impractical because of high conversion costs and boiler derating. Burning beneficiated COM in a compact, oil-designed boiler may be a solution to these problems. However, test burns are required to prove this concept.

In the past, coal loading in COM usually had been limited to 50-percent by weight because COM viscosity increases rapidly beyond that concentration. Recently, there have been indications that a highly loaded COM may be possible. Currently, Gulf and Western produces a 60-percent coal in COM for small boiler testing. A low-sulfur, low-ash, highly loaded COM could become an economical alternative fuel for the future.

COAL-WATER-MIXTURE DEVELOPMENT

The drive to obtain a highly loaded CWM with acceptable viscosity and stability became the focal point in recent CWM research and development activities.

In 1977, Atlantic Research Corporation developed a two-stage grinding technique which employed dry-grinding and wet-grinding ball mills to produce coarse and fine coal particles, respectively. The optimum particle-size distribution was achieved by blending appropriate proportions of coarse and fine coal particles. Additives were used during grinding and mixing to lower the viscosity, promote stability, control slurry acidity, and to prevent bio-degradation. CWM containing 70-percent pulverized bituminous

coals were burned for the first time in the United States in 1979 at the Atlantic Research test furnace. Carbon burnouts in the mid-90 percent range were achieved. The successful CWM test burn by Atlantic Research marked the beginning of an intensive CWM program in the United States.

In Sweden, the Carbogel concept started under government funding at Scaniainventor in 1974. Carbogel is a coal-water dispersion containing 70-percent by weight of upgraded coal (less than 4-percent ash) and 30-percent water and is stabilized with organic additives to create a low-viscosity, storable fuel. Carbogel AB was formed to develop and market this fuel. A unique feature of the Carbogel process is the inclusion of a modified froth flotation process to reduce the ash and sulfur. The Carbogel process is applicable to a wide range of coals of various ranks. There are more large-scale CWM projects in Sweden than in any other country on the European continent. Swedish companies have signed license agreements with major corporations in Canada and the United States and are actively marketing CWM worldwide.

CWM developments have experienced a very rapid growth in the last two years and the projected growth rate is even greater. Pilot CWM preparation plants in Canada, Japan, Italy, Sweden, and the United States, can be scaled for commercial production. CWM combustion tests in both utility and industrial boilers have been conducted and long-term tests are scheduled for the near future.

CWM COMBUSTION TESTS

Recent combustion trials in Japan, Spain, Sweden, United Kingdom, and the United States are summarized in Figure 4. One hundred tons of Co-Al, prepared by SlurryTech, was transported to Japan and burned in an 80 million Btu/hr test furnace. This was the first large-scale CWM combustion test in Japan and demonstrated that CWM can be burned in a large furnace without supplemental oil or gas firing.

CWM combustion demonstrations in utility boilers are shown in Figure 5. In 1982, the Italian Electricity Generating Board (ENEL) conducted a CWM test burn in a 125-MWe boiler originally designed for lignite and fuel oil at the S. Barbara Station. Snamprogetti, an engineering firm produced CWM with 68-72 percent by weight of coal. Good results on flame ignition, stability, and atomization were achieved.

In 1982, Energy, Mines and Resources Canada, the New Brunswick Electric Power Commission, and Cape Breton Development Corporation entered into a collaborative agreement to demonstrate the preparation of CWM and its utilization in utility boilers. The major objectives of the joint project are to build a pilot plant to produce 6000 tons of CWM for burner evaluations to be undertaken at two coal-designed utility boilers at Chatham Station. Tests in the front-wall-fired 12.5 MW unit were to start in June and in the 22 MW unit in September of 1983. Both units were originally designed to burn coal and then converted to burn No. 6 oil.

In the United States, the Electric Power Research Institute plans to sponsor a demonstration one-year burn at an as-yet-unspecified utility.

Thirty utility boilers are currently being considered for the project and a decision on the test site will be made in next year.

Industrial Boilers

The major CWM market in Sweden is the industrial and district-heating boiler sector which is mostly less than 20 years old and burns imported oil. Several large-scale demonstrations in industrial and district-heating boilers, shown in Figure 6, were conducted to assess CWM conversion potential.

DuPont Co., EPRI and other organizations sponsored a 30-day trial burn of CWM in 65,000 pounds of steam-per-hour boiler in August 1983 in Memphis, TN. About 2,500 tons of CWM were supplied mainly by Atlantic Research Corporation, with the remainder coming from Slurrytech, Inc. This represents the first, large-scale, long-term CWM test in the United States. Occidental Research Corporation has planned to convert a larger boiler at a rated capacity of 130,000 pounds of steam per hour to CWM firing in 1984. Data from CWM industrial boiler test firings have shown that CWM can be burned in oil-designed boilers with modest boiler and facility modifications. However, long-term operation on CWM is needed to demonstrate its reliability and to obtain operating and maintenance costs.

Industrial Applications

Utilization of CWM in industrial applications is shown in Figure 7.

CWM PREPARATION PLANTS

The CWM preparation process is more sophisticated than COM preparation so as to achieve high coal loading with minimum viscosity. Major CWM preparation plants, Figure 8, are listed in two groups according to whether the coal benefication process is an integral part of the CWM preparation process.

Beneficiated Coal in CWM

Coal beneficiation is relatively more important to CWM than to COM. It is conceivable that an ultra-clean CWM could be burned in an oil-designed boiler without installing expensive particulate removal and flue gas desulfurization systems. The potential also exists that ultra-clean CWM could improve boiler performance by reducing erosion and ash slagging/fouling.

Most physical coal cleaning processes utilize water as the medium by which pyrites and ash particles are separated. The coal particles are then dewatered or thermally dried. The cost of dewatering increases dramatically as the particle size decreases. Therefore, fine coal cleaning is sometimes too costly although the ash separation potential is high. However, for CWM applications, it may be economically advantageous to beneficiate fine coal particles because expensive dewatering can be avoided. Variations of multi-stage froth flotation have been incorporated into Carbogel, G&W, EPDC, and Fluidcarbon AB processes. Other coal cleaning processes, including chemical deashing, have been considered for future production of ultra-clean CWM.

Carbogel has operated a 7- to 10-tons/hr plant since 1980 with a wide range of coals. Two wet-grinding mills are used to obtain the desired coal size distribution. The ground coals are beneficiated in a multistage froth flotation system. The beneficiated coals have less than 4-percent ash, with up to 95-percent of the inorganic sulfur removed. Chemical additives are used to enhance yield and selectivity in the separation process. Three-tenths weight percent of organic additives are added to the dewatered coal concentrates to obtain a stable CWM containing 70 weight percent coal. Carbogel AB has signed license agreements with Cape Breton Development Corporation (CBDC) in Canada and Foster Wheeler Corporation in the United States. The CBDC has built a 7-ton/hr CWM pilot plant at Sydney, Nova Scotia, and will produce a sell CWM with exclusive rights to Eastern Canada.

Unbeneficiated Coal in CWM

Snamprogetti in Italy, Atlantic Research Corporation, Slurrytech, Inc., Occidental Research Corporation, Standard Havens Research Corporation, and the Pittsburgh Energy Technology Center in the United States have CWM preparation plants which currently do not include a coal-benefication process.

STATUS OF CWM TECHNOLOGY

The review of the current status of CWM technology focuses on the major areas: preparation, combustion, and boiler performance.

CWM Preparation

Ball mills were selected for early CWM tests because of the abundance of data on wet grinding of coals and minerals, their reliability, and economics. Atlantic Research Corporation (ARC) and Carbogel favored a two-stage grinding technique to produce a bimodal distribution of coal particles. Recently, both ARC and Slurrytech have demonstrated that for a number of coals, satisfactory CWM can be produced by a one-step grinding technique in a ball mill. This improvement will simplify the CWM process and reduce production costs. Dispersants, to reduce viscosity, and stabilizers are added at various points of the CWM preparation process. An effective dispersant will produce CWM with a high-solids loading and minimum viscosity.

Currently, there is limited experience on CWM pumps. Progressive cavity pumps which were also used in COM applications are now being used with CWM. PETC reported that the rotary gear pump, which was effective for slurry recirculation or transfer service with COM, experienced total flow blockage when operated on CWM. The pump cavities tended to foul with coal particles. Compressed air-driven diaphragm pumps have been installed to replace the rotary gear pumps. Wear rates of a pump used for CWM are expected to be higher than those of COM pumps operating under the same conditions, (1) CWM has a high solids loading and therefore is more abrasive, and (2) the fuel oil in COM provides lubrication during pumping and, thus, reduces the impact of solid particles on the surfaces of a pump.

The U.S. DOE is presently funding a project to evaluate equipment and instrumentation in utilizing CWM. Various types of pumps will be installed

in a test loop. Test data will be correlated to the physical properties, such as density and viscosity, of each slurry tested.. Records on the operation and maintenance of the pumps will be collected to evaluate pump performance. Erosion/corrosion coupons or wear plugs will be installed to evaluate the wear rate and to predict the useful service life of various materials and components. Canada, Japan, Spain, and Sweden all have plans to evaluate slurry pump performance during their CWM demonstration tests.

CWM Combustion

Burner development has been identified as one of the major areas for investigation. Bench scale and full-scale test programs are now being conducted to evaluate burner performance. COM burner experience is helpful, but not totally useful for CWM development because of large differences in fuel composition and combustion characteristics.

Since 1981, PETC has burned CWM with 63 wt% coal loading in a 700-Hp watertube boiler. The COEN burner used with the 700-Hp watertube boiler was modified for CWM firing. Nozzle holes were enlarged to double the area to reduce fuel velocity and pressure drop. Air register modifications were made as well. With 500°F preheated combustion air, stable CWM combustion was achieved without the use of supplemental fuel.

With the proper combination of burner and atomizer design, CWM can be successfully burned with carbon conversion efficiencies in the range of 96 to 99+ percent.

Boiler Performance

The testing of CWM industrial boilers is at an early stage while it is only at a planning stage for utility boiler testing. In the next two years more boiler data will be available.

Boiler Efficiency

In the 700-Hp boiler at PETC with a 60% CWM, at full load the boiler efficiency was 75-percent with a carbon conversion efficiency of 96-percent. The boiler efficiency with CWM was approximately seven percentage points lower than that with oil firing. This lower boiler efficiency appears to be due to differences in heat losses caused by water and hydrogen in the fuels, heat losses due to the lower carbon conversion, and differences in combustion-air temperature. The combustion-air temperature for oil was approximately 80°F compared to about 500°F for the CWM.

CWM burner and atomization are still in the developmental stage. Boiler efficiency and carbon conversion efficiency will improve when the CWM burner is optimized.

Derating

Full load on CWM was reached at PETC's 700-Hp oil-designed, industrial boiler after burner and air-register modifications. Derating could occur when CWM is fired in an oil-designed utility boiler. The amount of boiler derating depends on boiler design and fuel characteristics. Estimates on

boiler derating and capital costs of boiler modifications have been reported by Burns & Roe and other engineering companies. Nevertheless, derating is still a site-specific problem which requires actual boiler testing.

FUTURE CWM DEVELOPMENT

At this time, CWM technology has not achieved commercial status and more R&D is needed. Some important areas to be considered are as follows:

1. Advanced physical coal cleaning and chemical coal cleaning processes should be evaluated to determine feasibility and cost for CWM applications.

2. More R&D for major equipment is desirable. CWM burners and pumps have been developed by private companies. However, more information is needed on durability and performance.

3. Long-term CWM combustion tests in oil-designed utility and industrial boilers are needed to determine boiler derating and reliability. Short-term test data are insufficient to convince users to accept CWM. The selected boiler should be representative of a major CWM conversion market segment.

4. More R&D activities are needed in the environmental control area. The trade-offs of using low-ash and low-sulfur CWM versus emissions control equipment should be evaluated.

5. Handling and transportation of CWM, particularly long distance transportation between the fuel preparation site and the user, should be evaluated.

IN SUMMATION:

COM technology has become a mature technology in the last decade while CWM technology is approaching commercialization rapidly. CWM has a competitive edge on cost over COM. CLM must compete with other coal utilization and coal conversion technologies such as coal liquefaction, medium-Btu gasification, and direct coal firing, for combustor retrofit and new combustor markets. CWM also has a potentially lower cost than liquefaction and gasification due to the lower capital and operating costs. Most of all, CWM has the advantage of earlier availability. Finally, CWM, as a liquid fuel, is easier to transport, store, and handle than solid coal, and may be the preferred way to get coal to the user, particularly in industrial plants.

Commercial acceptance of CWM technology hinges on the magnitude of the price differential between the cost of oil and cost of coal, and the projected long term availability of oil. Market acceptance will also require proven operating reliability. Additional research and development opportunities exist for further expanding CWM market penetration into new areas such as transportation and heat engines. The importance of coal benefication in CWM to an expanding market is paramount. A low-ash and low-sulfur CWM needs to be developed to create a greater demand for CWM fuel.

Figure 1.
COM UTILITY BOILER DEMONSTRATIONS

Country	Power Station	MWe	Test Period
Canada	Chatham Station	10	1977 - 1980
China	Yang Shupu Station	20	1981 - 1983
	Anshan Iron and Steel Company	20	1981 - 1983
Japan	Takehara Unit 1	250	1981 - 1982
	Takehara Unit 2	350	planned
	Yokosuka (2 units)	265	planned
Spain	Almeria Plant	30	1981 - 1982
Sweden	Uppsala, Kraftvarma, Cogeneration Plant (315 MW thermal for heat)	200	1980
United Kingdom	Padiham Power Station	120	1981
United States	Crystal River Station	383	1977 - 1978
	Salem Harbor Station	80	1979 - 1981
	Sanford Station	400	1980 - 1981
	P.L. Bartow Unit 1	120	1982 - current

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Figure 2.
COM INDUSTRIAL BOILER EXPERIENCE

Country	Project	Capacity	Test Period
Canada	Ontario Research Foundation	1.2 MWt	1980 - 1981
United Kingdom	British Petroleum, Inc.	Various boilers in U.K. and other countries	1979 - 1981
	Shell Research, Ltd.	60,000 pph	1976 - 1977
United States	PETC/DOE	100 hp	1976 - 1981
		700 hp	1977 - 1981
	Coaliquids, Inc.	65,000 lb/hr	1980
	General Motors	120,000 lb/hr	1977
	Occidental Petroleum	135,00 lb/hr	1981
	Ohio Univ. at Athens	150 hp	Ongoing Since 1981
	Adelphi Energy Center	350 hp	1978 - 1981

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Figure 3.
COM PREPARATION PLANTS

Process	Country	Project	Capacity	Additive
Dry-Grinding and Mixing	China	Yang Shupu Power Plant	10 TPH	No
		Anshan Iron and Steel Co.	12 TPH	Yes/No
	France	Blanzy Station	8 TPH	Yes
	Spain	Almeria Power Station	N.A.	No
	U.S.	New England Power Service	6,440 bpd	Yes
		PETC	100 bpd	No
		Florida Power and Light Co.	10,000 bpd	Yes
		COM Energy, Inc.	3,000 bpd	Yes
		Coalliquids, Inc.	1,200 bpd	No
		Allied Oil Co.	1,500 bpd	Yes
Wet-Grinding	Japan	EPDC - Takehara Unit 1	10 TPH	Yes
		Sumitomo Metal Industries	20 TPH	Yes
	U.K.	Shell International Pet.	N.A.	No
	U.S.	Interlake, Inc.	1,540 bpd	Yes
		Allied Oil Co.	1,500 bpd	Yes
Ultrafine Coal Grinding	Canada	General Comminution, Inc.	3 TPH	No
	U.S.	COMCO	3,500 bpd	No
		ERGON	5,000 bpd	No
Beneficiated Coal	Canada	Scotia Liquicoal, Ltd.	6 TPH	No
	Japan	EPDC - Takehara Unit 2	10 TPH	N.A.
	Sweden	Uppsala Kraftvarme AB	3 TPH	No
	U.S.	Gulf & Western Ind.	1.5 TPH	No
Coal-Oil Dispersion	U.K.	British Petroleum	100,000 TPY (planned)	No

Figure 4.

RECENT CWM COMBUSTION TRIALS

Country	Organization	Test Furnace	Test Period
Japan	Babcock Hitachi K.K.	80 x 10^6 Btu/hr test furnace	1982
	Electric Power Development Co., Ltd.	1.3-MWt Btu/hr Cylindrical test furance	1982
Spain	UNESA	4-MW test furnace	1983 - 1985
Sweden	AB Carbogel	Various prototype burners with capacities up to 3.5-MW have been tested	From 1979
United States	Atlantic Research	1.3 x 10^6 Btu/hr furnace at ARC, and 4.0 x 10^6 Btu/hr test furnace at Babcock & Wilcox Alliance Research Center	From 1979
	Slurrytech, Inc.	4.0 x 10^6 Btu/hr test furnace at B&W Alliance Research Center	1980
	Gulf & Western Industries, Inc.	80 x 10^6 Btu/hr test furnace at Combustion Engineering, Inc. 70 x 10^6 Btu/hr test furnace at Forney Eng. Co.	1982
United Kingdom	NEI International	5 x 10^6 Btu/hr	1982 - 1983

Figure 5.
CWM UTILITY BOILER DEMONSTRATIONS

Country	Power Station	MWe	Test Period
Canada	Chatham Station	12	1983
		22	1983
		100-150	1984
Italy	S. Barbara Station	125	1982
United States		To Be Determined	1984 - 1985

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Figure 6.
CWM INDUSTRIAL BOILER DEMONSTRATIONS

Country	Organization	Size	Design Fuel	Test Period
Sweden	NYCOL AB	In Several Industrial Boilers		From 1980
	Svenska Fluidcarbon	5 MW	oil	1981
	Thermal Engineering Research Foundation	50,000 lb/hr	oil	1983
United States	PETC	100 hp	oil	From 1981
		700 hp	oil	
	DuPont Co.	65,000 lb/hr	oil	1983
	Occidental Research Corp.	130,000 lb/hr	oil	1984

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Figure 7.
CWM INDUSTRIAL APPLICATIONS

Country	Project	Application	Test Period
Canada	EMR/B&W	Fluidized-Bed Combustor	1983
Italy	Centro Sperimentale Metallurgico	Blast Furnace Fuel Injection	Planned
Sweden	Carbogel AB	Gasifier	N.A.
United Kingdom	National Coal Board, Coal Utilization Research Laboratory	Pressurized Fluidized Bed	1982
United States	Standard Havens Research Corporation	Rotary Rock Dryer	1983

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Figure 8.
CWM PREPARATION PLANTS

Process	Country	Company	Capacity (TPH)	Status
Beneficiation Included	Canada	New Brunswick Electric Power Commission, Cape Breton Development Corp., Licensee of Carbogel (Sweden)	7	Start up in In June 1983
	Japan	Electric Power Development Corp.	1.5	Start up in mid 1983
	Sweden	AB Carbogel	7-10	Operational
		NYCOL AB	3	Operational
		NYCOL AB	100	Start up in late 1983
		Svenska Fluidcarbon AB	5	Operational
		Svenska Fluidcarbon AB	44	Start up in late 1984
	United States	Gulf & Western Industries	1.5	Operational
Beneficiation Currently Not Included	Italy	Snamprogetti	N.A.	Operational
	United States	Atlantic Research Corp.	4	Operational
		Slurrytech, Inc.	5	Operational
		Occidental Research Corp.	15	Start up in late 1983
		Standard Havens Research Corp.	N.A.	Start up in late 1983
		Pittsburgh Energy Technology Center	0.5	Operational

BSI/3942

THE STATUS OF COAL CLEANING IN INDIA

A. K. CHAKRAVARTI

The status of coal cleaning in India

A.K.Chakravarti

India with 112 billion tonnes of coal resources-proved, inferred and indicated- representing 0.8% of the total world coal resources is the sixth largest coal producer in the world with a production of 124.92 million tonnes in 1981-82. The drift nature of the coal seams of the major Indian coal basins has resulted in the fine dissimination of mineral matter throughout the coal substance. Thus beneficiation of Indian coals present many formidable problems. This intergrown dirt necessitates crushing to small size for release of the dirt resulting in excessive production of fines which pose problems of handling, beneficiation, dewatering, water clarification, drying, heavy medium regeneration etc. Low differential in specific gravity between coal and extraneous matters leads to large percentage of near gravity materials (NGM) as much as 70 to 80 percent in some cases. This causes considerable migration of ' sinks'in 'floats' and 'floats' in ' sinks'. Besides, there are several other problems associated with Indian coal washing which are(i) wide fluctuation of ash content of coal seams (ii) small production of majority of the mines needing construction of central washeries and (iii) progressive deterioration of the quality and washability characteristics of the feed to washeries.[1,12] On account of these factors, washing plant in India are sophisticated and thus 30 to 40 percent costlier than those in other countries.

Pioneering washability studies which were done on Indian coals in the early forties had concluded that the Indian coals were not amenable to techno-economic beneficiation. Subsequent washability studies conducted under the aegis of the Fuel Research Committee and at Central Fuel Research Institute

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established feasibility of beneficiating Indian coal seams, though in general, the washability characteristics of Indian coals were found to vary from difficult to very difficult. The washability indices[2] of Indian coals are compared with the coals of different countries of the world in Table 1. The low value of washability indices of Indian coals indicate difficult cleaning characteristics.

Since 1950 the Central Fuel Research Institute has been engaged in R&D activities covering various aspects of coal preparation namely evaluation of the washability characteristics of Indian coals, development of suitable techniques for their effective beneficiation, upgrading and dewatering of fine coal, properties of heavy medium suspensions and application of H.M. cyclones for the preparation of Indian coals- CFRI has also been playing a major role in the planning of all the public sector washeries which were set up during the last 3 decades. During the period 1951-1983 seventeen washeries were set up with aggregate throughput capacity of about 29 million tonnes per annum (Table 2.).

The coking coal reserves in India are concentrated in the Jharia coalfield. The upper seams are having comparatively better quality and washing characteristics as compared to the lower seams. The yield of clean coal from lower seam coals is poor with high yield of middlings when washed in lump sizes (Table 3) when crushed to smaller sizes, the yield of clean coal increases with decrease in the yield of middlings(Table 4)[3]. The middlings release considerable percentage of clean coal on crushing to very fine size like minus 0.1 mm(Table 5)[4]. For fine and ultrafine coal beneficiation, processes like oleoflotation, oil agglomeration and chemical demineralisation have been developed at the Central Fuel Research Institute[5,6,7]. Oleoflotation and oil agglomeration processes permits easy dewatering of cleaned product in addition to efficient beneficiation. Chemical demineralisation gives high order of refinement with practically no loss of carbon in the discord. Typical result of beneficiation achieved by the processes are given in Table 6.

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Static heavy medium coal cleaning processes are effective for comparatively coarser size coal having bottom size around 6 mm. Below the size, the separation becomes progressively ineffective due to large settling time taken by the particles in the viscous heavy medium. Gravity processes other than static heavy medium are also not effective for cleaning such small size particles particularly those having inferior cleaning characteristics. Heavy medium cyclone washers using centrifugal force instead of gravity hold much promise to beneficiation smaller size of coal with high capacity & efficiency .

Heavy medium cyclones was invented in the mid forties at the D.S.M. and these came into commercial existence in early fifties. At the Central Fuel Research Institute, Dhanbad studies on the applicability of heavy medium cyclone was carried out for a decade starting from early fifties.[8,9,10,11] The studies have established the suitability of heavy medium cyclones for beneficiating Indian coals. So far heavy medium cyclones have been installed in 13 commercial coal washeries in India out of seventeens having total throughput capacity about 3500 tonnes per hour. Heavy medium cyclones are in very common use to-day. There is a trend towards increasing both the top size of feed as well as to feed the cyclones with zero size particles.

With the progressive depletion of easy and medium washable coals in India it has now become imperative to utilise the inferior grade difficult washable coking coals for metallurgical use. Study on the liberation characteristics of these difficult washable coking coals has revealed that they are to be crushed to 10 mm or even 6 mm prior to washing. The $\pm$ 0.1 NGM in these crushed coals generally remain in the range 50-60% at the desired separation point. HM cyclone is the only washer which can deal with such a difficult washable and smaller size coal.

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The only limitations in conventional heavy medium cyclones washers is its inability to accept particles finer than 0.5 mm which trend to contaminate the separating medium. Generally the fines below 0.5 mm are screened off from the feed to the cyclone and are treated by froth flotation technique. Quantity of fines below 0.5 mm in coals crushed to 10/6 mm remain in the range of 20 to 40%. It has been found that most of the fines consist of intergrown particles of vitrinites and inertinites which do not respond properly to flotation treat and as a consequence considerable amount of coal particles get lost along with flotation tailings.

Of late, lot of R&D studies have been made in western countries particularly in USA and Netherlands, regarding applicability of HM cyclone extending to a bottom size limit of 0.1 mm or even upto zero. A number of such HM cyclones have recently been installed at Pennsylvania, Pittsburg, Virginia, West Kentucky in USA and are successfully being operated with a feed size down to 0.1 mm. If such ~~sys~~ systems be incorporated for treatment of difficult cleaning smaller size crushedc feed, much of the existing problems of Indian coking coals will be overcome. A collaborative study in this area between India and the USA may be useful.

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Table 1

Comparison of washability characteristics of coals from different countries of the world.

Details of samples	Size of coal	Overall ash%	Washability index	Remarks on characteristics.
A. India				
Jharia Coalfield Seam I-XVIII	76 mm-0	20-30	15-40	Difficult to very difficult.
2. East Bokaro Coalfield Kargali seam	76 mm-0	18-25	24-27	Difficult
B. England				
3. Manvers main colliery Park gates, Silkotones & Haigh moor seams	203-51 mm	11-14.5	66-76	Very easy
4. Askarn colliery	203-25 mm	26.0	61	Very easy
5. Worshop colliery	203-51 mm	38.3	65	Very easy
C. U.S.A.				
6. No.6 Coal bed, St.Chair country, Illionois	38-.15 mm	17.4	48	Easy
7. Upper Freeport bed Cochrace Mine Westmoreland country	38-0	11.0	61	Very easy
8. Rose hill mine, Maskingum country, Ohis	38-.15	14.0	57	Easy
9. No. 12 mine, Maykingum country, Ohio	38-0.15	21.0	65	Very easy
D. Germany				
10. Deura seam	30-0.3	13.5	67	Very easy
11. Heramaun	30-0.3	21.5	68	-do-
E. Australia				
12. Victoria Tunnel seam	ROM(excluding -0.5mm fines)	19.8	43	Easy
13. Young wall and seam stackton	ROM(ex-0.5mm)	23.2	45	-do-
F. South Africa				
14. London colliery	Nuts	15.6	36	Medium
15. Phoemix colliery	Nuts	12,1	21	Difficult

Table 2

Details of coal washeries installed between 1951-1983

Name of washery	Year of commissioning	Nominal capacity in m.tonnes/year	Feed size (mm)	Principal washing systems
A. Prime coking coal sector				
1. Jamadoba	1952/1973*	1.44	76	Chance cone, HM cyclone and froth flotation.
2. Lodna	1955	0.40	13	Acco Foldapur jig
3. Durgapur	1960	1.50	76	DrewboyBath &Foldapur jig
4. Dugda I	1961	2.40	76	Baum jig & Tromp baths.
5. Bhojidih	1962/63*	2.00	76	Leeber bath, Baum jig & HM cyclone.
6. Pathardih	1964	2.00	76	Baum jig, Barvoys bath HM cyclone.
7. Durgapur(DPL)	1967	1.35	13	HM cyclone
8. Dugda II	1968	2.40	13	HM cyclones& Hydrocyclon
9. Chasnalla	1968	2.00	76	Leeber bath & HM cyclone
10. Sudamdih	1981	1.60	35	HM cyclone & froth flotation.
11. Monidih	1983	1.60	35	HM cyclone & hydrocyclon.
12. Barora I	1982	0.50	75	Baum jig, HM cyclone & fr flotation.
B. Medium coking coal sector				
13. West Bokaro	1951/73*	0.57	76	Chance cone, HM cyclone froth flotation.
14. Kargali	1958/66*	2.72	76	Wemco Drm, Baum jig & HM cyclone.
15. Katahra	1969	3.00	76	Drewboybath, HM cyclone & froth flotation.
16. Sawang	1978	0.75	20,	HM cyclone-Hydrocyclone
17. Eidi	1970	2.84	76	Disabath &Baum jig
C. Non coking coal sector				
18. Nowarazabad	1959/60	0.50	76	Humboldt bath & Baum jig

* Date of completion of expansion/modification.

Table 3

Recovery of washed products from lower seam coals of Jharia Coalfield, Bihar

Raw coal crushed to 75 mm

Seam	Overall ash%	Clean coal (1.50 SG)		Middlings (1.50-1.80SG)		Rejects (1.80 SG)	
		wt%	ash%	wt%	ash%	wt%	ash%
1. V/VI/VII	27-30	26-36	16-18	52-66	33-35	8-13	50-56
2. VIII	22-33	30-40	16-18	48-57	32-36	10-15	55-60
3. IX	25-30	35-55	16-18	42-55	32-36	5-15	56-60
4. X	25-32	35-60	16-18	30-50	33-36	7-12	52-62

Table 4

Recovery of cleans from a typical lower seam coal (IX-X) of Jharia coalfield, Bihar by progressive crushing/grinding of the coal.

Size of crushing or grinding	% Recovery of cleans at different ash levels	
	18%	20%
Minus 13 mm	32.0	38.0
" 3 mm	34.5	42.0
" 0.5 mm	43.0	50.0
" 0.21 mm	56.0	62.0
" 0.15 mm	57.0	63.0
" 0.10 mm	59.0	64.0
" 0.076 mm	60.0	66.0
" 0.044 mm	64.4	70.0

Table No.5

Theoretical recovery of clean coal from middlings on crushing to different sizes.

Sl.No.	Size of crushing/ grinding.	Recovery of clean coal	
		wt%	Ash%
1.	75-6mm middlings crushed to below 6 mm	16.5	17.5
2.	75-0.5 mm middlings crushed to below 0.5 mm	36.6	17.5
3.	75-0.5 mm middlings ground to below 0.1 mm	52.7	17.5
4.	75-0.5 mm middlings ground to below 0.044 mm	61.0	17.5

STATUS OF COAL CLEANING TECHNOLOGY IN THE U.S.

A. DEURBROUCK

CURRENT COAL PREPARATION PRACTICES IN THE UNITED STATES

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CURRENT COAL PREPARATION PRACTICES IN THE UNITED STATES

Today in the United States coal provides approximately 22 percent of our total energy needs, up about 5 percent from 1975. Certainly, increasing price and supply uncertainties associated with oil and natural gas have provided the impetus for this increased dependence upon coal. However, if our use of coal is to grow, we must make it a more acceptable fuel and in the United States the resistance to coal usage is based upon its physical nature and organic makeup. Being a solid fuel, it is harder to transport, store, and utilize than either liquid or gaseous fuels. Further, the organic impurities in coal provide a serious drawback because of environmental concerns.

How do we make the most immediate impact on the desirability of coal as an energy resource? I suggest we wash more coal. There is no quicker, less expensive way, to significantly reduce ash and sulfur content from coal than to wash it. This is true in the United States, and I am sure there are many parallels to be drawn with the coal industry in India. In the United States about 50 percent of all coal washed is processed in jigs; however, the utilization of dense-medium processes, in particular cyclones, is growing at a very rapid pace owing to the fact that dense-medium processes provide the sharpest separations attainable, especially for fine-size coal. Further, they provide the flexibility required to keep abreast with changing market quality demands. The cleaning of fine coal by froth flotation is also increasing substantially. Although only a small percentage of the clean coal is produced by dry separation processes, there is renewed interest in upgrading of the lower rank coals by dry techniques, particularly in the arrid regions of the western United States.

Our typical coal preparation plant is operated approximately 13 hours a day, 5 days a week, 220 days a year; however, new plants going on-line are being designed for a minimum of two and the capability of three shift per day operation. Plants of one or two thousand ton per hour capacity are being developed with parallel circuits. An interesting example is the Paradise plant recently built by the Tennessee Valley Authority (TVA) which has four absolutely independent 500 ton per hour circuits. Thus, one circuit can be down for maintenance and the other three can be processing coal at full capacity.

An interesting trend is the small modular coal preparation plant of from 50 to 200 ton per hour capacity. Such facilities can be built and brought on-line in a very short time frame.

An interesting example of a new flowsheet configuration designed specifically to reduce pyritic sulfur content is provided by the Homer City Coal Preparation Plant. The Homer City facility provides an ultraclean low sulfur content product to feed a 650 megawatt generator that is subject to strict SO_2 emission standards. This facility also provides

an intermediate sulfur content middling product to feed two older 600 megawatt generators. The Homer City plant has a capacity of 1,200 tons per hour of 1 1/4 inch by 0 raw coal that has an average sulfur content of 2.7 percent. Product yield is approximately 87 percent by weight and about 94 percent of the available Btu's are recovered. The two 600 ton per hour parallel circuits provide maximum flexibility allowing the plant operator to change the specific gravity of separation quickly and, hence, control the quality of the final products.

Coal preparation provides a means for providing custom feedstocks of desired quality to meet end use specifications. The attached appendices are an overview of this technology.

1982 FOSSIL FUEL CONSUMPTION BY MARKETS IN QUADS*

	Energy Use			
Fuel	Electricity	Industrial	Residential/ Commercial	Transportation
Coal	12.7	2.7	0.2	—
Oil	1.8	7.6	3.0	18.0
Gas	3.3	6.9	7.5	0.7

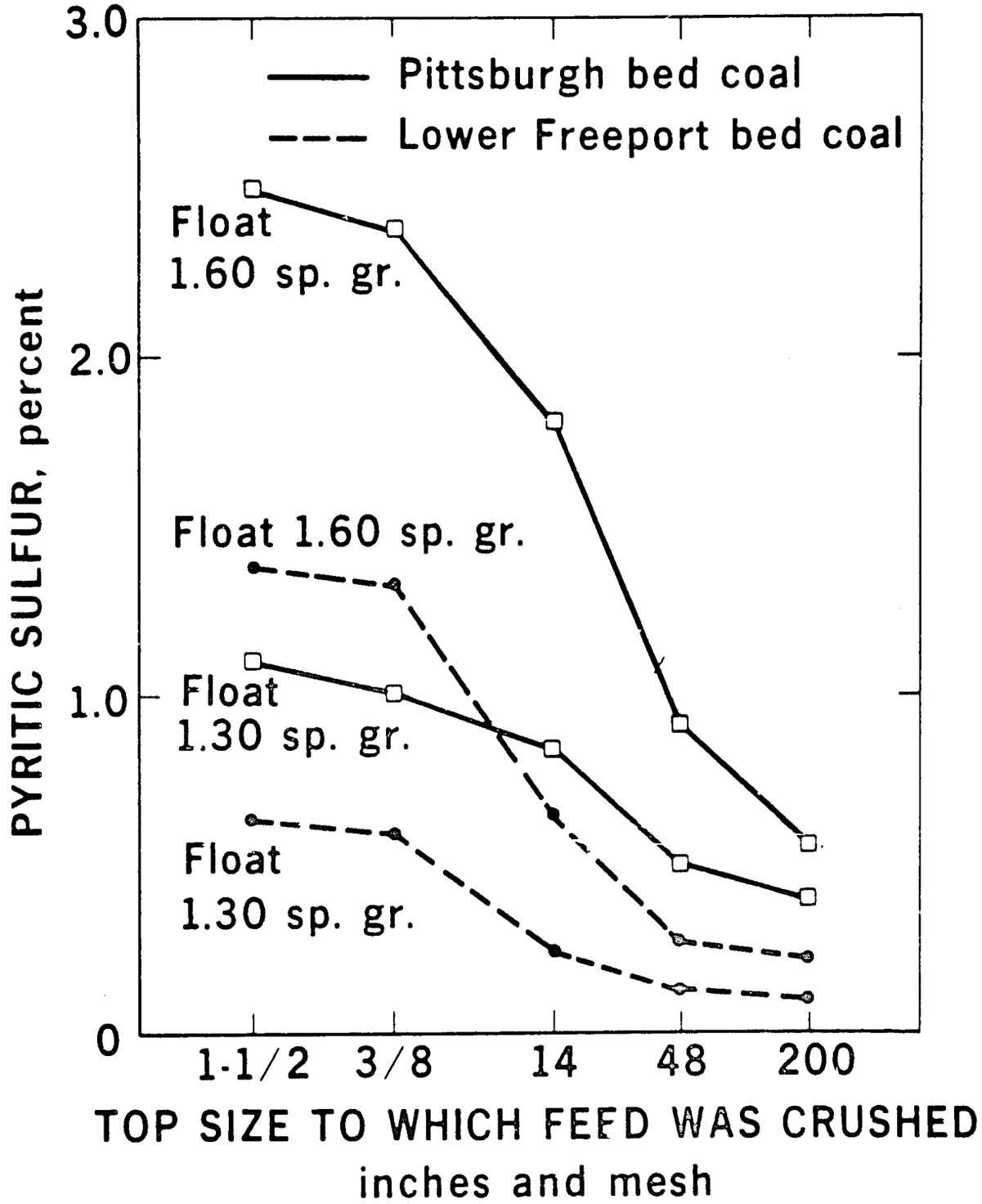
*1 quad = 10^{15} Btu ~ 50,000,000 short tons of coal

BENEFITS OF COAL PREPARATION

- Sulfur and Ash Contents are Reduced
- Carbon is Concentrated
- Trace Element Concentrations are Lowered
- A Product of Uniform Quality is Produced

ASH AND SULFUR RELEASE POTENTIAL OF U.S. COALS (AVERAGE)

Top Size, Inches (mm)	Btu Recovery, Percent	Reduction, Percent		
		Ash	Pyritic Sulfur	Total Sulfur
1½ (38)	80	53	56	31
⅜ (10)	70	64	69	38


3.0
2.0
1.0
0
PYRITIC SULFUR, percent
Pittsburgh bed coal
Lower Freeport bed coal
Float
1.60 sp. gr.
Float 1.60 sp. gr.
Float
1.30 sp. gr.
Float
1.30 sp. gr.
1-1/2
3/8
14
48
200
TOP SIZE TO WHICH FEED WAS CRUSHED,
inches and mesh

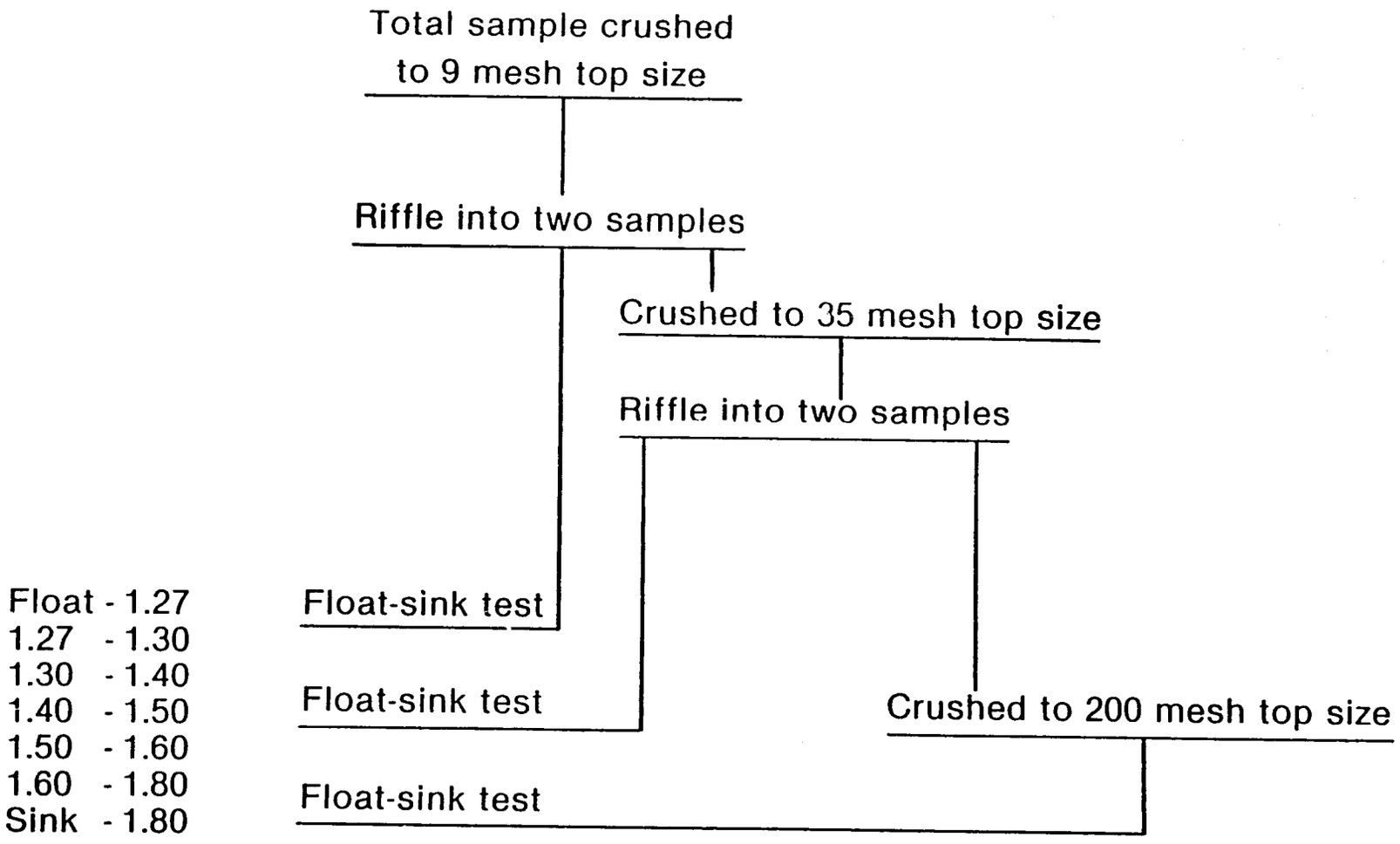
Percent Possible Reduction Using Coal Preparation

Iron	35%
Mercury	34%
Nickel	15%
Cadmium	36%
Chromium	21%
Manganese	64%
Lead	49%
Copper	25%

ANALYSIS NECESSARY TO CHARACTERIZE A GIVEN COAL

- Size Analysis of Raw Coal
- Float-Sink Analysis of Coal Crushed to Various Top Sizes
- Chemical Analysis of the Various Size Fractions and Float-Sink Increments
- Petrographic Analysis of Macerals in the Coal

WASHABILITY ANALYSIS



BENEFITS OF USING A CLEANED COAL

- Increased heat content of cleaned coal (greater Btu content per unit weight)
- Transportation savings (less weight to ship for same Btu content)
- Pulverizing cost less (less coal needs to be crushed)
- Unit capacities are increased (at a given feed rate Btu's to boiler increased)
- Boiler and related maintenance savings (clean coal is less corrosive)
- Ash disposal cost reduced (clean coal leaves less ash)

COST SAVINGS FIRING A CLEAN COAL IN A UTILITY BOILER

	$/Ton Coal
— Reduction in Ash Disposal Costs	0.25
— Reduction in Coal Transport Costs	0.58
— Reduction in Maintenance Costs	1.73
— Reduction in Capacity	3.23
— Increase in Plant Availability	1.32
Total Cost Impact	7.11

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Mechanical Cleaning of Coal by Type of Equipment, Percentage of Clean Coal Produced [1]

Washer Type	Year				
	1938	1948	1958	1968	1978
Jigs	47.2	53.4	52.2	46.7	46.6
Dense-medium processes	7.6	12.6	23.9	29.2	33.2
Concentrating tables	1.7	2.7	8.2	13.9	10.5
Flotation	—	—	—	2.6	4.5
Pneumatic methods	17.6	9.9	8.6	4.9	1.9
Classifiers	7.7	11.1	4.0	1.4	2.7
Launders	18.2	10.3	3.1	1.3	0.6

[1] From USBM and DOE Data

MECHANICAL CLEANING OF BITUMINOUS COAL AND LIGNITE - 1978

TYPE OF EQUIPMENT	COAL PRODUCED (THOUSAND SHORT TONS)
WET METHODS:	
JIGS	104,811
CONCENTRATING TABLES	23,549
CLASSIFIERS	6,153
LAUNDERS	1,358
DENSE MEDIUM PROCESSES:	
MAGNETITE	65,823
SAND	7,765
CALCIUM CHLORIDE	924
FLOTATION	10,068
PNEUMATIC METHODS	4,330
GRAND TOTAL	224,780

DENSE-MEDIUM CYCLONES

- Generally Clean ¼-Inch x 28-Mesh Size Fraction
- Can Process up to 100 TPH

ADVANTAGES:

Will Produce the Sharpest Intermediate-Size Coal Separations

Can Separate at any Specific Gravity from 1.3 to 1.9

Can Produce Good Separations Down to 100 Mesh

Can Maintain Tight Control of Separating Specific Gravity

Have no Moving Parts

DISADVANTAGES:

Are Relatively Expensive

Involve Complex Circuitry

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DENSE-MEDIUM CYCLONING OF FINE COAL AT LOW SPECIFIC GRAVITIES

1. Cyclones cleaning 9 by 100 mesh coal at 1.30 S.G. are still able to make sharp separations ($E_p \cong 0.029$).

2. Classifying the feed allows the finer sizes to be cleaned almost as efficiently as the coarse sizes.

3. Inlet pressures in the range of 5-12 psi (as a function of increased flow rate) do not significantly influence performance.

4. Within the range tested, overall performance deteriorates as the M/C ratio is decreased.

5. For the 9m x 100m feed, performance deteriorates with decreasing particle size, as anticipated.

6. Even at such an extended range of application, the dense-medium cyclone shows consistently good performance when compared to other cyclone performance studies.

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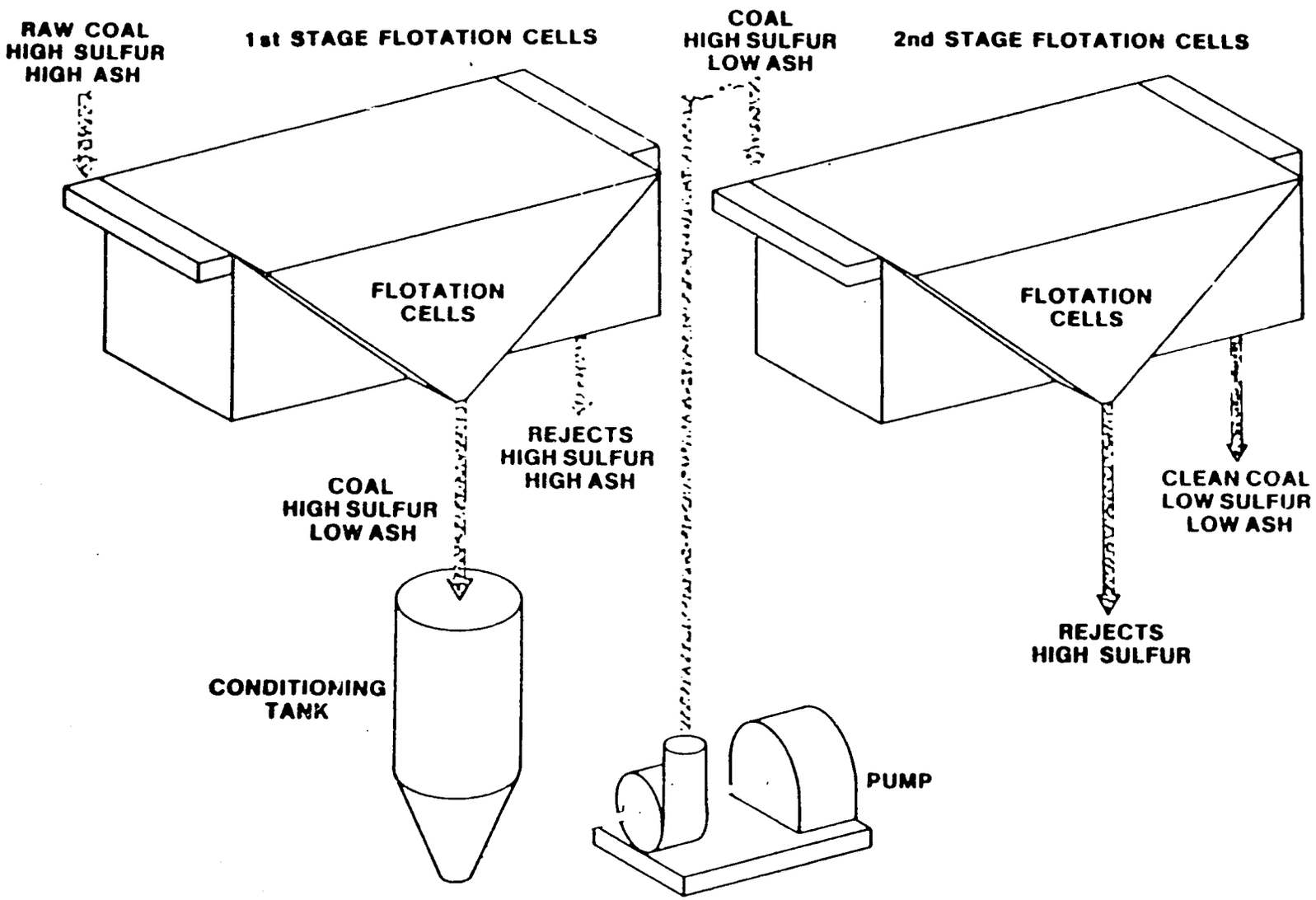
COMPARISON OF DENSE-MEDIUM CYCLONE PERFORMANCE BY SIZE FRACTION FROM VARIOUS SOURCES

Data Source	Killmeyer	O'Brien	Deurbrouck	Geer	Deurbrouck	Taylor	Sokaski
Cyclone Diameter	8″	10″	8″	6″	20″ & 24″	24″ & 28″	10″
Composite S.G.	1.30	1.65	1.35	1.58	1.50	1.64	1.48
Size Range Treated	9m x 100m	28m x 100m	6m x 200m	¼″ x 28m	½″ x 28m	1½″ x 0	½″ x 0
+9m	——	——	——	.035	.027	.024*	.038
~9m x 14m	.016	——	.024	.034	.037	.048*	.057
14m x 28m	.022	——	.024	.039	.052	.064*	.060
28m x 100m	.065	.055	.040	——	——	.154	.108
-100m	——	——	.103	——	——	——	.205
Composite	.029	.055	.030	.036	.029	.044	.047

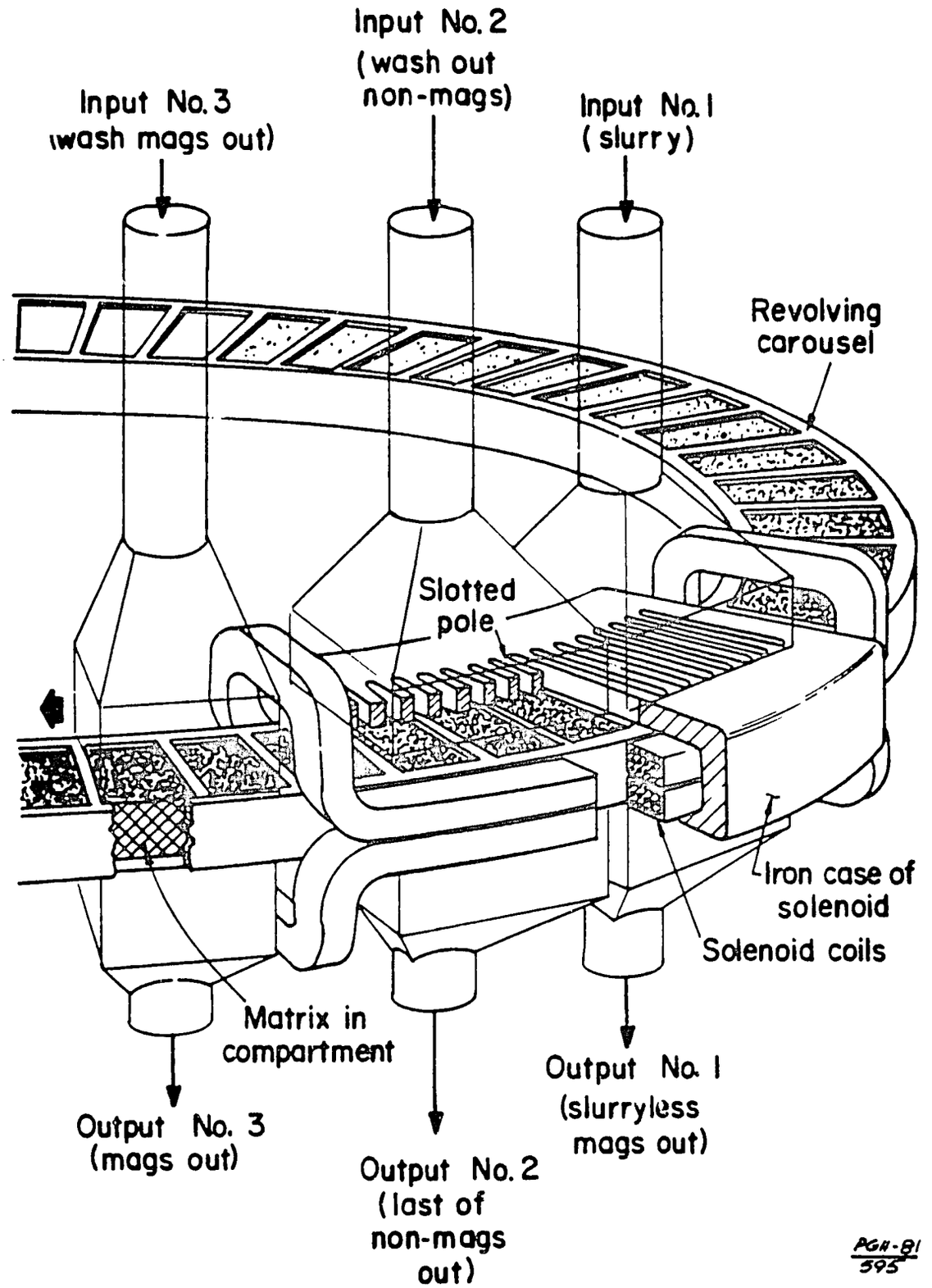
Actual 1¼″ x 28m Composite was 0.031; values for size fractions were extrapolated by R&S formula.



COAL-PYRITE FLOTATION PROCESS

PROJECTION OF REVERSE FLOTATION PERFORMANCE AT BARNES & TUCKER DEMONSTRATION UNIT BASED ON LABORATORY TESTS

	WEIGHT, PERCENT		ASH, PERCENT		SULFUR, PERCENT	
	CONVENTIONAL FLOTATION	PYRITE FLOTATION	CONVENTIONAL FLOTATION	PYRITE FLOTATION	CONVENTIONAL FLOTATION	PYRITE FLOTATION
FROTH CONCENTRATE	80	80	17	17	2.6	1.5
TAILINGS	20	20	32	32	5.6	10.0
FEED	100	100	20	20	3.2	3.2



CAROUSEL HIGH-GRADIENT MAGNETIC SEPARATOR

DRY HGMS

ADVANTAGES:

- Eliminates need to dewater fine-size clean coal product
- Eliminates need for refuse slurry disposal
- Reduces plant requirements for water
- Ideal for use as on-site pre-utilization benefication process where slurry disposal is prohibitive

DISADVANTAGES:

- Requires feed coal moisture content of less than 4 or 5 percent (i.e. feed coal must be dried)
- Requires removal of the ultrafine particles prior to separation

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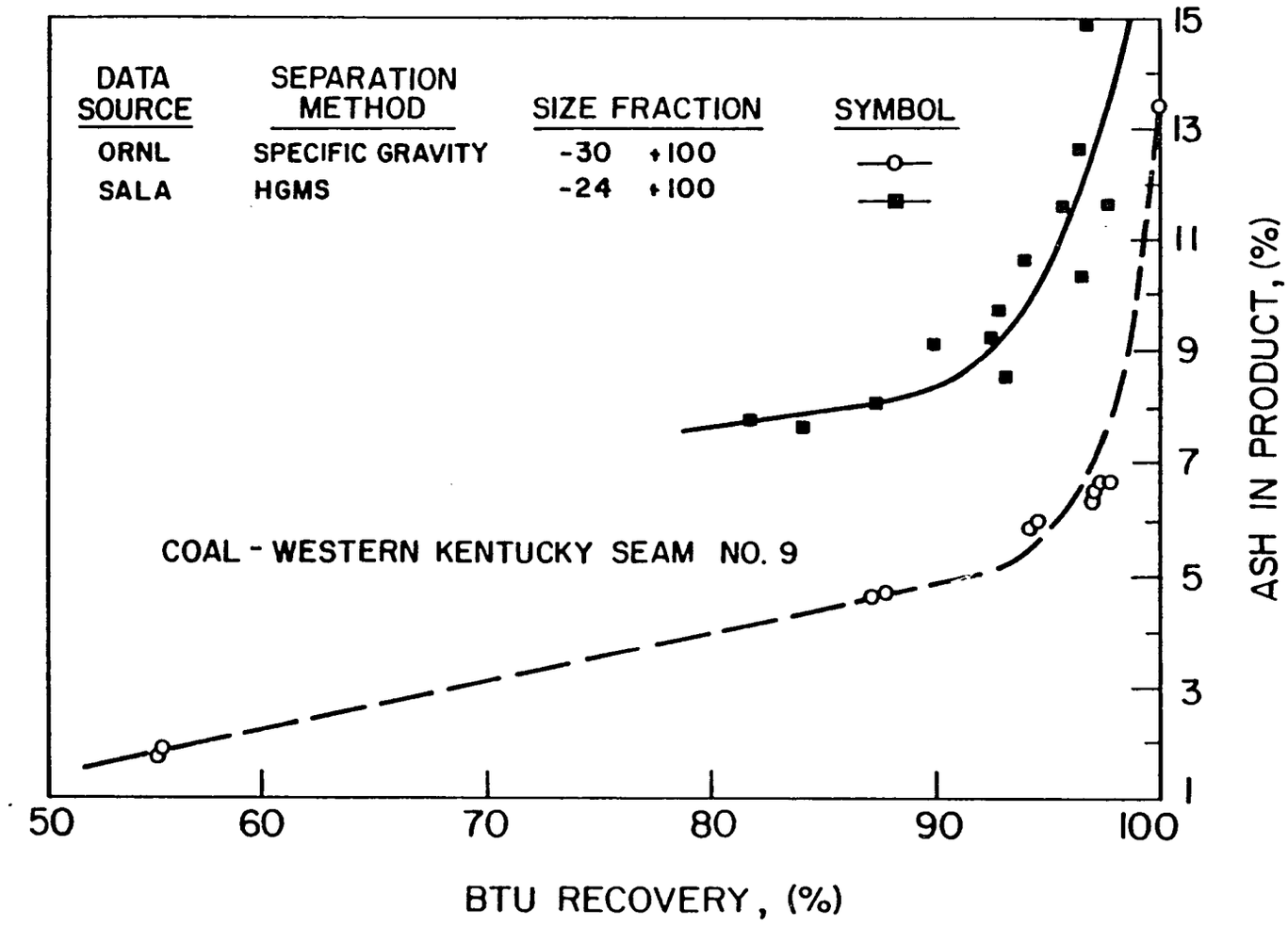

Comparison of ash removal by dry high-gradient magnetic and specific-gravity processes.

BSI-4354

SUMMARY OF THE PERFORMANCE DATA OF AIR TABLE CLEANERS ON COMPOSITE FEEDS

Plant Feed Size, Inches and Mesh	A 2 by 200	B-1 2 by 200	B-2 2 by 200	C 1 by 100
Ash, percent:				
Feed	26.0	14.4	16.2	15.8
Clean coal	18.7	9.1	9.1	9.0
Refuse	67.6	47.2	40.7	29.9
Pyritic sulfur, percent:				
Feed	3.69	4.79	5.49	*****
Clean coal	2.50	2.64	2.64	*****
Refuse	10.48	18.14	15.26	*****
Btu recovery ... percent	95.6	93.7	87.2	67.4
Weight recovery (yield) ... do..	85.1	86.1	77.4	67.4
Theoretical weight recovery ... do..	88.1	90.2	85.6	88.3
Weight recovery efficiency ... do..	96.7	95.5	90.4	76.3
Specific gravity of separation	2.67	1.99	1.78	1.56
Probable error	*****	.334	.296	.312
Imperfection	*****	.337	.381	.555
Error area	311	264	251	272

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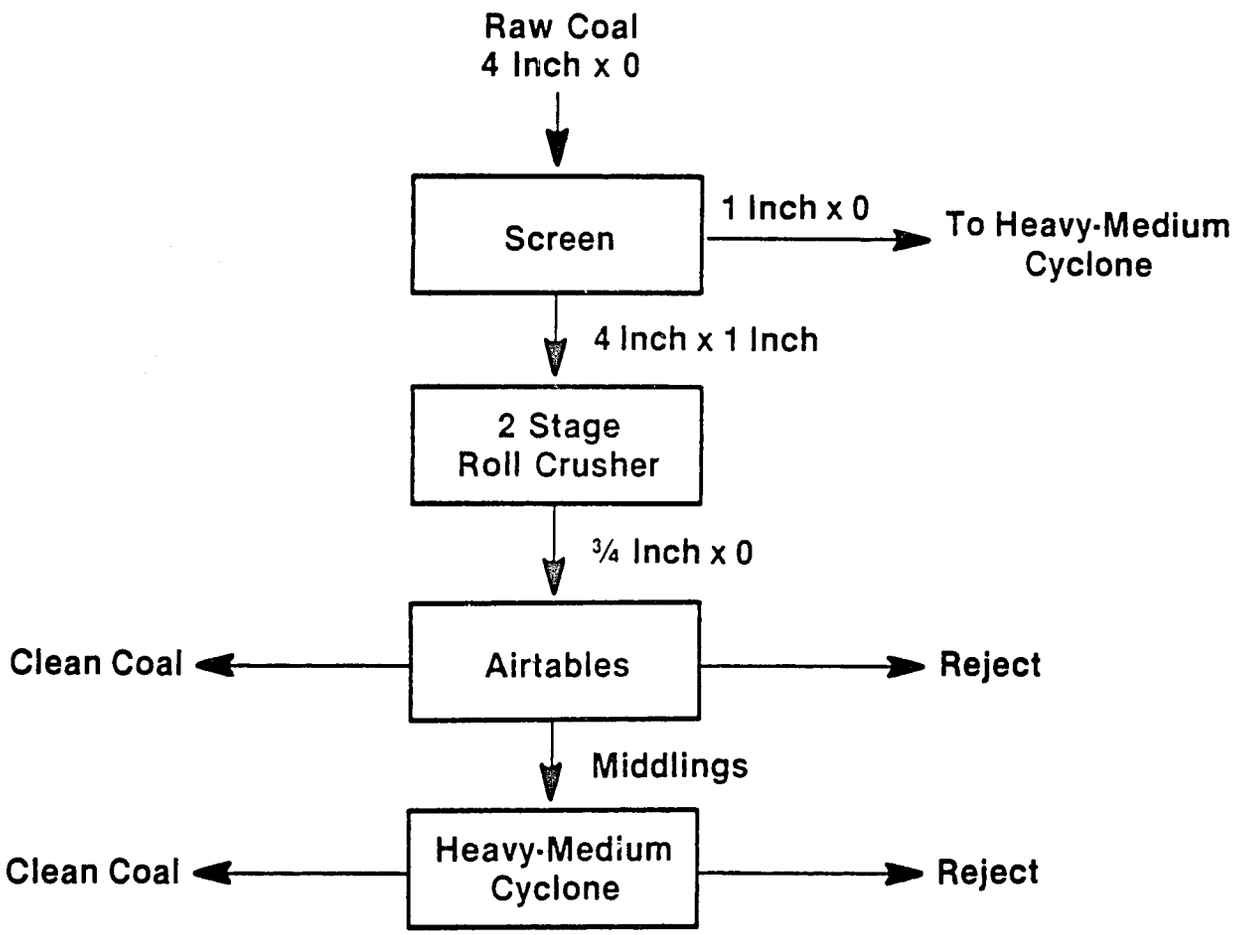
WILLOWBROOK AIRTABLE — HEAVY-MEDIUM PREPARATION PLANT



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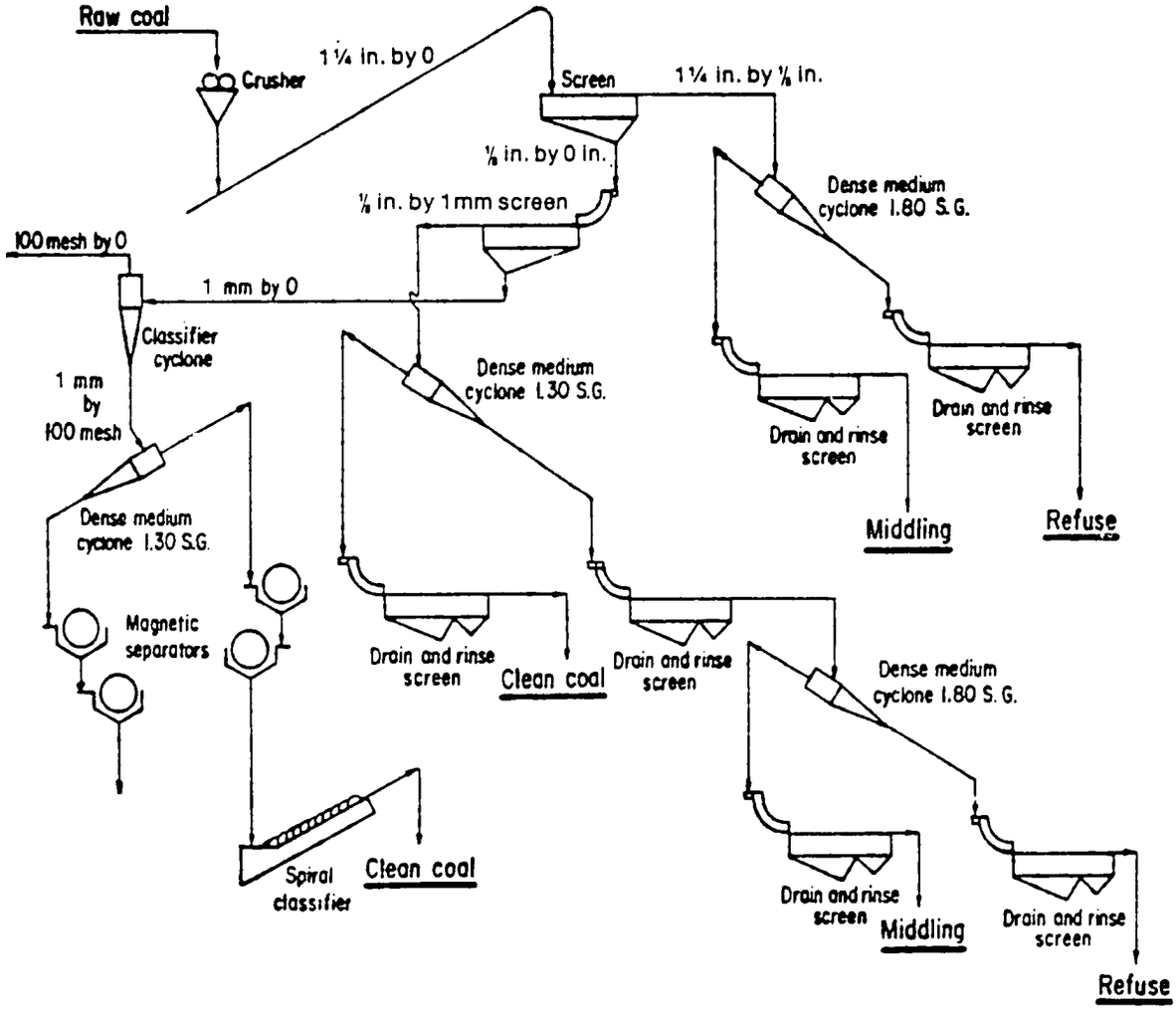

SIMPLIFIED FLOW DIAGRAM OF HOMER CITY PREPARATION PLANT

PANEL DISCUSSION - November 8, 1983

Q. Is there any information available as to the expected impact of changing an oil-fired boiler to coal-water mixtures, so far as the environment is concerned, particularly with regard to emission of particulate matter and oxides of nitrogen?

A. That has been very well-defined in the literature and there are quite a few papers on the subject of emissions from coal-oil and coal-water mixtures. Particulates are no problem. In our station we use a bag house; very effective against particulates. The utility may prefer to use an electrostatic precipitator.

Q. What about NO_x?

A. The NO_x in coal-water tends to be lower by 100 ppm than in the parent coal itself, because of the lower temperature in the boiler. With respect to SO_x, there is 100% conversion of sulfur to SO_x.

Q. Are people using limestone for combating SO_x in the effluent or in the combustion stage?

A1. Limestone and preferably lime can be used as a slurry for SO_x removal. However, there are more effective sorbents SO_x than limestone. Limestone can be added directly when you are using fluidized bed combustors. When you talk of replacement of oil-fired burners by coal-water slurries, the slurry has to be sulfur-free and ash-free to make it approach oil firing.

A2. We have tested alkali carbonates and bicarbonates in the effluent from a coal-oil and coal-water mixture . The particulates then can be trapped in a bag house. That's quite effective.

Q. Is there any scavenging of the flue gas necessary if the coal is not desulfurized to meet the regulations for oxides for sulfur emission?

A. It has been shown that it is beneficial and economical to do part of the sulfur removal during the coal preparation, rather than removing SO_x from the flue gas. An economic analysis has to be made here so as to known how much you should try to remove in coal preparation and how much you should try to remove in the effluent gas cleanup.

Q. I would like to know whether the physical and chemical properties of the coal have been taken into consideration or have had any influence in the preparation of coal-water slurry. For instance, the low rank coals, bituminous coal, are humic in nature. The humic content itself may lead to the stable production of the slurry, without any stabilizers or additives. Secondly, some coals are hydrophillic and some are hydrophobic in nature. The higher rank are hydrophobic, the low rank hydrophillic. In situ, maybe the generation of humic acid from the lower ranks would help develop a better stability and lower viscosity. Have these factors been studied?

A. The type of coal has an influence on the viscosity as well as stability. Stability and viscosity are a function of the surface. The property of the surface is important. If the coal is humus in nature, or functional groups are exposed at the surface, it will definitely help dispersion and stability. But by and large stability is a function of particle size, so if the particle size is low, definitely any type of coal can be dispersed without any additive. But the fact remains that, whatever additive

is added, it must be optimized and be established on the basis of the coal used. We have made no visual study but the surface and type of coal have property qualities; however, we cannot quantify this fact as yet. In fact, one of the slides presented by Dr. Bienstock was concerning an American experience where the particle size was extremely fine and additives were not needed to stabilize the slurry.

A2. Particle size is also a very very important factor but, apart from that, if we can liberate the humic acid, or if we combine two coals -- one principal coal (90-95%) and the other which is humic in nature -- which liberates humic acid in situ, perhaps a better slurry can be made. Maybe Dr. Bienstock can suggest the basic part of this work we could study in CFRI, while the technological part, on the combustion side, is done by BHEL. That work plan has to be sorted out at the end of this Workshop.

A3. This subject is wide open and there has not been very much success with it.

Q. Is there any information on the direct firing of coal-oil mixture or coal-water mixture in a gas turbine, and is there any work being done in the U.S.?

A. There is some work being done at METC in the use of coal slurries and you might want to check with Ghate when he returns.

Q. We have been studying the quality of coal in coal-water preparations but haven't done any study on the quality of water. Looking at the additives, I think the effectiveness of the additive or type of additive may also depend on the water quality in addition to coal. The second question is on the process flowsheet that was given by you. At one stage after the wet grinding you are trying to filter out the water. What is the particle size and what is the concentration before and after filtration? Have you faced any difficulty in filtration or have you had to adopt a technique which is not normal -- that is, give some special treatment to give better filterability of the material?

A. There are three ways of dispersing coal or, for that matter, any solid substance in liquid. One is ionic, which creates a layer of electrostatic charges. It is called electrostatic repulsion, a cause of dispersion. Another is non-ionic, caused by steric hindrance, and another is solvation. So if you choose to disperse by ionic substances which are partly adsorbed on the surface of the coal, and keep another part of the molecule charged and repel that charged particle, in that case the type of water has a role. But normally it is done by steric hindrance, particularly with water-soluble coal substance -- high molecular coal substance -- or polyoxyethelyne substances, which are adsorbed on the surface and have a long chain all around the coal and cause great hindrance in settling. In that case the role of water may not be significant, but certainly the role of water does have a significance if you choose to disperse by ionic principles. We have not studied it in detail although we have initiated it, and hence cannot give you an exact answer.

With regard to the second question, we have given one of the schemes but there are any number of schemes, depending on the particle size you choose. It may not be wet grinding alone; it may be dry grinding and wet grinding mixed together. Dry grinding will give you larger particles, wet grinding will give you finer particles. Mixed together, you need not dewater it at all. Normally, if you select wet grinding, you get a very dilute slurry. Then you have to dewater it and have to adjust the water later on.

Q. Do you see a potential for using an oil and coal-water mixture together?

A. The potential is that if you replace oil by some portion of coal-water slurry it can be cost effective because there is a high difference in the cost of oil and the cost of coal-water slurry.

Q. This question is with regard to the apparatus used for viscosity measurements. The apparatus used may not be able to give the yield stress at all and, under Indian conditions, there are frequent power shutdowns. So

when the slurry is standing in a tank or pipeline and the stress is very high -- almost a prerequisite for good stability -- then you require very high power to start the pumping. The yield stress is an important factor so you could use a better viscometer to provide a better picture.

A1 I have illustrated only a very simple type of measurement and Dr. Bienstock can offer some suggestions on the type of instrumentation to measure the viscosity of coal-water slurry -- instrumentation which is available in the U.S.

A2. A whole series of instruments are available to measure viscosity, for different shear rates from very low to very high.

A3. There are two which are very well known. One is the Weisenberg Rheometer, which can give you from .1 cp to $10^{(10-12)}$ cp, which was used in the polymer industry. The next practical one is Haake, where you can vary the viscosity from 0.1 to 10^4 cp and this can give you very accurate results with time-dependent behavior as well.

Q. I have been working with a design and construction organization where we are looking at the transportation of coal over long distances. So far we have been working on the conventional transport such as is available in the States. Recently there are two organizations, one in Germany and one in Italy, and both have advertised that they are able to transport the CWM they are preparing over long distances. We did some preliminary calculations based on the reported properties and found that the power requirement of transportation is about 3 times that required in the States where there is a slightly coarser particle size distribution.

I know the transportation you have is by barges and tank cars, but do you have transportation through pipelines for long distances?

A. There are two systems -- one is the pipeline slurry, another is slurry fuel. Slurry fuel is definitely not suitable for long-range transportation through a pipeline since the viscosity is more, and hence the energy consumption is more. So slurry fuel is generally transported through tank cars or barrels. Another is in situ preparation. Why should you transport water along with coal? In situ preparation and combustion requires only transportation from pump to the atomizer. Moreover, you can preheat it and lower the viscosity at the site.

Q. Coal-water mixture is approaching commercialization and the benefits obtained by replacing oil firing with coal-water mixtures are well understood. In the Indian context, is there a potential in that there are a lot of stoker-fired boilers? I would like Dan to comment on the possibility of converting stoker-fired to coal-water mixtures. Is it beneficial.

A. I have no information on that.

Q. What are your views on it?

A1. Under the circumstances in which we are considering this possibility, the stoker-fired boilers designed earlier were designed for wood-coals and not more than 25-30% ash. But presently we are faced with a situation where the coal availability is so poor and the coal available is poor. The output available has to be drastically limited and there is a 30-40% reduction in output on the stoker-fired boiler. A number of customers are approaching us as to how to retain this lost output -- whether coal-water slurry can be a solution for this.

A2. I have no experience -- I can only speculate.

Q. As far as Indian coals are concerned, coal beneficiation is a must. One step we will have to go through before we think of coal-water mixtures. This beneficiation is going to add additional cost. When Mr. Chakraborty

suggested 11% ash coal, that is the dream of a user in India. Is there any work being done in the world on the making and burning of high-ash coal-water slurries considering the cost economics and capital costs involved for the beneficiation process itself? With the present beneficiation process which we know and are exploiting commercially we are not able to get beneficiated coals of even 16-17% ash. What is your suggestion and what work should be carried out in this direction?

A1. I know of none. It is very difficult. I would hope that would be a part of our going program here to look at the potential for doing this. The washability seems to indicate that there will be such a small recovery that it can be very difficult. Some of the work done by Sarkar, I think, with some oil flotation recovery has a very small portion of low-ash coal. In the U.S. we are able to produce a 2% ash coal readily, by dense medium cycloning by crushing down to perhaps 28 mesh or something of that nature, then removing that incremental fraction. Again it will not be a major portion, and what you will wind up doing is producing a low ash clean coal perhaps or a coal-water slurry, and a middling product which you may use in some conventional way.

A2. In CFRI, a chemical demineralization technique has been developed and a pilot plant is coming up. This has been directed by Mazumdar and I would appreciate it if he would speak a few words.

A3. For the second part of the question, we have a technique -- chemical leaching -- by which we can demineralize any coal of any ash content, down to any ash level, even almost ashless. Technologically it is possible but you still have to answer whether or not it will be economically viable. The principle is that coal and alkalis react together at atmospheric pressure at temperatures of the order of 110-120°C, followed by washing with water and leaching with dilute sulfuric acid. The alkali penetrates into the physical matrix of the coal, converts the mineral matter into a soluble matter. In this treatment,

even the caking properties of the coal are unaffected. On the other hand, removal of 30-60% of mineral matter from high ash coal or from high ash middlings improves the caking index and the cokability of the coal. The cost of alkali in India is prohibitive. We are able to regenerate and recover 80-85% of the alkali used, depending on the type of coal. Secondly, we have also been able to retrieve byproducts of the mineral matter due to the use of caustic soda and acid. The by-products are sodium sulfate, aluminum sulfate and silica gel. We are undertaking a feasibility study to see if we can find a market for the byproducts which are substantial per ton of coal depending on the ash content. Then the cost of the coal having 1-2%, below 5% ash would not be prohibitive. Summing up, yes, we can reduce the ash content to any desired level for Indian coals or any coals of the world, depending upon its end use.

A4. In answer to the second part of the question, I believe from the presentation that coal-water mixture has two kinds of applications. One is the replacement of oil-fired boilers partly by coal-oil mixtures and then completely by coal-water mixtures. In case of CWM, it is preferable that there is no ash. However, by putting in some soot filters and bag filters they have been able to overcome the problems associated with low ash CWM. The other application is the feeding of CWM in the fluidized bed boilers and gasifiers. The advantage is that it is easy to pump, but the disadvantage is that fluidized bed boilers and gasifiers may be able to take up coarse coal, and hence the grinding cost comes into the picture.

Q. When talking about chemical leaching, it was told that we can go down to any level of the ash content but that in itself is to me not an answer because, to my knowledge, when you burn this coal in a boiler it looks like you are going to end up with high corrosion rates with the alkali and acid leaching. Do you have any comments on this?

A. The apprehension is legitimate but can be discounted. It all depends on how you do the washing. You can make the coal almost free from residual chemicals, i.e., alkali. Because you are treating finally with acid, you may be left with a little sodium sulfate but we have

seen that this level of sodium sulfate can be brought down to 5-6 ppm, which is the amount of alkali you have in the coal itself. In mineral matter, 1-2% could be alkalis, so a lower amount of alkali is present after treatment than what you had in the coal itself in the form of mineral matter.

INDIAN EXPERIENCE IN GASIFYING AGRICULTURAL RESIDUES

P. D. GROVER

GASIFICATION OF AGRICULTURAL RESIDUES

-VILLAGE LEVEL GASIFIERS-

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GASIFICATION OF AGRICULTURAL RESIDUES
—VILLAGE LEVEL GASIFIERS—

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About 80% of population in India lives in 5,00,000 villages. By the year 2000 the population is expected to reach one billion and it seems likely that most of the people will continue to inhabit the rural sector. To sustain such a vast population and developing rural and agricultural economy, a considerable increase in energy production will be essential.

To meet this growing energy demand, one of the major approaches is to utilise the agricultural residues efficiently. Over 200 million tonnes of these residues are being produced annually. Gasification of agrowastes has great potentials provided an appropriate gasifier capable of operating under village environments is developed. The gasifier is then used to power an engine-pump set for irrigation. The objective of this development is to have a decentralised system for irrigation for which the farmer has not to depend upon the availability of Diesel fuel and grid power, and the only fuel available to him, that is, agrowaste, is utilised. Most of

the agro-wastes can not be used directly for gasification in small scale gasifiers. These have to be modified in accordance with the requirements of feed stock for such gasifiers. For gasification, most of the experience in this country is based on gasification either of coal or of charcoal made from wood. Experience in gasification of wood is also very recent and limited and has yet to be utilised in the field.

Agro-waste fuels are entirely different in physical and chemical characteristics compared to traditional fuels for gasification such as charcoal and coal.

The comparison of chemical constituents of agro-wastes, charcoal and coal is given in the Table-I and Table-II.

TABLE-I: Comparison of constituents of selected fuels

	Moisture	Volatiles	Fixed Carbon	Ash	HHV K.Cal/Kg.
Biomass (Sawdust)	10	68-78	9-14	1	4500
Charcoal	10-15	5-10	77-85	3	6050
Coal	2-3	27-35	40-47	20-40	5000
Paru Fuel	3-8	40-60	25-35	10	5600

TABLE-II: Constituents of Wood and Coal.

	Biomass (Wood)	Coal
C(%)	51.5	76.9
H(%)	6.9	5.1
O(%)	40.8	6.9
N(%)	0	1.5
S(%)	0	2.4
Ash(%)	1.0	7.2
HHV.BTU/lb	7,125	13,000
K.cal/Kg.	4,000	7,000
VARIATION: K.Cal/Kg.	3000 -4,500	4000 - 7900

Compared to coal and charcoal, agro-wastes contain much higher percentage of oxygen. Therefore direct gasification of agro-wastes tends to give more of oxygenated products. As an example, the percentage of CO_2 is 3-4 times more than what is obtained by gasification of charcoal. However, higher content of volatiles in the biomass tend to give more of hydrocarbons such as methane resulting in higher heating value of gases. Typical heating values of producer gas from biomass and charcoal alongwith composition are given in table-III.

TABLE-III: Composition of Producer Gas.

Product	From wood	From charcoal
CO_2	9.5-9.7	3.0
C_xH_y	0.0-0.3	0.1
O_2	0.6-1.4	1.3
CO	20.5-22.2	28.7
H_2	12.3-15.0	3.8
CH_4	2.4-3.4	0.2
N_2	50.0-53.8	63.0
HHV	1330 K.cal/m^3	980 K.cal/m^3

Although direct gasification of biomass has many advantages, yet it is an established fact that this gives gas combined with ash and tar particles. For large units (> 30 KW), wet gas cleaning can be incorporated but for small units it becomes highly complicated and uneconomical.

Charcoal, though most suitable for gasification is an expensive material, costing around Rs. 2.25/Kg. in Delhi and also is energy inefficient. The use of charcoal made from wood will also put pressure on already scarce forests. Therefore, detarred materials like partially carbonized biomass briquetted fuel such as "PARU FUEL"(1) is the most suitable material for a village level gasifier. A typical analysis of Paru Fuel is included in Table-I.

APPROPRIATE GASIFICATION TECHNOLOGIES:

For gasification of agro-wastes for motive power, three appropriate technologies for India and other developing countries have been identified and presented in Table-IV. These are steam pyrolysis, direct gasification of biomass and gasification of charred briquetted fuel. While the first two are discussed briefly, detailed analysis of the third technology which forms the major subject matter of this presentation, is elaborated.

STEAM PYROLYSIS-GASIFICATION:

The pyrolysis of biomass in the presence of steam as carrier improves the reaction kinetics and enhances gaseous yields even at lower temperatures. Both these factors are demonstrated by experiments on pyrolysis of rice husk carried out by TGA with and without steam, the result of which are shown in Fig.1. In practive this process can be best carried out in indirectly heated rotary or fluidised bed gasifiers. The gases can be used for heating and for captive power generation. Such a system is well suited for rice mills and other agro-based industries. Catalysts such as alkali salts may be used to enhance the rates of gasification. A typical rice mill which may consume 50-60 KW can generate a power output of about 100 KW based on rice husk input of 250 Kg./hr. In

TABLE-IV

SUITABLE TECHNOLOGIES FOR GASIFICATION OF AGRICULTURAL RESIDUES

Process	Product/Typical HHVKcal/m^3	Advantages	Drawbacks
1. Steam Pyrolysis (600°C) Catalytic-non catalytic Fluidized-rotary gasifier	Pyro-gas/3,860	a) Medium BTU gas b) by-product recovery c) Captive power generation	a) Capital intensive b) For large scale c) Thermal efficiency =40%
2. Direct air gasification with or without densification packed bed gasifier	Producer gas/1330	a) Thermal efficiency =75%	a) Elaborate gas cleaning b) Suitable for large sized feed
3. Air gasification of charred briquettes	Producer gas/1330	a) Simple in design/ operation b) Less gas cleaning problems c) Suitable for most biomass d) Suitable for small gasifier	a) Preparation of feed b) Lower thermal efficiency 55-60%

addition, about 50 Kg./hr. of amorphous silica, suitable for making pozzuolana cement, is also obtained as a valuable by-product. An integrated system based on gasification of rice husk is shown in Fig. 2.

DIRECT GASIFICATION:

The direct gasification, for motive power, of wood chips and certain agro-wastes such as corn cobs and chopped cotton sticks is being carried out mostly in downdraft gasifiers. Although such units are commercially available, yet these are expensive and not so far within the reach of small farmers. Apart from definite size of feed required for these gasifiers, extensive cleaning systems, both dry and wet, have to be employed which are responsible for its high costs. Unless the method is further developed and its cost reduced, this may not find utility with small farmer accustomed to using 3-5 H.P. irrigation pump.

Further, some other light and small size agro-wastes such as rice straw and coir waste can not be used unless these are densified. Direct densification or pelletisation for small gasifier is not economical as these machines are expensive. The experience in India with these densification machines and direct wood/biomass gasifier is too limited to arrive at any positive conclusion. However, direct gasification of biomass could be

considered for large and medium scale units having more than 30 KW output.

GASIFICATION OF CHARRED AND BRIQUETTED BIOMASS:

For the successful development of a 3-5 HP village level gasifier, apart from its low cost, two major factors must be incorporated. The gasifier should be simple in design and operation and secondly the gas cleaning system should be either eliminated or made very simple. Past experience with gasification of charcoal, a clean fuel, justify this possibility. However charcoal made from wood being expensive in developing countries and because of the low overall thermal efficiency 30-35%, can not be used as a fuel. This implies that a similar fuel should be made available from agricultural residues. Therefore the overall development of this gasifier has two major components. These are (a) preparation of suitable fuel and (b) the use of this fuel in the gasifier.

PREPARATION OF FUEL:

Charring of Biomass:

As mentioned previously, the characteristics and operation of small gasifier put limitations on the quality of fuel. Gasifier similar to Rogers Harvard micro gasifier (2) has been operated successfully on wood charcoal at I.I.T. Delhi. Now it remains to be operated on partially charred briquetted

fuel. The extent of charring is one parameter that needs extensive studies. It is a well known fact that the temperature, rate of heat transfer and residence time of biomass in the charring unit determine the yield and quality of char obtained. Typical data for charring of Douglas fir needles (3) is given in Table-V.

TABLE-V: Carbonisation of Douglas Fir needles.

Temp. °C	Weight Loss %	Distribution of heat of combustion (K.cal/Kg.fuel) In volatile	In char	Calorific value of char (K.cal/Kg.)
100	-	13	5120	5120
150	-	20	5107	5107
200	4.5	60	5073	5310
250	13.5	297	4836	5590
300	24.6	644	4489	5950
350	40.0	1268	3865	6440
400	50.0	1992	3141	6280
450	56.3	2500	2633	6030
500	63.5	2730	2403	6580

Compared to direct briquetting of biomass, the briquetting of charred biomass with suitable binders does not involve the use of high pressure machines. Once the physical structure of the fibres in biomass is thermally degraded at about 200°C, its resistance to briquetting is eliminated. This technology of partial charring and briquetting at family, community and the mechanised levels have been developed at I.I.T. Delhi(4), widely known as "PARU" fuel technology. About fifteen mechanised plants of capacity 4 tonnes/day of "PARU" fuel have been installed and many more are being installed in the country.

At village level, the charring of biomass can be carried out in 200 litr drums. These can be operated easily by(Fig.3) any semi skilled perso . In such a unit, the charge is added continuously and air inlet holes are also continuously blocked. In this manner the air flow is controlled and also brought in immediate contact with fresh charge. About 25-30 Kg. of char can be obtained from materials such as straw, cotten sticks, coconut shells and such like materials, Due to lower bed porosity, fine materials such as rice husk, sawdust,coffee husk etc. can not be charred in this system.

For charring of rice husk and similar materials, a number of of internal segmental trays have to be incorporated, with a grate furnace at the bottom of the drum. This unit, shown in Fig. 4, though comparatively more complicated has the main

advantage that ash residues of fuel burnt on the grate do not get mixed with the char.

Fig.5 shows another model of drum charring system, simpler in design and operation, and gives uniformly charred material. Because of central chimney effect the air is drawn downward through the charge. After igniting the charge, the feed is added continuously. While the top layer of charge is under combustion to provide heat for pyrolysis, the bottom layers are being carbonized. Once the charge is partly carbonised, the top portion of the chimney is removed and the drum is covered for the carbonisation to be completed. Collection of tar shown at the bottom of Fig.5 is advantageous as this tar after washing with hot water can be applied on the outside surface of the retort to protect it from corrosion. However no corrosion is experienced in the internal surfaces of these units due to the formation of tar coatings. All these units have been operated at I.I.T. Delhi.

BRIQUETTING OF CHAR:

The char obtained is thoroughly mixed with wet binders such as lime, clay, inedible starches or molasses. The mixture can be either briquetted with hand or in a hand operated extrusion machine similar to the green fodder cutting machine being used in the villages. Briquetting by hand can be

carried out in a similar manner as moulding of clay bricks, cutting of these wet bricks into small pieces, and drying the same in the sun.

MACHANISED 'PARU' FUEL PLANTS:

As mentioned earlier, 15 plants, each having capacity of 4 tonnes/day, have already been installed in the country and many more are being installed. At present these plants are producing fuel for domestic cooking but these fuels can be modified in their physical and chemical characteristics and made suitable for gasification. Once widely available, the fuel can be purchased in the market. The flow sheet of these plants is given is Fig.6.

Advantages of Briquetted Fuels for Gasification:

The major advantage of charred briquetted fuel is its inherent property of being a clean fuel. Gasification of such fuel will tend to give clean gases, relatively free of tar, such that wet scrubbing of gases can be avoided. Being synthetic in nature, its heating value can also be enhanced by using cheap organic binders. Inorganic binders and inerts should have to be selected carefully such that the ash layer formed is either very porous or can be easily removed to make the carbonaceous materials available for gasification. Further, these additives should not lower the fusion/sintering point of ash to avoid formation of clinkers. In general, alkalies

lower the fusion temperature of silica, the main chemical constituent of ash, while alumina and iron oxides tend to improve the characteristics of clinker formation. Other advantages of these fuels are:

1. Lower ignition temperatures compared to coke or charcoal
2. Pellets can be made in any size and shape, thereby the bulk density and their flowability in gasifier can be improved.
3. Unlike agricultural residues, this fuel can be stored for longer periods.

Fig.7 gives the importance of Paru fuel for energy and food production.

Gasification of Charred Briquetted Fuel:

A gas producer reacts quite sensitively to the fuel parameters such as ash content and its composition, moisture content, reactivity of carbon and its volatile contents. These parameters are proposed to be studied in a down draft batch type gasifier. Further the fuel characteristics and the design and operating parameters of the gasifier must match to give troublefree operation with I.C.Engines.

At I.I.T, Delhi, preliminary tests have been carred out with a modified Harvard Micro-gasifier (2). The gasifier was operated with compressed air and commercial grade charcoal as fuel. The details of the gasifier are shown in fig.8 and the general layout in fig.9. Typical performance data are given in table-VI.

TABLE-VI

PERFORMANCE RESULTS OF A MINI-GASIFIER

FUEL USED:- CHARCOAL

H.H.V. 6380 K.Cal/Kg
(11,470 BTU/lb)

FUEL ANALYSIS

CARBON	71.5%
HYDROGEN	5.1%
MOISTURE	3.7%
ASH	3.6%
VOLATILES	34.6%

QUANTITY

2Kg. FOR INITIAL HEATING

3Kg. FOR GASIFICATION

RESULTS

PERIOD OF GENERATION	50 Mts.
GAS FLOWRATE	15500 Lit/hr.
	9.12 CuFt/Min

GAS COMPOSITION

CO_2	9.9%
O_2	0.5%
CO	21.4%
H_2	10.9%
N_2	57.3%
H.H.V.	979K Cal/m^3
GASIFICATION RATE	3.6 Kg/hr
OVERALL TH.EFFICIENCY	66.2%

The results show that a peak output of 60,190 BTU/hour (17.6Kw) could be obtained for a short duration of about 1 hour at thermal efficiency of only 66.0%. Further this performance was obtained with compressed air, so the pressure drop which is an important parameter when air is sucked in by engine, was not considered.

One of the major problems with minigasifier is its low heat capacity. This leads to fluctuations in temperature and the quality of output gases. To improve thermal efficiency, heat losses though the wall shall have to be minimised by having refractory lining in the oxidation reduction zones. However the thickness of lining should be minimum other-wise initial heat losses during start up shall be substantial.

A farmer will need an irrigation pump to run on a single fuel charge, which based on overall thermal efficiency of 20% and 5 Kw output would need 43 Kg. of fuel with calorific value of 4000 Kcal/Kg. This will require increased size of the fuel storage in the gasifier. So it is desirable that quick opening and charging doors should be provided for periodic charging of fuel so that the overall size and hence the cost can be reduced. These are some of the parameters that have to be studied during the development of this village level gasifier.

Another important parameter to study is the performance of the gas cleaning system. As mentioned earlier, the wet scrubbing of gases is complicated for such small gasifier. The proposed system shall have to use a dry method for cleaning of the gases. A 100-200 litres vessel filled with dry agro-wastes such as rice husk should act as a good filter. Cruz (5) in the Philippines has used dry coconut husk as filter for charcoal gasifier with good results. In addition to cleaning the gases, the above vessel also acts as a surge tank to dampen the fluctuations in gas production. The filter medium has to be replaced periodically.

CONCLUSION:

In this paper, we have described the importance and urgency of developing a small scale, simple village level gasifier for irrigation. It has been estimated that some 30 million house holds have available but unexploited water sources in the Indian subcontinent (Meta Systems 1980) (6).

To eliminate the problems associated with gas cleaning, it is most desirable to use detarred fuels made from agro-wastes. Technologies at Village family, community and mechanised commercial levels to make briquetted fuel "PARU" have already been developed. However to make this fuel suitable for gasification, the extent of charring and other fuel characteristics need to be studied.

The 'Harvard Microgasifier' appears to be a good general configuration, although further development is required to optimise its design.

A conversion process for biomass to mechanical power will reduce burden on the consumption of petroleum products. Use of biomass for pumping water will ensure timely irrigation of crops thus augumenting food production and associated agro-wastes which can be recycled.

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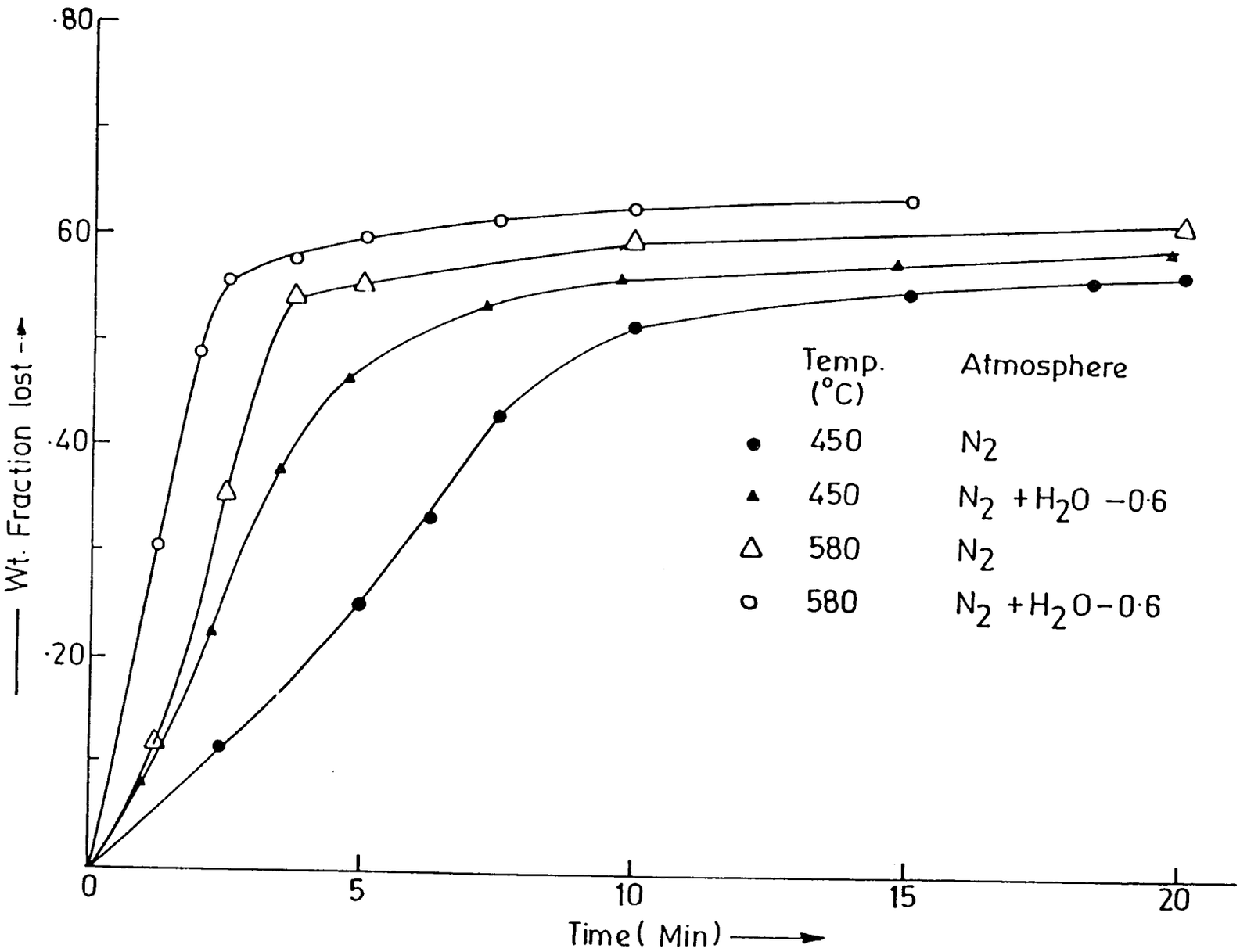

FIG.1. STEAM GASIFICATION OF RICE HUSK.

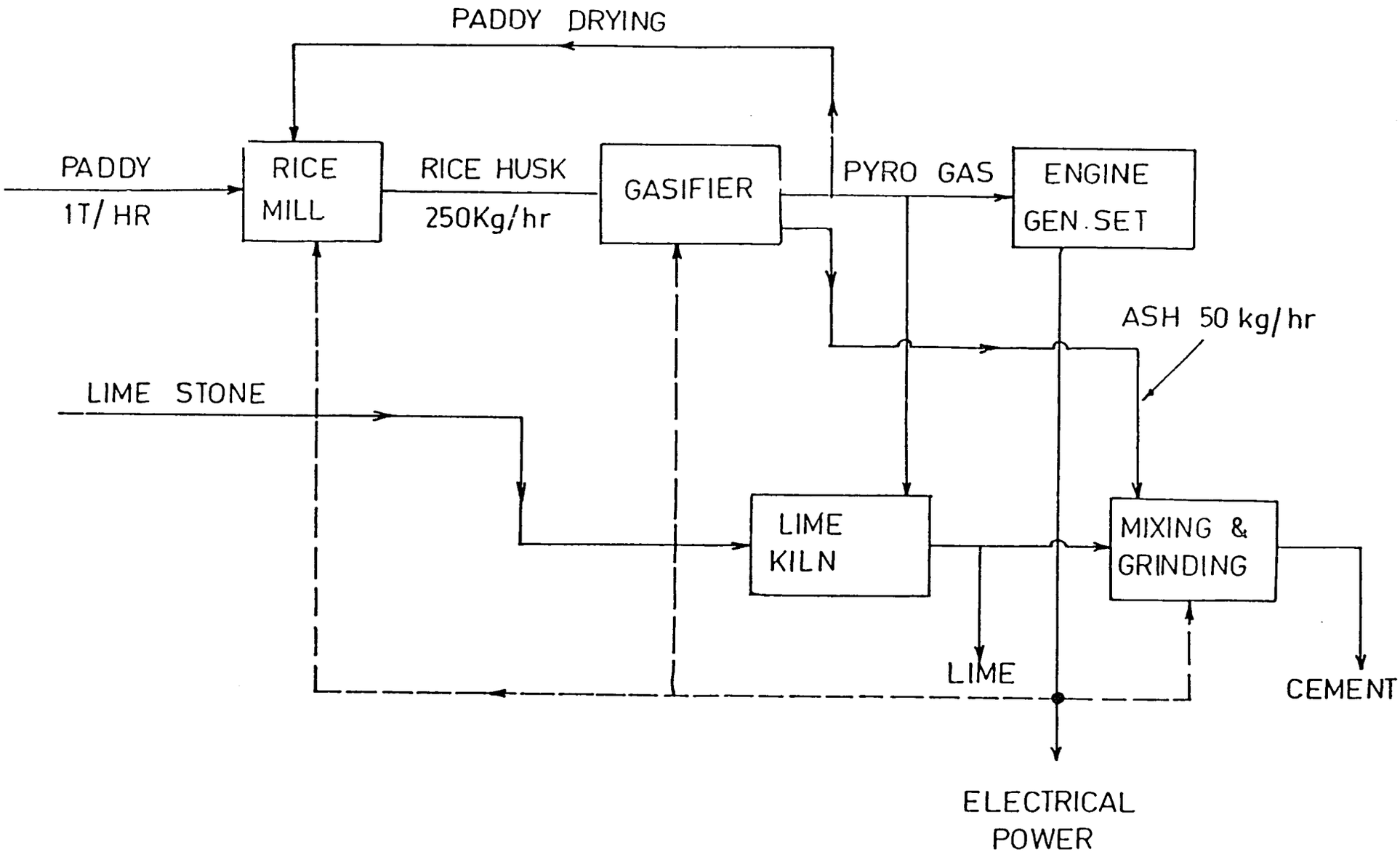

FIG. 2. INTEGRATED SYSTEM FOR GASIFICATION OF RICE HUSK FOR RICE MILLS.

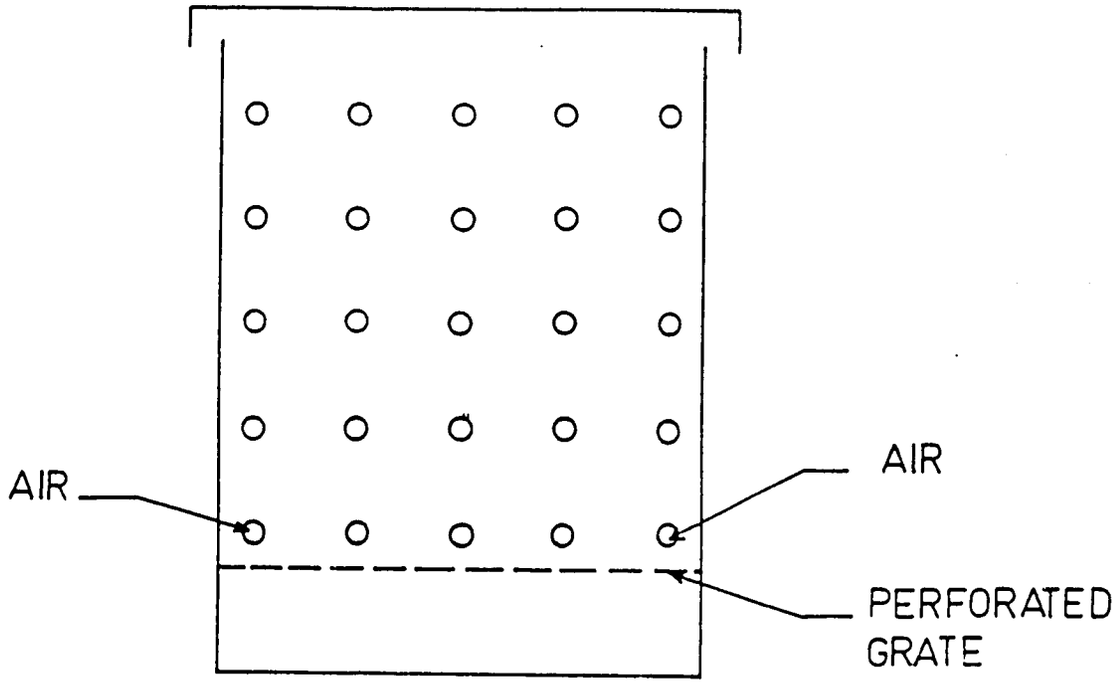

FIG. 3. PERFORATED DRUM CHARRING UNIT.

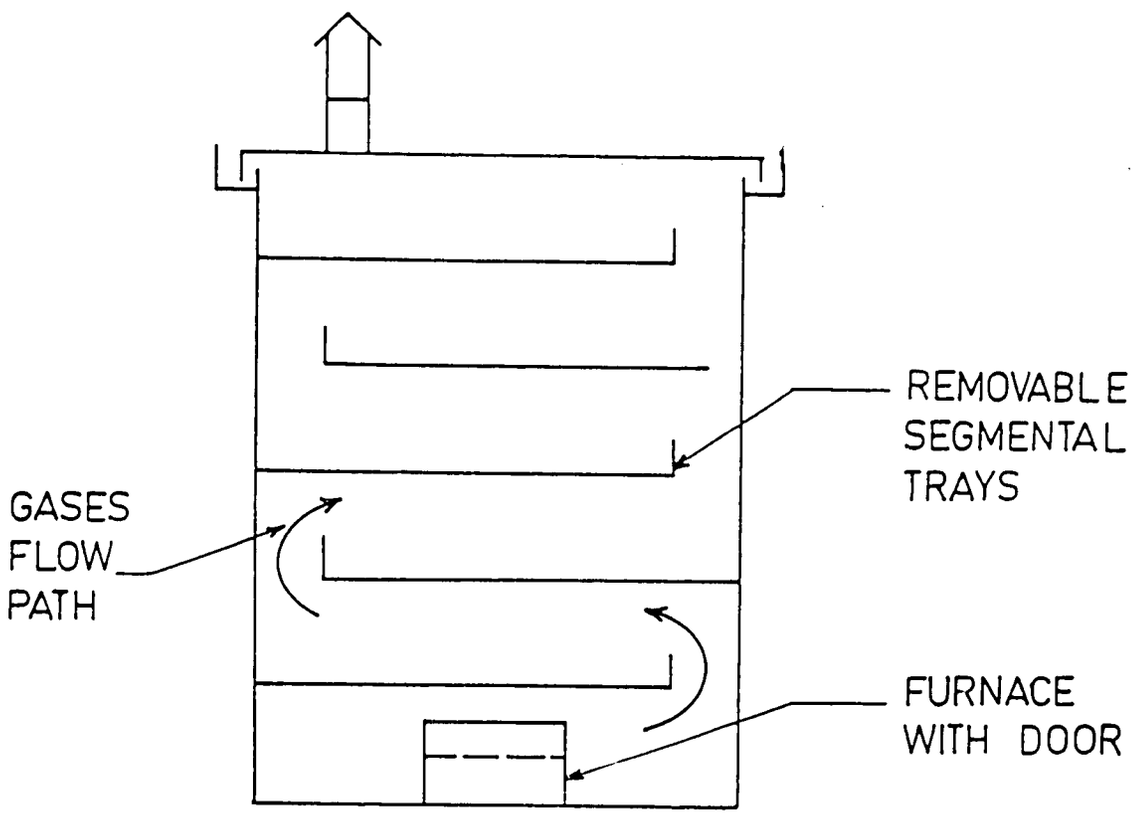

FIG. 4. TRAY CHARRING SYSTEM

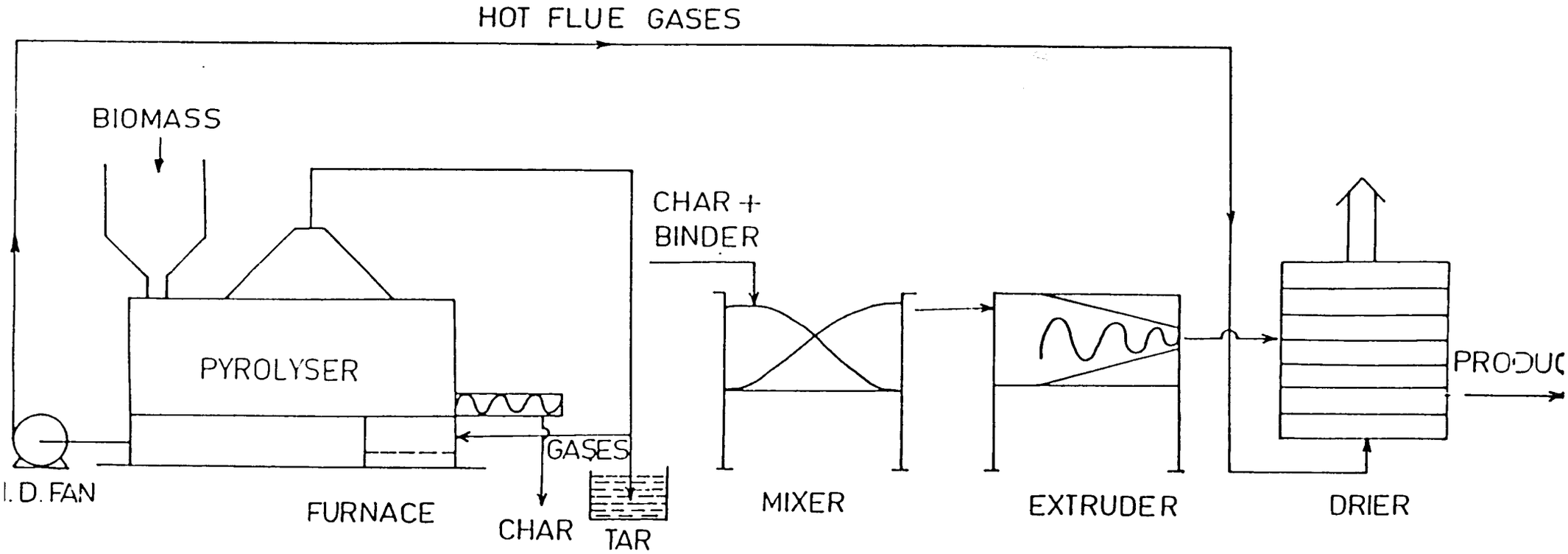

FIG. 6. FLOWSHEET OF MECHANISED BRIQUETTED (PARU) FUEL PLANT

IMPORTANCE OF "PARU FUEL" FOR ENERGY AND FOOD PRODUCTION CYCLE

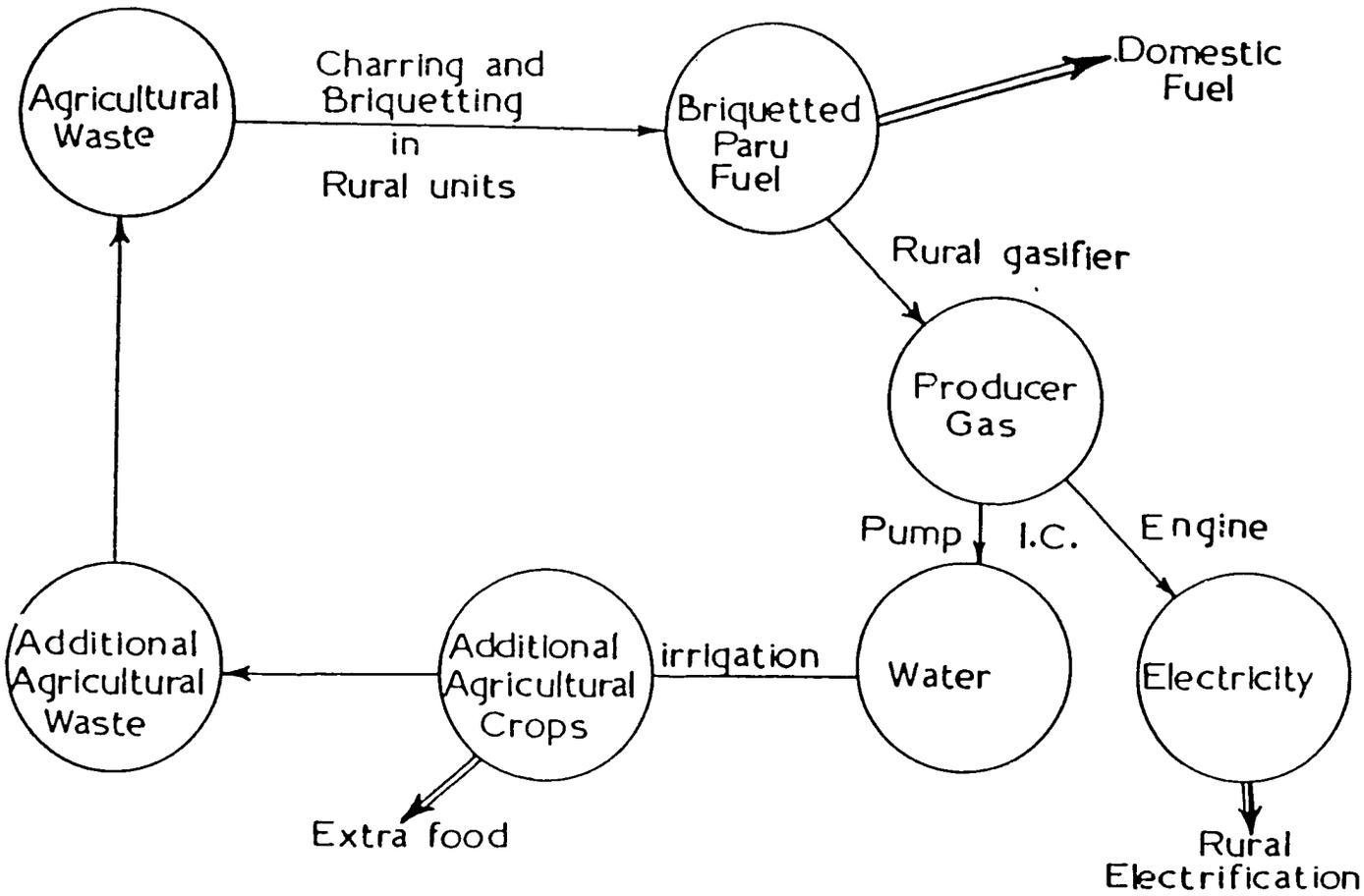

FIG. 7 . SCHEMATIC PLAN

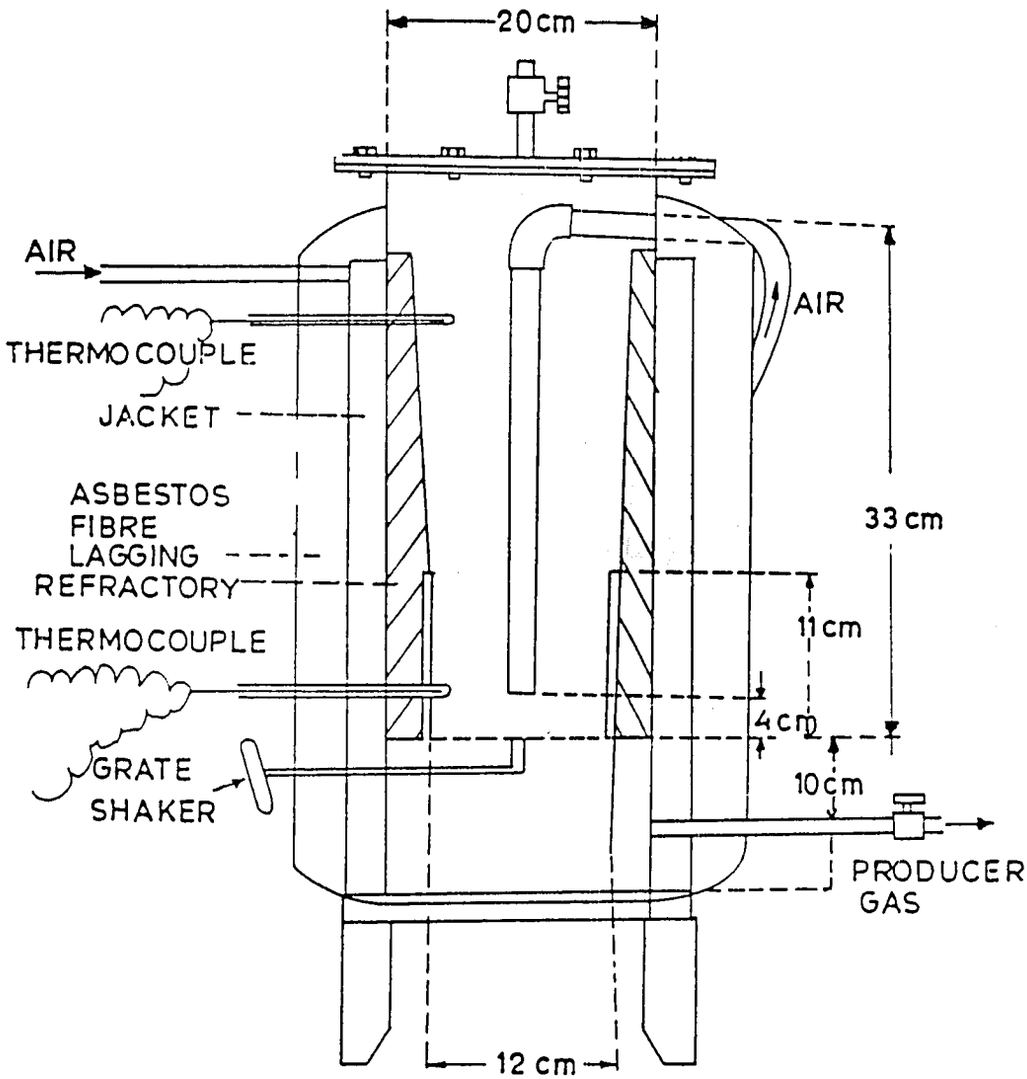

FIG.8. SCHEMATIC OF MINI GASIFIER.

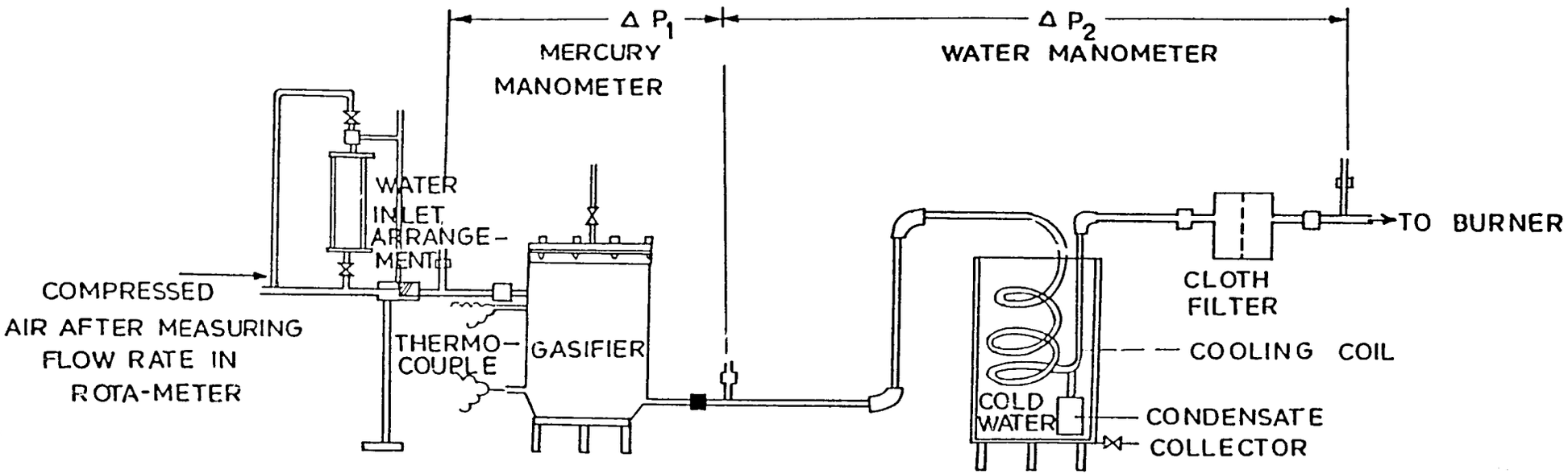

FIG.9. GENERAL LAYOUT OF GAS PRODUCER.

SMALL INTERNAL COMBUSTION ENGINES FOR PRODUCER GAS APPLICATION

H. D. MATHUR

PRODUCER GAS GENERATION AND UTILISATION IN SMALL HORSE POWER UTILITY ENGINES

By

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1. INTRODUCTION:

Small horsepower combustion engines are being widely employed for driving irrigation pump sets, portable generating sets, pesticide spray sets etc. etc. Their numbers are repidly growing and it is hard to see a replacement for them in foreseenable future. These engines operate on petroleum based fuels such as gasoline and diesel oil, which are getting more and more scarce. Therefore, the need to find alternate fuels for these engines is increasingly being realised the world over.

Biosolar fuels such as Alcohols and Biogas, Biomass fuel such as Producer gas are the possible alternate renewable fuels which have attributes of perennial renewal. The suitability of these fuels for part or complete replacement of petroleum based fuels, in combustion engines, has been under investigation in the department of mechanical engineering for last 10-12 years.

In the institute project entitled Project 'U' "Utilization of Alternate Fuels for National Energy Needs", initiated and being coordinated by the author, extensive work has already been completed on efficient utilization of alcohals and biogas as fuels in combustion engines of various types and ratings. Demonstration units of biogas and alcohol operated engine driven pump sets, generating sets have been developed. Alcohol have also been tried in vehicular engines with very encouraging results. Apart from this experimental work computerised design details of 'Alcohol Engines' and 'Biogas Engines', have been prepared for future use.

Overthe years, during these investigations, necessary infrastructure of laboratory facilities and technical expertise has been developed for R & D work on engines and fuels. These facilities at I.I.T. Delhi are considered to be amongst the best available in the country.

Apart from the work on alcohols and biogas some R & D work has also been carried out on production and utilization of producer gas in small size utility engines. While large size producer gas plants are commercially available little or no work had so far been done in the country on the design and development

of small capacity plants for operating combustion engines of 1 to 5 horse power range.

Development of small size producer gas plants requires considerable R & D effort to over come the problems associated with the variations of fuel composition and characteristics, charging, of fuel and its efficient combustion, cleaning and cooling of the gas produced, etc. etc.

Efficient utilization of producer gas in existing petrol or diesel engines also poses certain problems because of the difference in the heat of combustion, stoichiometry, combustion characteristics and composition of producer gas and the petroleum based liquid fuels for which these engines are designed.

These and such other related problems need to be solved by a concerted R & D effort before the small size producer gas powered engines can acquire commercial viability. They are currently under investigation in the mechanical engineering department and centre of energy studies at I.I.T. Delhi.

2. SCOPE OF THE RESEARCH PROGRAMME:

The proposed research programme aims at the efficient utilization of producer gas in existing small size utility engines and development of 'Producer gas Engines' specially designed to burn producer gas as a complete fuel.

It is proposed to achieve these aims and objectives through a set of short term and long term R & D projects designed to achieve certain immediate and certain long term goals.

The existing small utility combustion engines are being modified to operate as bifuel engines with minimal possible amount of conventional fuel supplied for initiating and sustaining combustion of producer gas the main fuel. The design modifications in the intake firing, and cooling systems of the engines, necessary for maximum amount of producer gas substitution is being experimentally determined, and standardised.

The performance characterisitcs of these modified existing engines is being evaluated through a series of performance, governing, and fuel consumption tests under different conditions of operation. The engine operating parameters are being optimised for best results and the performance characterisitcs so obtained are being compared with those of the unmodified engine operating on the conventional petroleum fuels. This phase of the project is planned to achieve efficient utilization of producer gas in existing combustion engines with no major engine modifications and to get a comprehensive idea about the relative performance of such engines.

The material compatibility of the engine components are proposed to be examined by subjecting the modified engines to a series of endurance tests and examining the components thereafter for wear, corrosion, errosion, gun-formation etc. Comparison of results with those obtained from similar tests on engines operating on the conventional fuels would give an idea about the material compatibility with producer-gas fuel. This phase of the project is planned to obtain guide lines for selection of suitable materials for greater reliability and durability of the producer gas powered engine.

With the growing awareness of environmental pollution from engine exhaust, it is necessary to investigate the emission characteristics of producer-gas powered engines. This study mainly involves exhaust gas analysis under various engine operating conditions to identify the various exhaust pollutants and their concentrations. It is proposed to compare these results with those obtained from similar tests carried out on the convetionally fueled engines so as to get a relative idea about the pollution potential of producer gas powered engines. This phase of the project would indicate the direction in which exhaust emission control measures, if any, would be required for producer gas fueled engine.

Some basic combustion studies, on producer-gas are being carried out to collect the requisite information regarding inflamability limits, flame velocity, ignition delay, stoichiometry, adiabitic flame temperatures etc. This basic combustion data would be useful in the design and development of the producer-gas engine which would be specially designed with the required fueling, firing, and cooling arrangements to achieve efficient utilization of producer gas as a total fuel. This part of the project has a long term implication in enabling the producer gas fired engine-pump or engine generating sets become commercially viable units in time to come.

In the above outlined research programme the R & D effort is mainly concentrated on the engine aspect of the gasifier (producer gas unit) engine set. The development work on the gasifier is being carried out by another group at IIT Delhi. However, to reduce the interdependence of these two groups we are making our own producer gas units. This part of the work is also requiring a certain amount of developmental effort. Small size gasifier designes are being evolved and fabricated so as to have the necessary source of gas available for uninterrupted, R & D work on the producer gas fueled engine.

In short this R & D effort is directed towards finding answer to the following:

1. How best an existing S.I./C.I. engine can utilise producer gas.
2. What modifications need be carried out to make existing combustion engines operate an producer gas.
3. What should be the best method of inducting, regulating the gaseous fuel in the engine.
4. What should be the optimum ignition arrangement, and timing for best results.
5. How the power out, fuel consumption and smoothness of operating are effected by switching over to producer gas fuel in the existing engines.
6. What should be the minimum quantity of conventional fuels used for bifuel operation of the existing engines.
7. How does the producer gas fuel effect the exhaust emissions from the engine. What are the major pollutants and their concentrations.
8. How is the engine component material compatibility with this fuel.
9. What is the extent of wear, errosion, corrosion if any and what changes in materials are required.
10. What should be the design parameters of a producer gas engine for total operation on this fuel.
11. How the fuel combustion characteristics, stoichometry and composition differing as they do with the conventional fuels, have to be accounted for in the redesign of fueling, firing and combustion system for best results.

3. SMALL SIZE GAS PRODUCER UNITS:

A couple of small size coal based gasifier units of both updraft and downdraft type have been designed, fabricated and operated to gain experience and overcome various problems associated with each type of unit.

Fig. 1 shows a schematic diagram of the producer gas plant. The plant consists of a gasifier, a scrubber and a receiver.

The engine suction draws a blast of air and stea through the fuel in the gasifier bed. At the base of the gasifier are provided the fire grate an arrangement for the removal of ash and an inlet for steam and air. A blower is provided for starting the gasifier and during the starting period the products of combustion are blown to waste through the starting cock. Fig. 2 illustrates different type of gasifiers and various zones in each of them.

In order to protect the engine from tar, dust and ammonia, the gas from the gasifier is passed through a scrubber containing soft coke through which percolates a steam of water. This cleans the gas as tar and dust are absorbed by the soft coke, while ammonia dissolves in the stream of water. The scrubber is a tall cylinder in which water is introduced from the top through a shower.

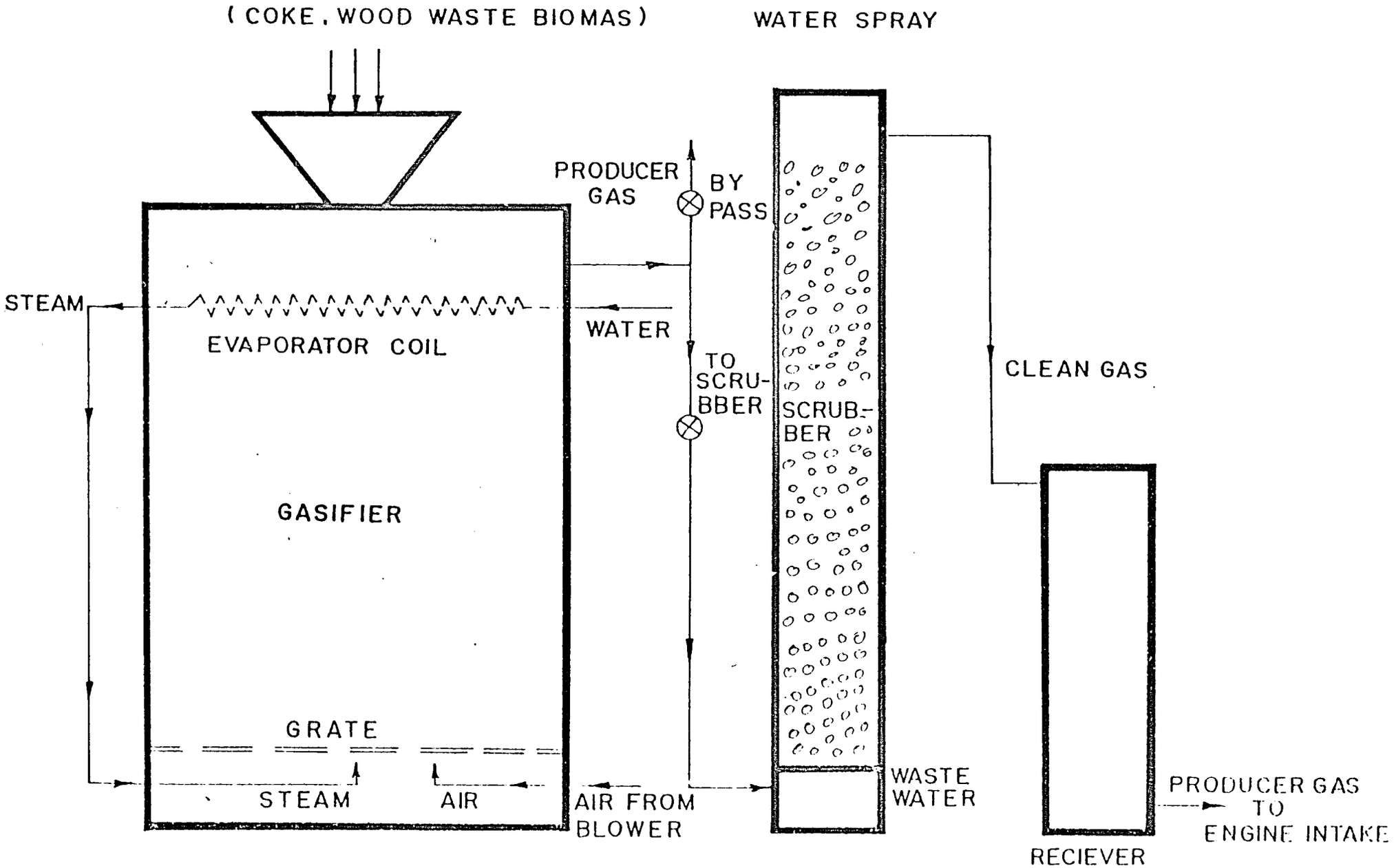


FIG. I. SCHEMATIC DIAGRAM SHOWING THE LAYOUT OF A PRODUCER GAS PLANT.

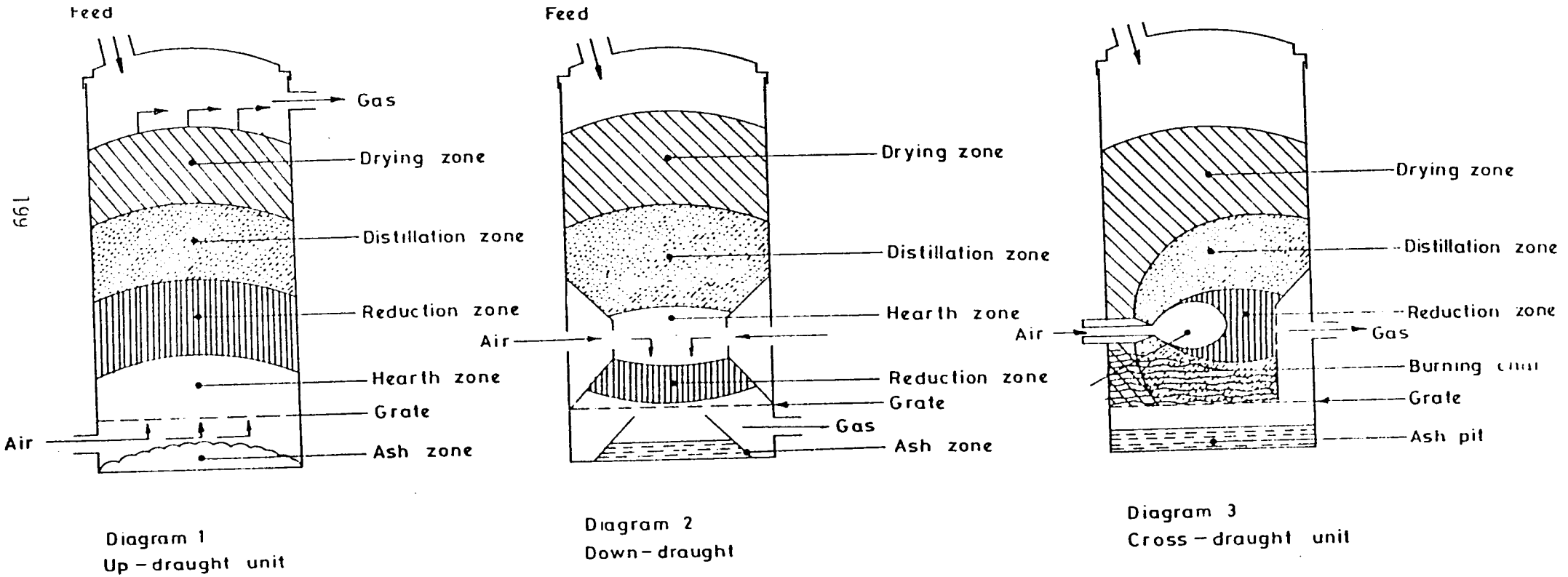


FIG. 2-1 Defferent type of gasifiers.

The shower is used to provide a uniform flow of water through the soft coke. At the base of scrubber, there is an outlet for the waste water.

The gas, after passing through the scrubber, is collected in a receiver which is essentially a cylinderical chamber having a capacity which is 500 times the engine swept volume. Use of a receiver chamber damps down the pulsations in the gas flow and ensures a steady supply of gas to the engine.

3.1 Gas Produced:

Producer gas is produced by blowing a mixture of air and steam through a hot bed of coal or coke. The gas leaving the fuel bed consist of a mixture of carbon monoxide and hydrogen, with some carbondioxide and all the nitrogen of the air used in the process.

The characteristic properties of producer gas depend firstly upon the fuel used and secondly upon whether the gas is used in the hot state or is just cooled and cleaned to remove tar and dust.

Owing to the high proportion of inert gases (over 55 percent of CO_2 and N_2) producer gas is characterised by a low calorific value and low flame temperature.

It requires a very small proportion of air for combustion. The stochiometric gas-air mixture has

a fairly high heat value of 575-640 kcal/m^3 not very much lower than the value of 815-845 kcal/m^3 for a stochiometric coal gas-air mixture. For this reason, and because of low unit cost, producer gas has very wide applications as an industrial fuel.

In order to have continuous running of an engine on producer gas, it is essential that a certain quantity and quality of gas is made available for as long as a time the engine has to be operate. Any fluctuation in the quantity and quality of the gas will be detrimental to the performance of the engine. Large varations may even cause the engine to stop. The air-fuel ratio has to be maintained close to the stochiometric ratio, so that optimum engine performance is obtained.

3.2 Plant Parameters:

There are certain parameters of the producer gas plant which have to be optimized so that a constant flow of good quality gas is available for the engine throughout the duration of its operation.

3.2.1 Retention Time:

The retention time of the blast through the fuel bed is one of the critical parameters to be controlled for maximum efficiency.. Figure 3 shows diagramatically the various reactions and reaction zones in the fuel bed of an updraft gasifier designed and used

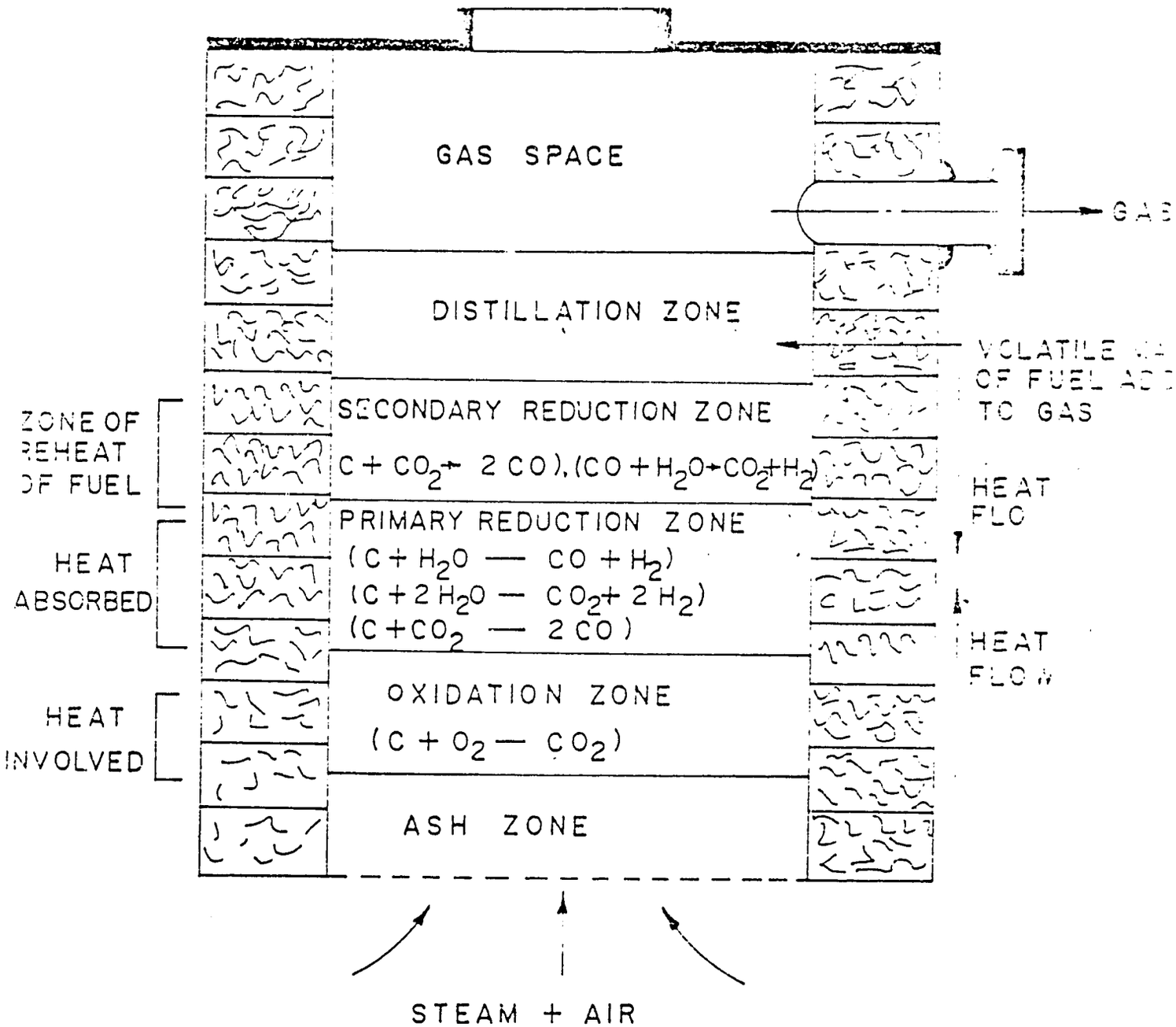


FIG. 3 SCHEMATIC DIAGRAM OF GASIFIER SHOWING VARIOUS REACTION ZONES AND REACTIONS

in this work. The blast entering the fuel bed consists mainly of saturated air. As it passes through the lower most zone of the fuel bed the ash zone, the blast gets heated up and while passing through the combustion or oxidation zone has its oxygen completely consumed. The main product of combustion being carbon dioxide. Since the temperature in the combustion zone is very high the conversion of oxygen to carbondioxide is almost instantaneous. Hence the retention time in combustion zone is not very important unless of course the air flow rate is so very high that all the oxygen is not consumed.

It is in the reduction zone that the retention time is vital. In the reduction zone the carbondioxide produced earlier is reduced to carbon monoxide. Since the amount of the carbondioxide that is reduced to carbonmonoxide has to be maximized, the retention time in this zone has to be sufficiently high. Higher retention time gives maximum opportunity to the carbon available in the reduction zone to reduce more and more of the carbondioxide to carbon monoxide.

One way of increasing the retention time in the reduction zone is to increase the overall fuel-bed height. This will obviously increase the height of the reduction zone also. The gases emerging from the combustion zone will now take a longer time to cross the reduction zone. Increasing the retention time ensures

greater percentage of carbon monoxide in the producer gas hence better quality gas. Table-1 below shows the improvement in the composition of the gas with increase in the bed height.

TABLE - 1

Height from grate (cms)	Percentage composition - by volume			
	O_2	CO_2	CO	H_2
12	4	20	2	1
24	1	16	13	5
36	5	11	16	7
48	5	7	20	10
60	5	7	22	12

3.2.2 Mass Flow Rate:

The mass flow rate of the saturated air through the coal bed also effects the retention time. If the flow rate is increased, the retention time will decrease and therefore the quality of gas will suffer. In a suction gas producer this mass flow rate varies with the engine load and speed which effect the pressure drop across the bed and therefore the flow rate of the saturated air. It should be kept in mind that the retention time should not fall below a certain minimum value below which, the amount of carbon dioxide converted to carbonmonoxide would fall drastically. Any increase

in retention time is advantageous in as much as it improves the quality of the gas. Hence the gasifier must be designed for the air flow rate related to the maximum load expected on the engine. This would ensure that under no condition of operation of the engine the retention time would fall below the minimum permissible value.

3.2.3 Lump Size:

The size of the lumps of fuel used in the fuel bed is also an important factor. It affects the retention time. Use of large size lumps of fuel not only decreases the retention time but also the surface area exposed. Both these factors adversely affect the carbon monoxide percentage, lowering thereby the quality of the gas produced. Use of small size lumps improves the quality of the gas due to increased retention time as well as increased surface area of contact.

The size of the fuel lumps used not only affects the time of contact, but it also determines one more important parameter of the producer gas plant, i.e. the pressure drop across the bed. If the size of the lumps is reduced, the retention time increases and along with it the pressure drop across the fuel-bed also increases. There is a limitation on the pressure drop across the fuel bed. This limitation is imposed by the suction pressure of the engine. The suction pressure

at the inlet manifold of the engine should be sufficiently high to overcome the pressure drops across the fuel bed, scrubber and the connecting pipes and ensure the desired gas flow rate through the plant. If the pressure drop across the fuel bed increases, it results in a decrease in the mass flow rate of the producer gas. Excessive increase in the fuel bed pressure drop may result in an extreme case of engine stopage because of insufficient gas flow rate. Thus the pressure drop across the fuel bed is an important parameter and has to be controlled to ensure a steady gas flow rate.

Hence a fuel lump size that does not increase the pressure drop across the fuel bed beyond the critical value, and yet permits adequate retention time has to be determined to obtain the desired quantity and quality of gas. Fuel lumps of around 2 cm size have been found to give the best results. Use of larger or smaller sizes tells upon the quality or quantity of the gas produced.

3.2.4 Fuel Used:

The type of fuel used also determines the pressure drop, across the fuel bed. If cooking coals are used - the main mass becomes "pasty" as the temperature is raised. Hence cooking coal bed offers a decided resistance to the passage of gas, where as non-cooking

coal fuel bed offers little or no resistance. Resistance to the passage of gas implies an increase in the pressure drop across the fuel bed. So if the pressure drop across the fuel bed is not to be increased, only non-cooking or weakly cooking coals should be employed in preference to other types of coal.

3.2.5 Fuel Bed.

The pressure variation in the fuel bed must be uniform, so that the passage of gases is uniform. If the state of the bed is such that the various zones are not distributed uniformly and horizontally across the gasifier then such conditions can result in "channeling" and "hot spots". This results in preferential passage of the gases for the gases will take the path of least resistance in the bed. This will result in lowering of the thermal efficiency and inferior gas quality. To reduce this, the fuel bed must be poked and levelled using poker red and levellers every half an hour so that a uniform fuel bed is maintained.

If the ash zone is not maintained properly, this could also lead to an increase in the pressure drop across the fuel bed. If the temperature in the ash zone rises above 1300 - 1400°C, the result is that the ash begins to fuse and forms clinker. This increases resistance to the flow of air and hence increases the pressure drop across the fuel bed.

3.2.6 Temperature Distribution:

Yet another critical parameter is the temperature distribution along the fuel bed. As mentioned above, the temperature of the fuel bed should not be allowed to reach close to the temperature where clinker formation starts, for this hinders the passage of the blast. Also, the temperature of the combustion zone must not be allowed to fall below 1000°C. If this occurs then the reaction in the combustion zone will slow down and all the oxygen in blast would not be utilised.

The control of the bed temperature is achieved by controlling the amount of steam in the blast. The criteria of the proportion of steam in the blast is the blast saturation temperature (BST).

Since the steam reaction with carbon $C + H_2) = CO + H_2$ is endothermic, any excess steam in the blast implies decrease of the bed temperature for the above reaction would absorb heat from the bed and so cool the bed.

If the amount of steam in the blast is not sufficient then the exothermic reaction

$$C + O_2 = CO_2$$

will further increase the bed temperature resulting in clinker formation.

3.2.7 Blast Saturation Temperature:

Table-2 and Fig. 4 show the effect of BST on the gas composition. In order to have the right proportion of the steam in the blast, the BST should be in the range 55° to 66°C preferably nearer to the lower value for maximum thermal efficiency of the plant and high heat value of the gas produced.

TABLE-2 - Composition of gas obtained with various Blast Saturation Temperatures.

Blast Saturation Temp. (°C)	Percentage Composition - by volume		
	CO_2	CO	H_2
45	75.5	24	10
50	7.5	22.8	10.8
53	8	22	12
55	8.4	20.8	13
58	8.9	19.3	13.6
60	9	19	14

Figure 4.2 through 4.4 pertain to a downdraft gasifier, its gas cooler and gas cleaner equipment which have been designed, fabricated at I.I.T. Delhi and extensively used in the trials on the producer gas operated spark ignition engine mentioned in this paper.

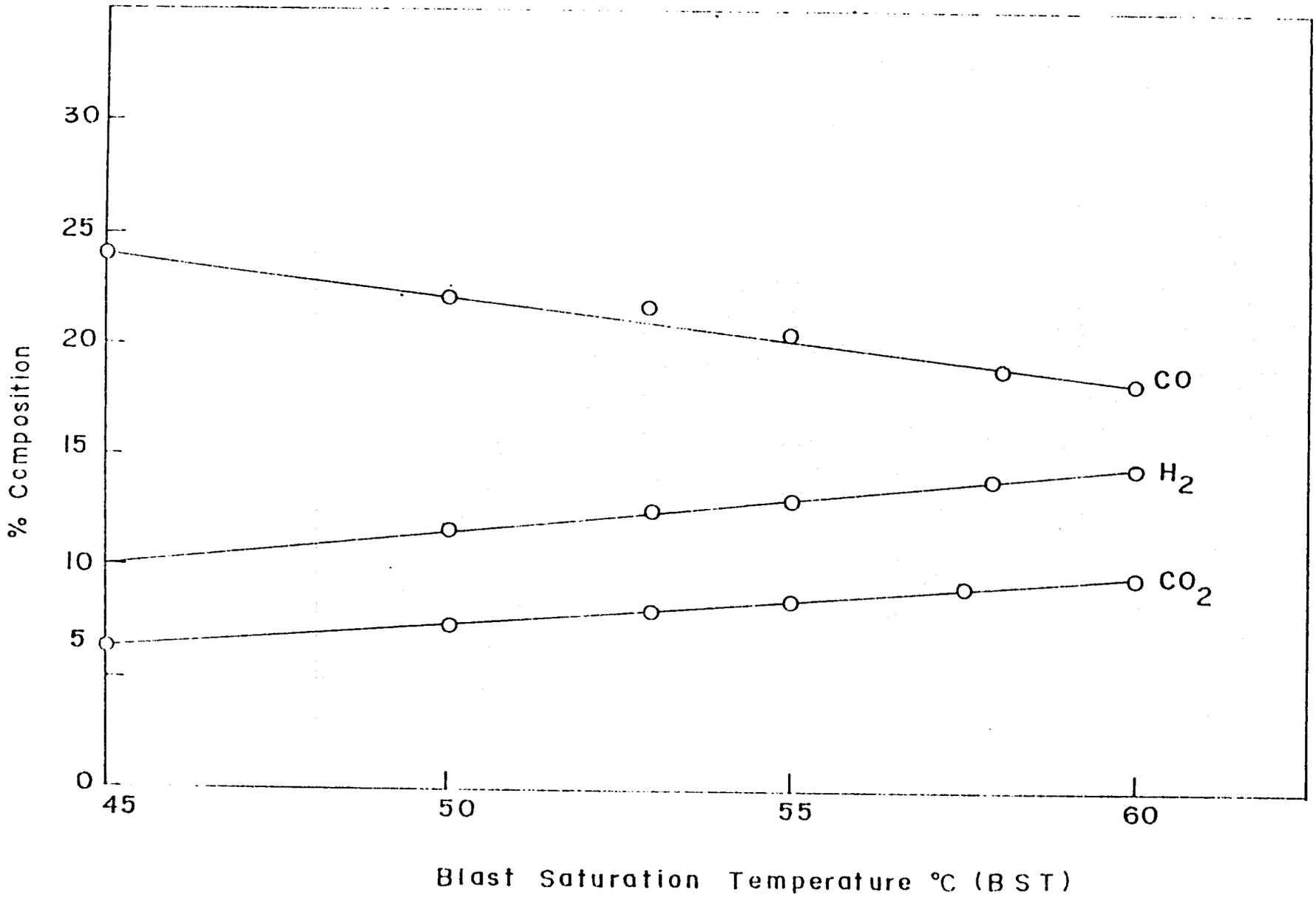
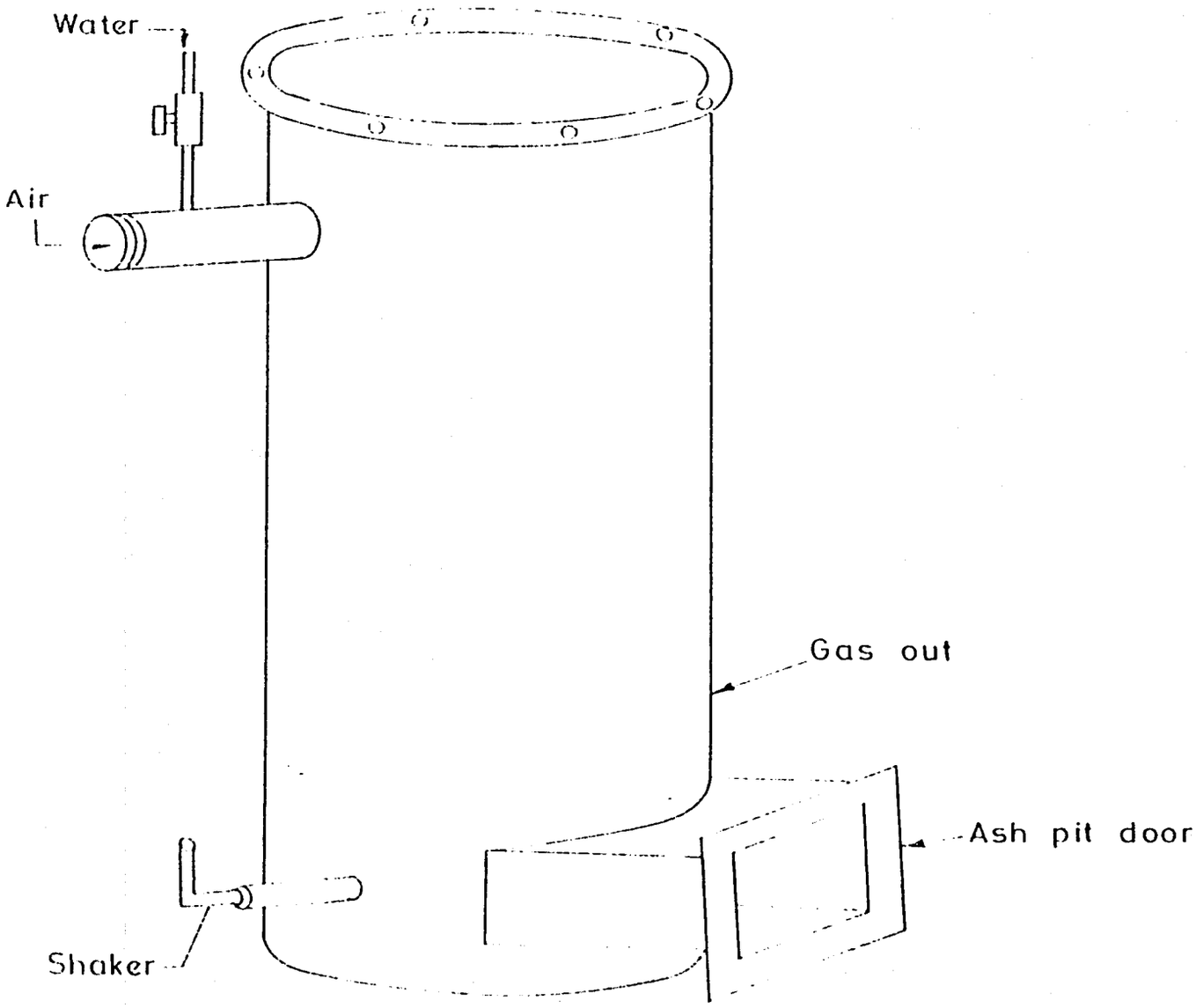


FIG. 4 GAS COMPOSITION vs B S T.


Water
Air
Gas out
Ash pit door
Shaker

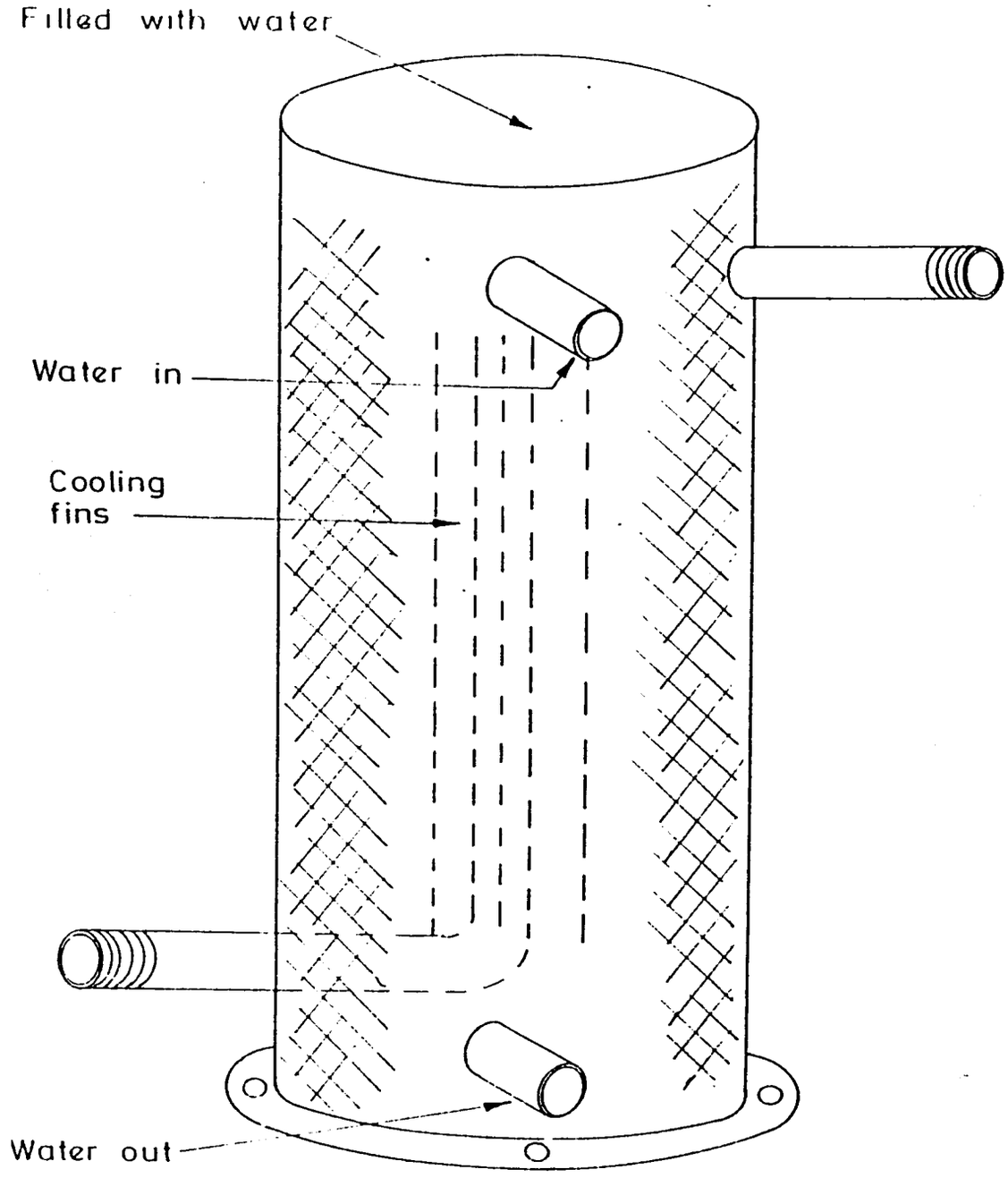


FIG. 4-3 A view of gas cooler

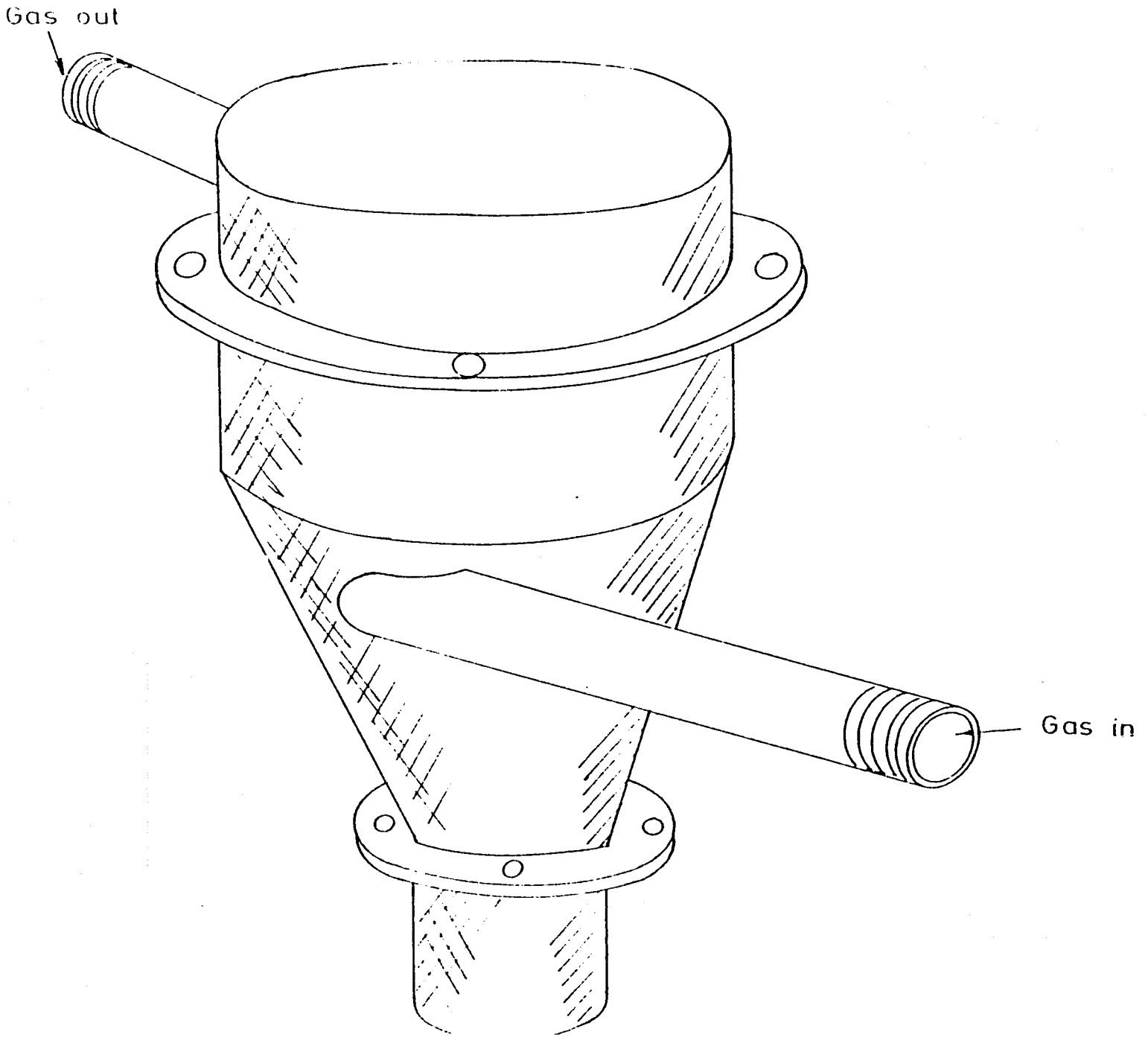


FIG. 4.4 A view of gas cleaner.

4. UTILISATION IN ENGINES:

After an optimally designed producer plant is developed to get the desired quality and quantity of gas, the next step is to efficiently use this gas as a fuel in existing combustion engines after carrying out the necessary engine modifications. Small size S.I. and C.I. engines have been operated on producer gas. The necessary modifications in the intake system and ignition timing have been effected and the engine performance data collected with a view to asses the engine performance with producer gas fuel and standardise the requisite engine modifications.

In case of S.I. engines the intake system has been modified for introducing the gas while the conventional carburettor retained to enable engine starting with gasoline. After warming up the engine producer gas intake valve could be opened and gasoline supply switched off to have operation of the engine on producer gas neat.

4.1 Intake System:

The arrangement for mixing fuel gas and air constitutes an important part of the modified engine intake system, because complete combustion and low fuel consumption can be obtained only with proper mixing of air and fuel gas. Three different mixing arrangements have been tried. In the first arrangement the air and

gas mixed by passing through opening or slots in a seperate box and the two admitted to the cylinder in the form of a ready mixture. In the second group the air and gas were mixed in the throat of a venturi tube making use of the high velocities created there as a result of the suction action of the engine piston. In the third group of mixing was affected immediately before admission.

Figure 5 shows two of the systems tried. One of the systems consisted of an arrangement of mixing the gas with air before the carburetor while in the other mixing was effected after the carburettor. Fig. 4.5 shows the gas-air mixing assembly finally adopted as it facilitated a more precise regulation of the air fuel ratio.

4.2 Experimental Set-up and Technique:

A schematic diagram of the experimental set-up is shown in Fig. 4.1. In the experiments a couple of four stroke single cylinder spark ignition engines having a rated horsepower in the range 5 to 6 h.p. at around 1500 rpm wer employed. The quality of gas entering the engine intake system was continously monitored. using a gas analyser and gas calorimeter. The engines were operated over their entire speed-load range and various types of tests were conducted to obtain the engine performance and emission data over the entire engine range of operation, with both gasoline and producer gas fuels.

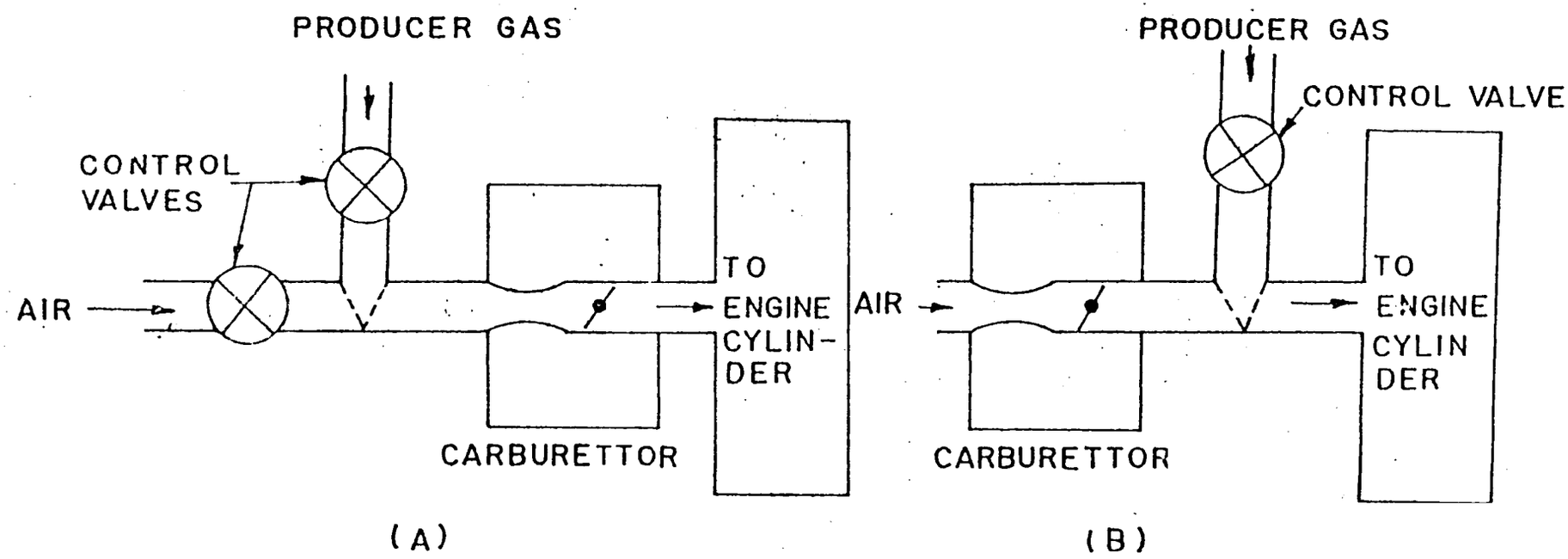


FIG.5 ALTERNATIVE MODIFICATION IN ENGINE INDUCTION SYSTEM FOR INTAKE OF PRODUCER GAS.

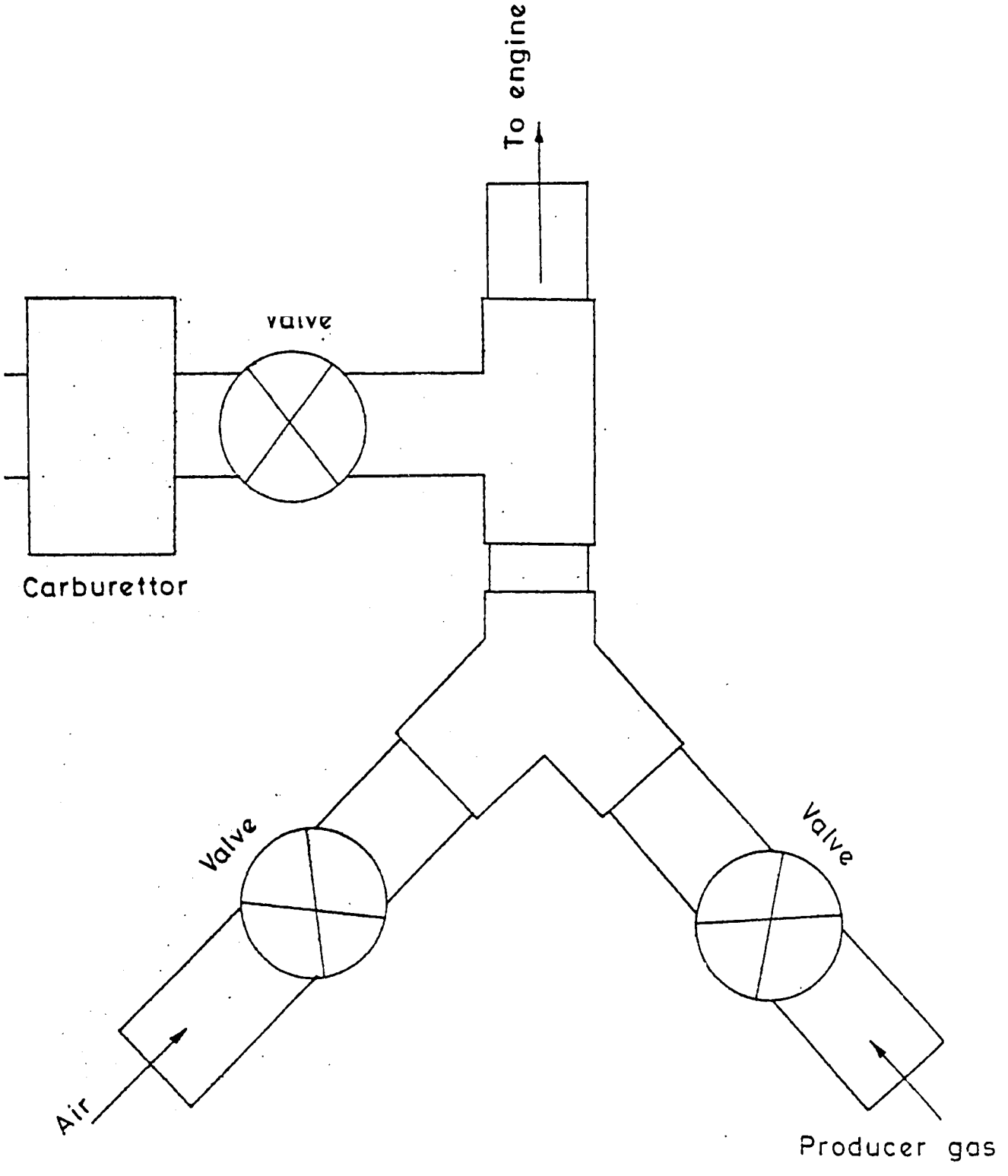
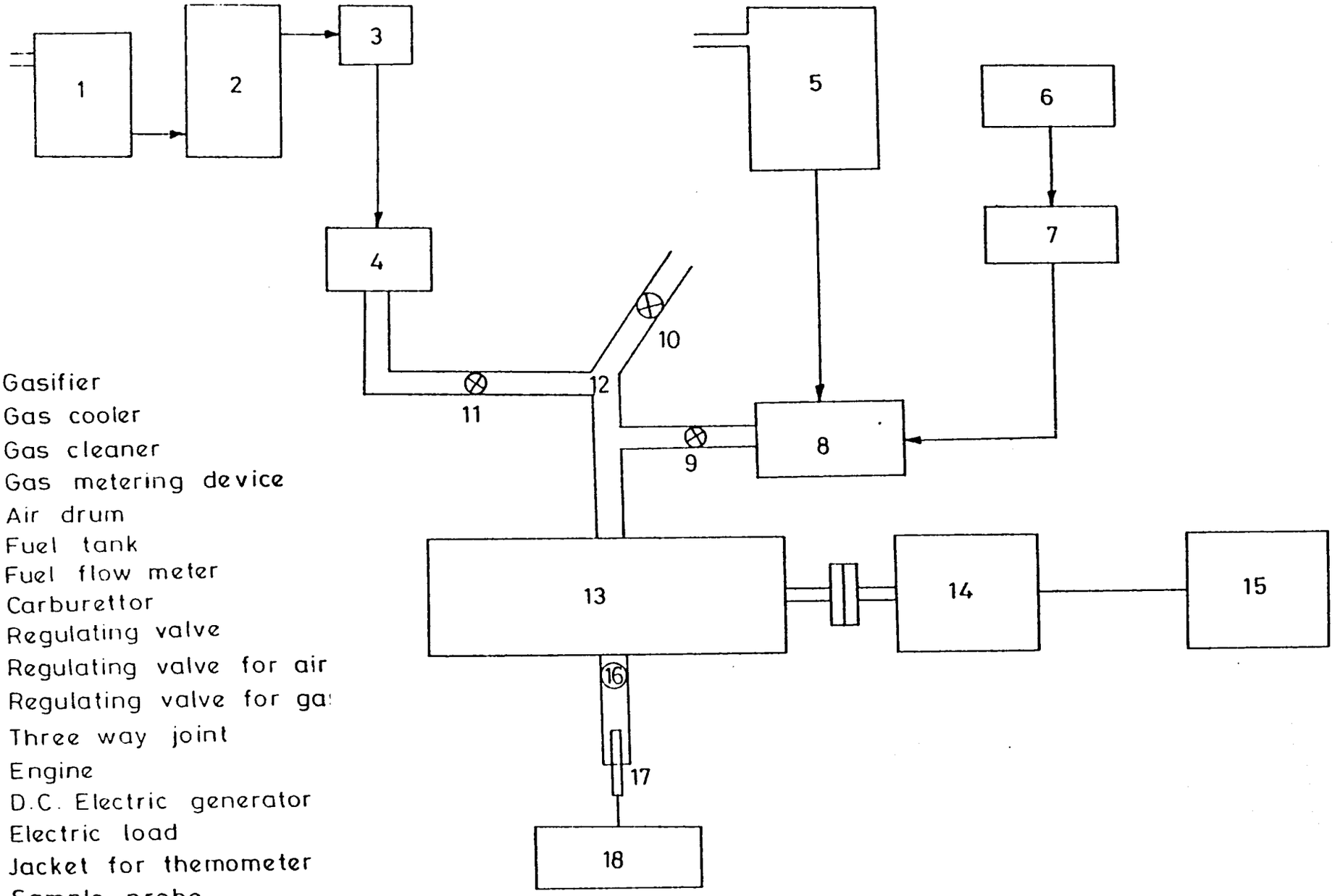


FIG. 4-5 Gas / Air mixture unit



1 Gasifier
2 Gas cooler
3 Gas cleaner
4 Gas metering device
5 Air drum
6 Fuel tank
7 Fuel flow meter
8 Carburettor
9 Regulating valve
10 Regulating valve for air
11 Regulating valve for ga
12 Three way joint
13 Engine
14 D.C. Electric generator
15 Electric load
16 Jacket for themometer
17 Sample probe
18 NDIR

FIG. 4-1 Schematic diagram for experimental setup.

Instruments such as NDIR were used to analyse the engine exhaust effluent.

4.3 Engine Performance and Emission:

Fig. 6 shows a typical performance characteristic of an S.I. engine while operating with producer gas and gasoline respectively. The differences in the performance is that the power developed by the engine when operated on the gas considerably lower/- the maximum output being only 50 percent of that developed with gasoline operation. The reason for this is the difference in the combustion characteristics and stoichiometry of producer gas and gasoline. This shows that the main draw back, inherent to the use of producer gas in S.I. engines is the loss of power.

Fig. 6.4 and 6.5 are representative plots for an engine operating at its rated speed while using producer gas and gasoline fuels respectively. The reduction in engine power due to switch over to producer gas could be because of (i) lowering of the heat value of the mixture (stoichiometric gas-air mixture has an energy density of 2.5 HJ/m^3 as compared to 3.5 HJ/m^3 of gasoline-air mixture) which may account for upto thirty percent reduction in power output (ii) contraction through combustion resulting in about ten percent volume reduction after combustion of producer gas (iii) increasing exhaust losses because of greater exhaust gas temperature

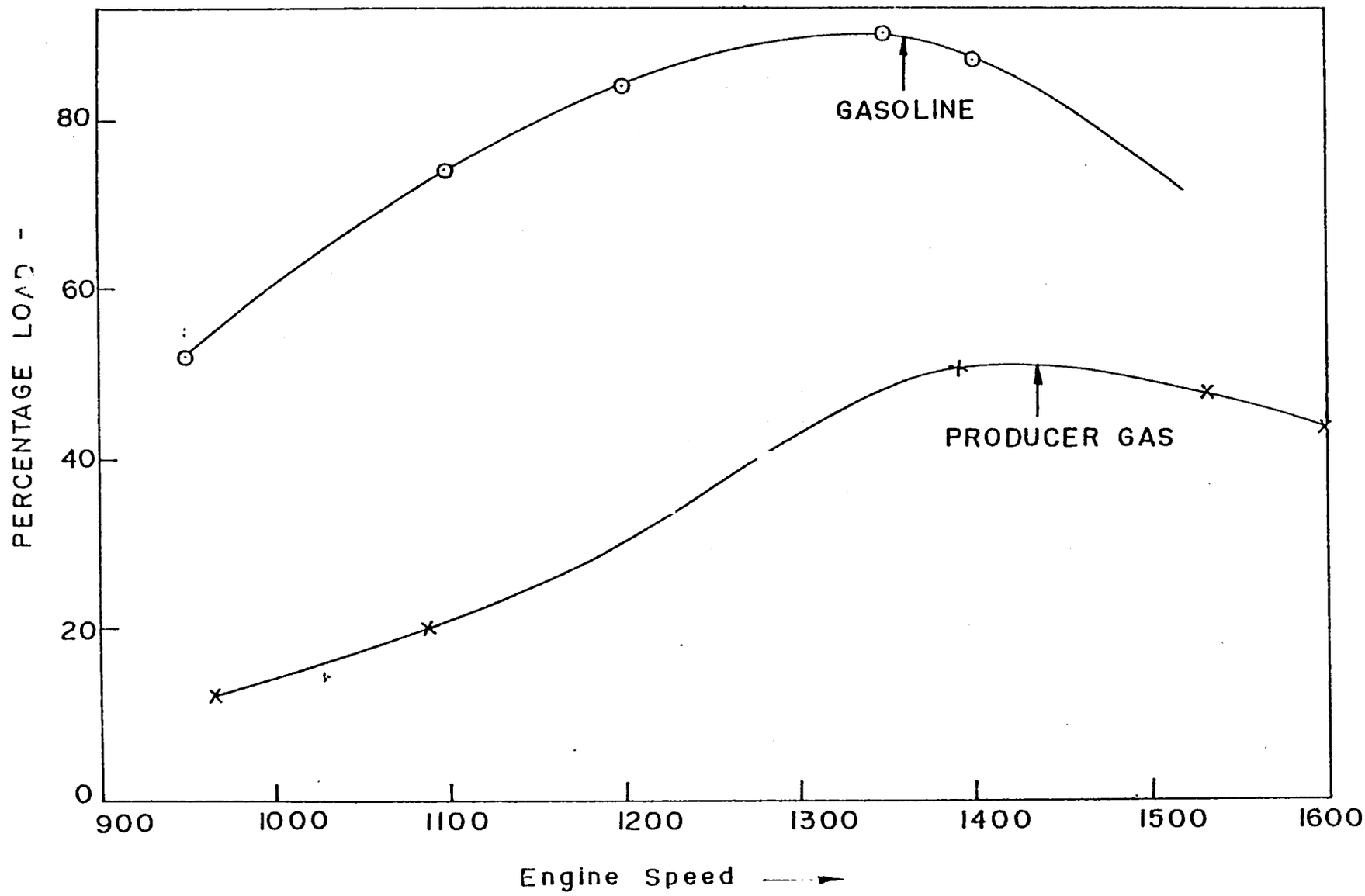


FIG. 6 ENGINE PERFORMANCE CHARACTERISTIC WITH (a) PRODUCER GAS AND (b) GASOLINE FUEL

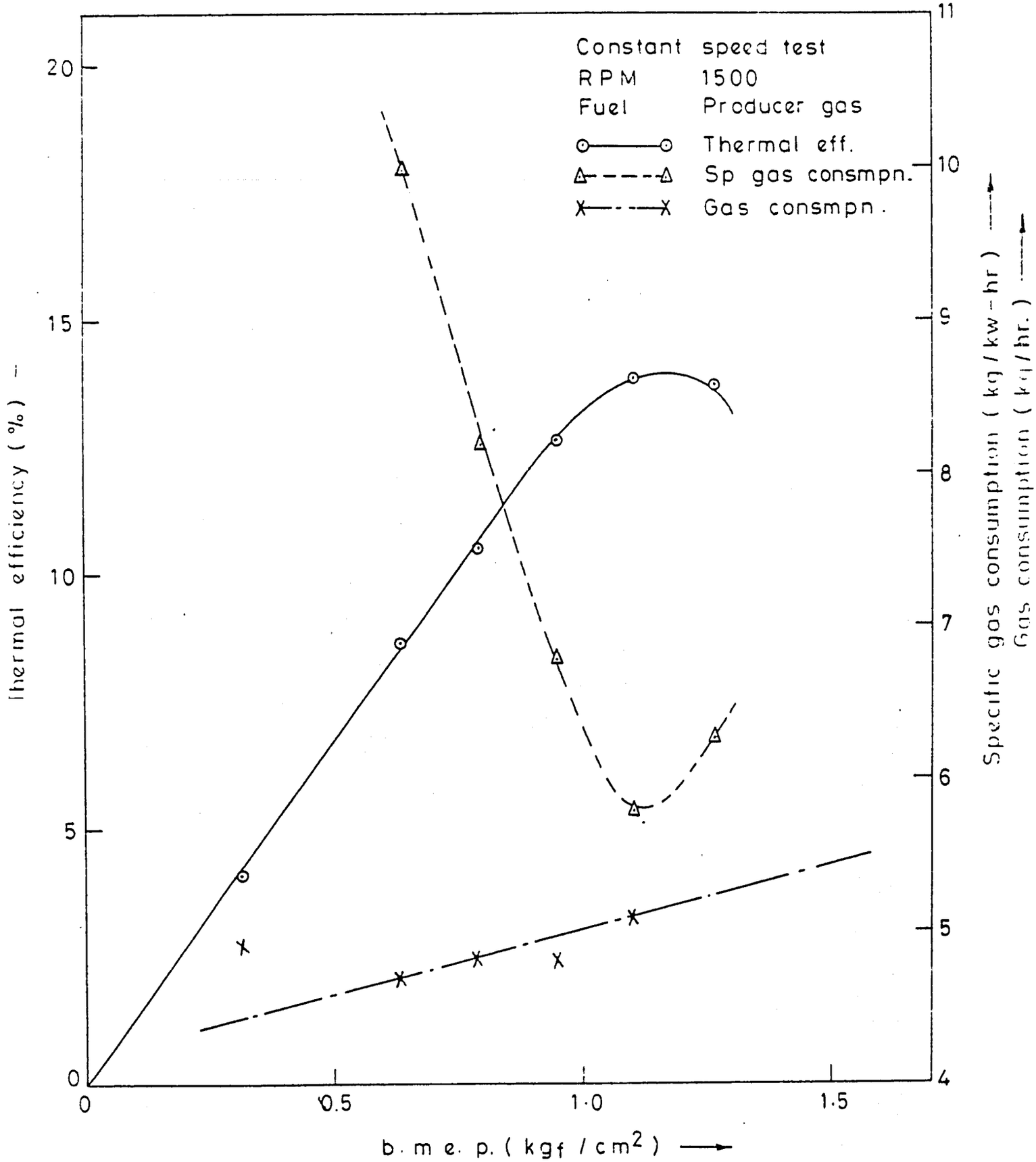
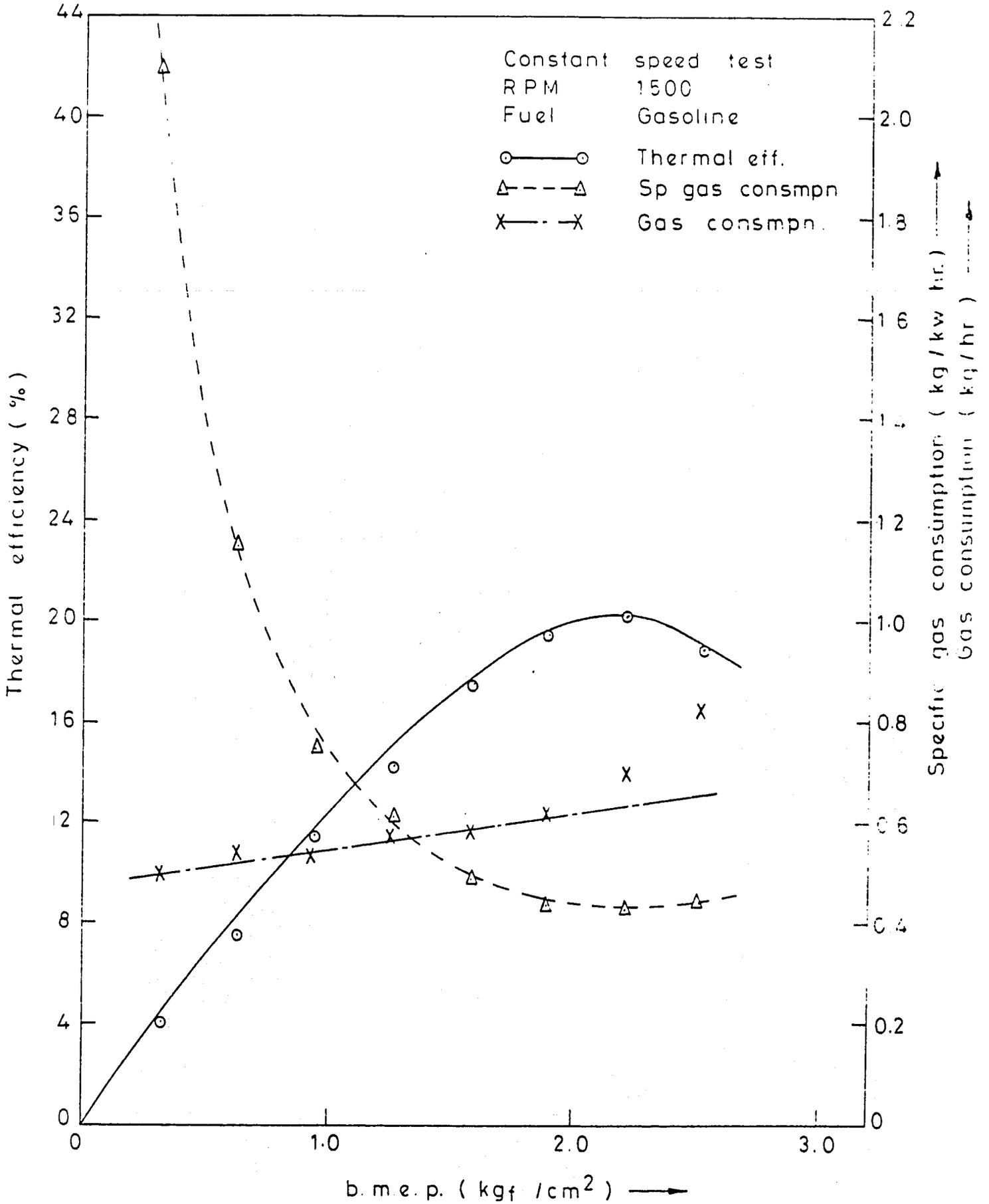

Constant speed test
RPM 1500
Fuel Producer gas
Thermal eff.
Sp gas consmpn.
Gas consmpn.
Thermal efficiency (%) →
Specific gas consumption (kg / kw - hr) →
Gas consumption (kg / hr.) →
b. m e. p. (kgf / cm2) →
0
5
10
15
20
0.5
1.0
1.5
4
5
6
7
8
9
10
11

FIG 6-4


Constant speed test
RPM 1500
Fuel Gasoline
Thermal eff.
Sp gas consmpn
Gas consmpn.
Thermal efficiency (%)
Specific gas consumption (kg / kw hr.)
Gas consumption (kg / hr)
b. m. e. p. (kgf /cm2)
0
4
8
12
16
20
24
28
32
36
40
44
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
1.0
2.0
3.0

with producer gas operation of the engine. Fig. 6.8 and 6.9 illustrate this variation in exhaust gas temperature at various engine speeds of operation which are higher with producer gas (iv) pressure losses in the gasifier and intake manifold resulting in a loss of upto one percent in power output.

The net result of these losses could be a reduction of upto fifty percent in engine power. This power loss can be compensated either by increasing the compression ratio of the producer gas fueled engine or by supercharging it.

In gasoline operation, an increase in compression ratio beyond a certain value results in a loss of power. This is because of the detonation of the end charge. Producer gas does not detonate that easily and the compression ratio can be increased to higher values in the gas engine than in a petrole engine.

There are two alternatives in the use of a super charger. A mixture of air and producer gas can be sucked by a rotory blower and supplied to the engine under the increased pressure. In this case engine is supercharged while the gas plant works under atmospheric pressure. Alternatively, the blower can supply air both to the engine and to the producer gas plant for generating gas under pressure.

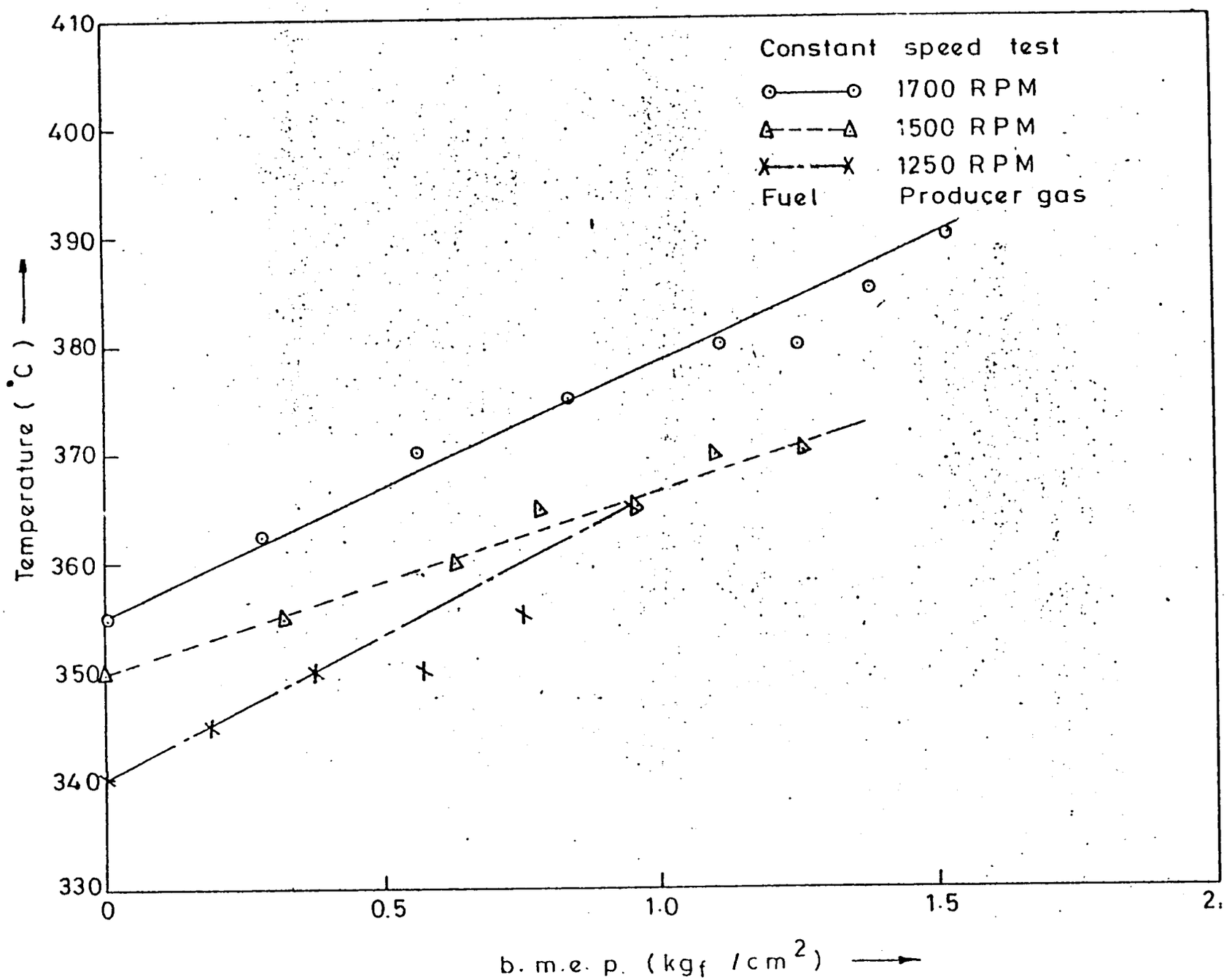

Constant speed test
1700 RPM
1500 RPM
1250 RPM
Fuel Producer gas
Temperature (°C)
410
400
390
380
370
360
350
340
330
0
0.5
1.0
1.5
2.
b. m.e. p. (kgf /cm2)

FIG. 6-8

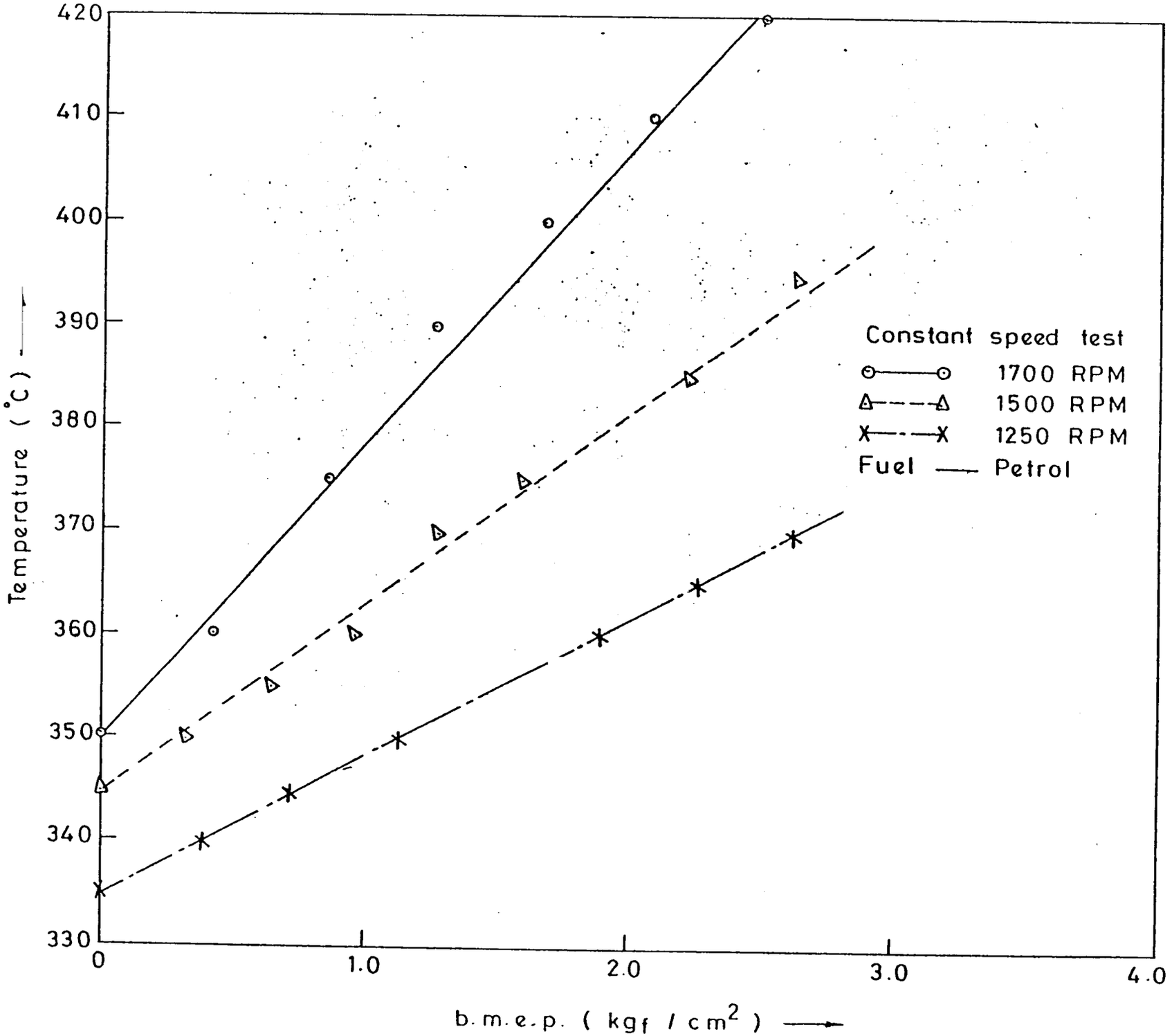

420
410
400
390
380
370
360
350
340
330
Temperature (°C)
0
1.0
2.0
3.0
4.0
b.m.e.p. (kgf / cm2)
Constant speed test
1700 RPM
1500 RPM
1250 RPM
Fuel — Petrol

FIG 6-9

A combination of supercharging and the increase in compression ratio of the engine can so improve the power characteristics of the gas operated engine that it would be possible to use producer gas as a fuel for an S.I. engine without any major modification in the engine.

Some typical exhaust CO and HC emission plots with producer gas and gasoline fuls are shown in figure 6.14, 6.15 and 6.20, 6.21. Use of producer gas results in increased exhaust CO emission but substential reduction of exhaust HC emission. In one of the trial runs it was found that while the maximum exhaust CO increased from 2 to 3 percent maximum exhaust HC emissions came down from 650 ppm to 120 ppm when chaning over from gasoline to producer gas, with the engine continuing to operate at the same speed.

5. CONCLUSIONS:

It has been seen that use of producer gas in existing spark ignition engines results in substantial loss of power.

The thermal efficiency of the engine also decreases with producer gas, but at higher loads it is close to that attainable with gasoline.

The fall in efficiency, particularly at part loads, is seen to be essentially due to slow developing combustion.

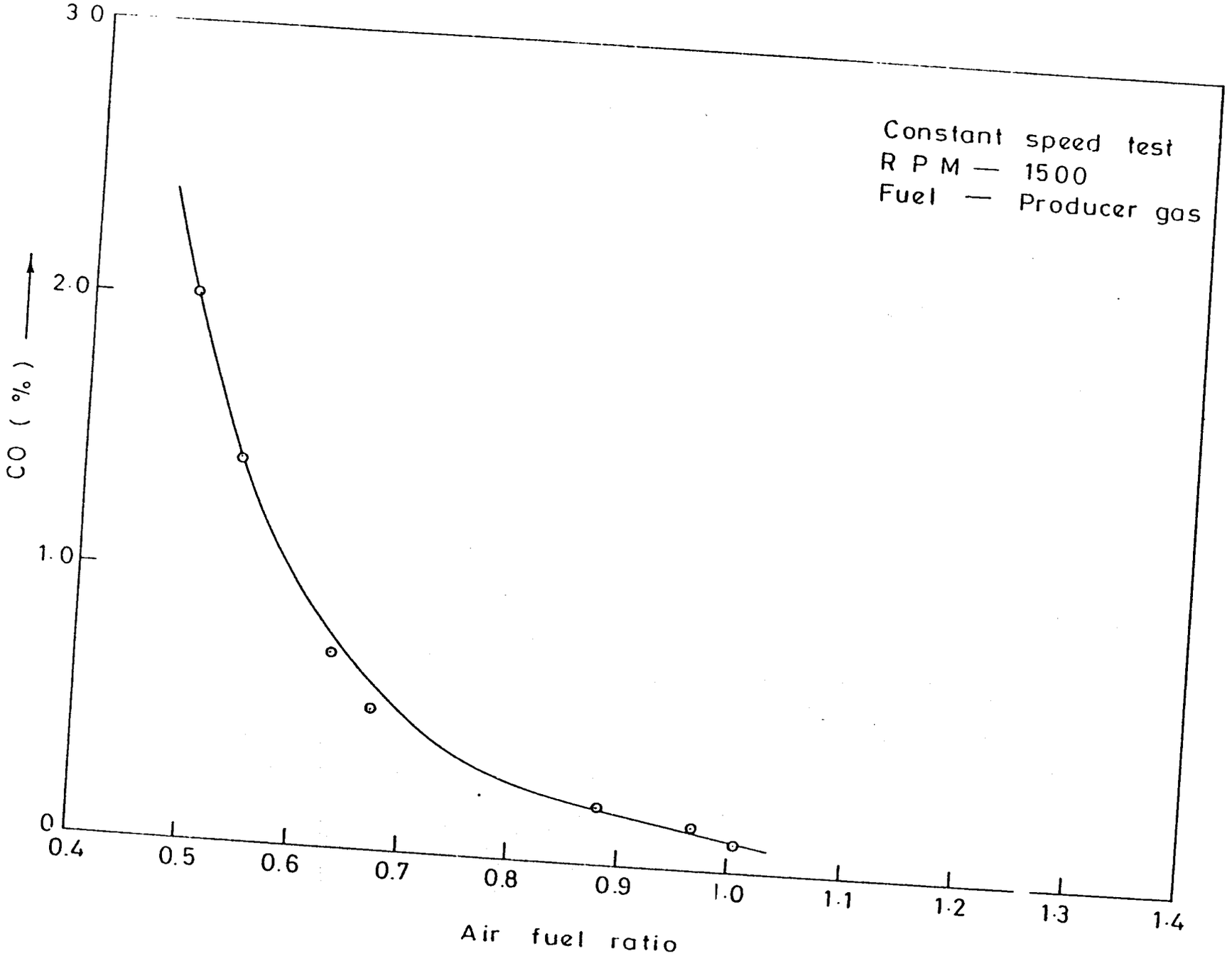
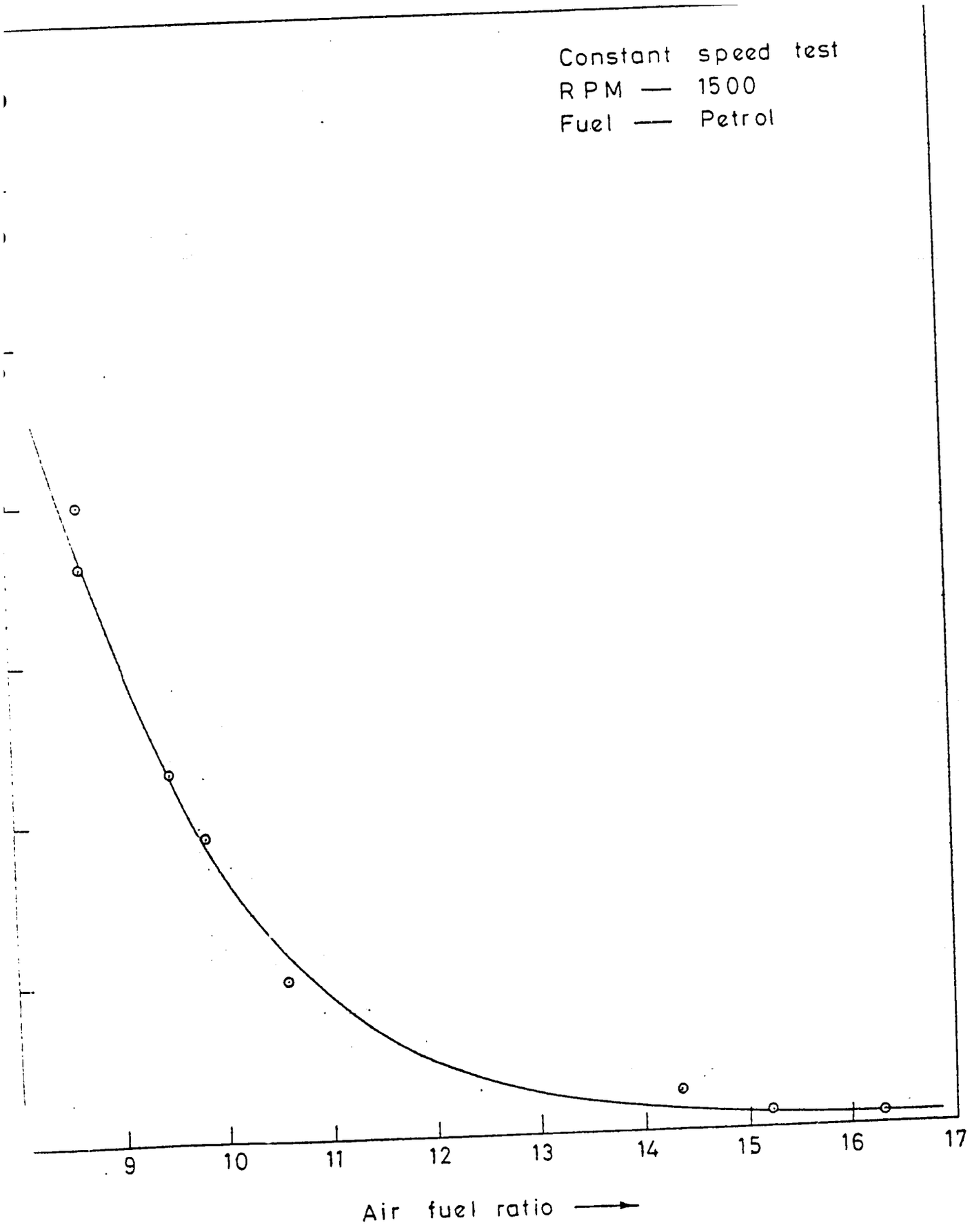

Constant speed test
R P M — 1500
Fuel — Producer gas
CO (%)
3 0
2.0
1.0
0
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
Air fuel ratio

FIG. 6 – 14


Constant speed test
RPM — 1500
Fuel — Petrol
9
10
11
12
13
14
15
16
17
Air fuel ratio

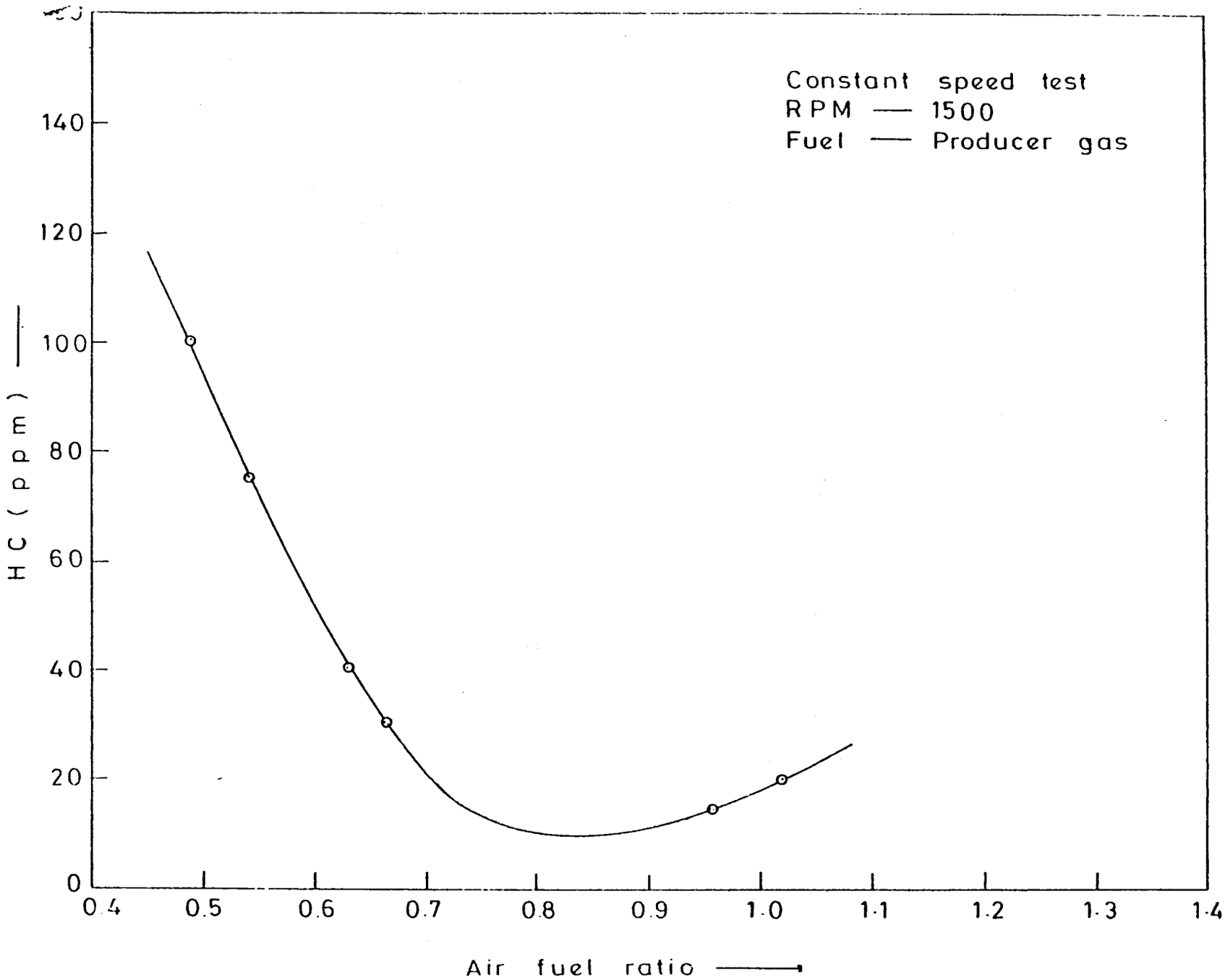

Constant speed test
RPM — 1500
Fuel — Producer gas
HC (ppm) —
0
20
40
60
80
100
120
140
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
Air fuel ratio —

FIG 6-20

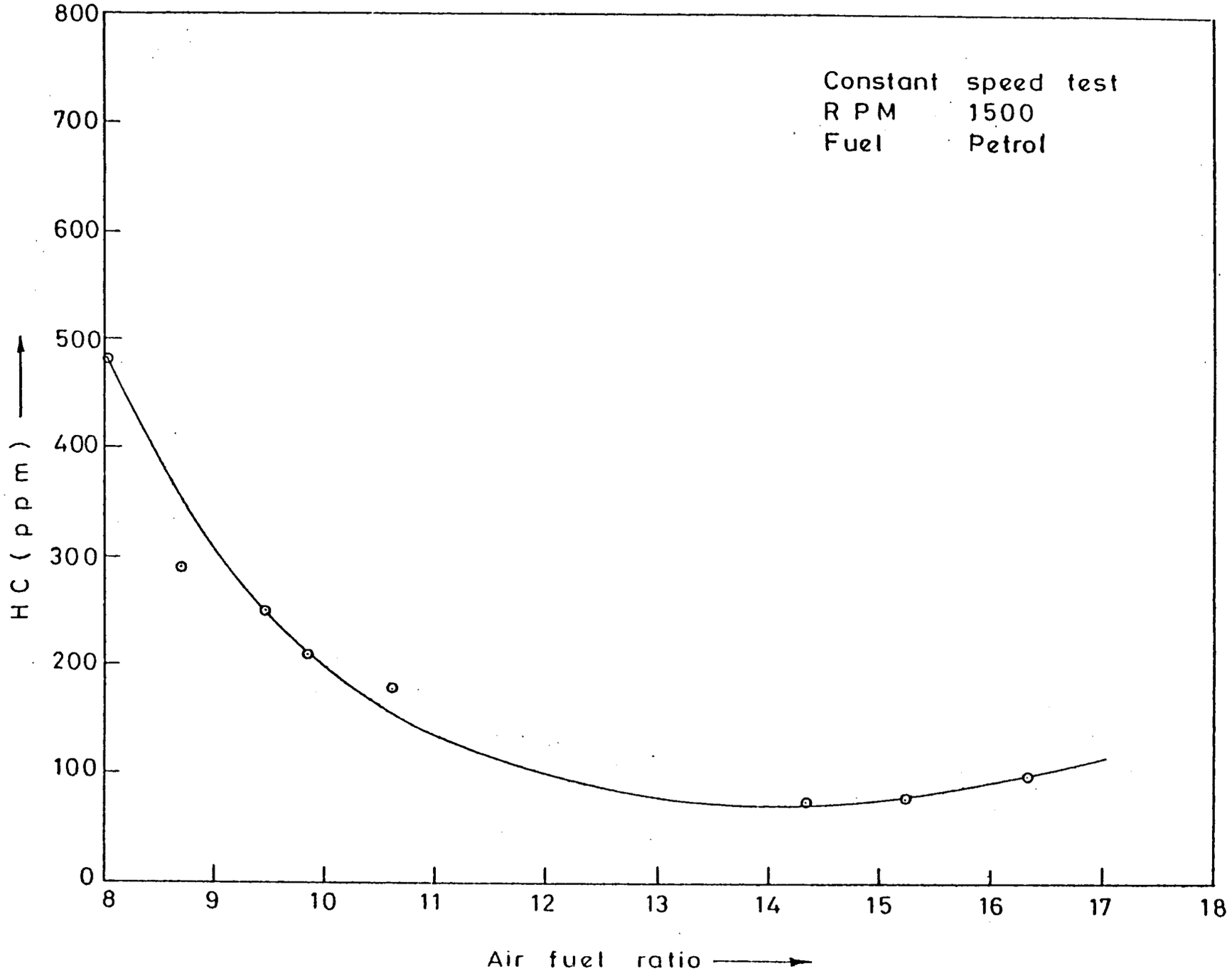

Constant speed test
R P M 1500
Fuel Petrol
HC (p p m)
800
700
600
500
400
300
200
100
0
8
9
10
11
12
13
14
15
16
17
18
Air fuel ratio

FIG. 6-21

Both of these losses can be compensated by either increasing engine compression ratio or by employing intake pressure boosting.

Use of producer gas would result in reduced HC emissions but would require stricter exhaust CO control measures.

Capable of being operated on coal, wood, biomass etc., producer gas engine units offer a promising energy source for meeting the agriculture sector energy needs of the country.

WOOD GASIFIER PROGRAM

SURENDRA KUMAR

JYOTI SOLAR ENERGY INSTITUTE

BIOMASS GASIFICATION

PROJECT SUBMITTED TO
DEPARTMENT OF NONCONVENTIONAL
ENERGY SOURCES
MINISTRY OF ENERGY
GOVERNMENT OF INDIA
NEW DELHI
AND
US AID

PRINCIPAL INVESTIGATOR
DR. SURENDRA KUMAR

OCTOBER, 1983
VALLABH VIDYANAGAR 388 120
GUJARAT - INDIA

JYOTI SOLAR ENERGY INSTITUTE

VALLABH VIDYANAGAR (GUJARAT) 388 120

US AID-DNES BIOMASS GASIFICATION PROJECT

A B S T R A C T

The Project will cover work on research & development of reliable wood-based gasifier coupled with internal combustion engine for field implementation. It will be carried out at Jyoti Solar Energy Institute (JSEI) Vallabh Vidyanagar, India, which has earned good reputation in this area. The Project Team is a dedicated one and includes two French gasifier engineers. JSEI has considerable experience in gasifier work and has developed a 5 HP gasifier which saves 70-80% diesel in diesel engines.

The Project work has been divided into three phases of one-year duration each (total three years). Gasifier modifications (to increase reliability) and field trials will be carried out in Phase I. Monitoring of field trial unit and relevant R & D work will form Phase II. Phase III will include finalisation of R & D work and conclusion of field trials. An operations manual for the system will also be prepared for the users.

The financial inputs envisaged for the Project are $ 2,05,000 from US AID and Rs.8,89,000 from DNES, Government of India, spread over three years. These will cover salaries of US consultants and the Indian personnel, equipment, spares, materials, travel costs of US consultants and Indian scientists and engineers, contingencies and inflation. Equipment costs will cover R & D instruments and gasifier hardware for field implementation.

The utilisation of the results of the R & D work will be made for providing and building technical infrastructure in rural areas, developing entrepreneurial activities among rural masses, dissemination of rural technology for wide applications including those in other developing countries.

The benefits of the project include substitution of biomass for petroleum-derived fuels, self-sustaining energy cycle in rural areas, availability of energy in rural areas, reduction in dependence on conventional fuels and providing reliable means for irrigation as required for improved cultivation thus enhancing food production.

JYOTI SOLAR ENERGY INSTITUTE

BIOMASS GASIFICATION

WOOD : AN ALTERNATE FUEL TO DIESEL

Through gasification technology, wood is converted into a combustible gas which can burn in a diesel engine, replacing most of the diesel.

On the sponsorship of Ford Foundation, and with the contribution of two French engineers deputed by the French Embassy, Jyoti Solar Energy Institute has developed a 5 HP pumpset running on 70 to 80% wood gas and 20 to 30% diesel.

DESCRIPTION OF A GASIFIER - PUMPSET

The system consists of three elements : a gasifier (or Gas Generator), a filter and an ordinary 5 HP diesel engine pumpset. Overall dimensions are, for the frame, length 1.60 m, width 0.65 m, and height 1.50 m.

The Gasifier is a furnace which allows partial combustion of wood : Instead of carbon dioxide, mainly carbon monoxide is formed, alongwith hydrogen, due to a limited supply of air and high temperature. Therefore, 60 to 65% of the energy present in wood is available in the combustible gas produced.

The wood gas is then cooled and cleaned in a filter : first through a scrubber, a bed of coke washed with water, and through a cotton wastes layer.

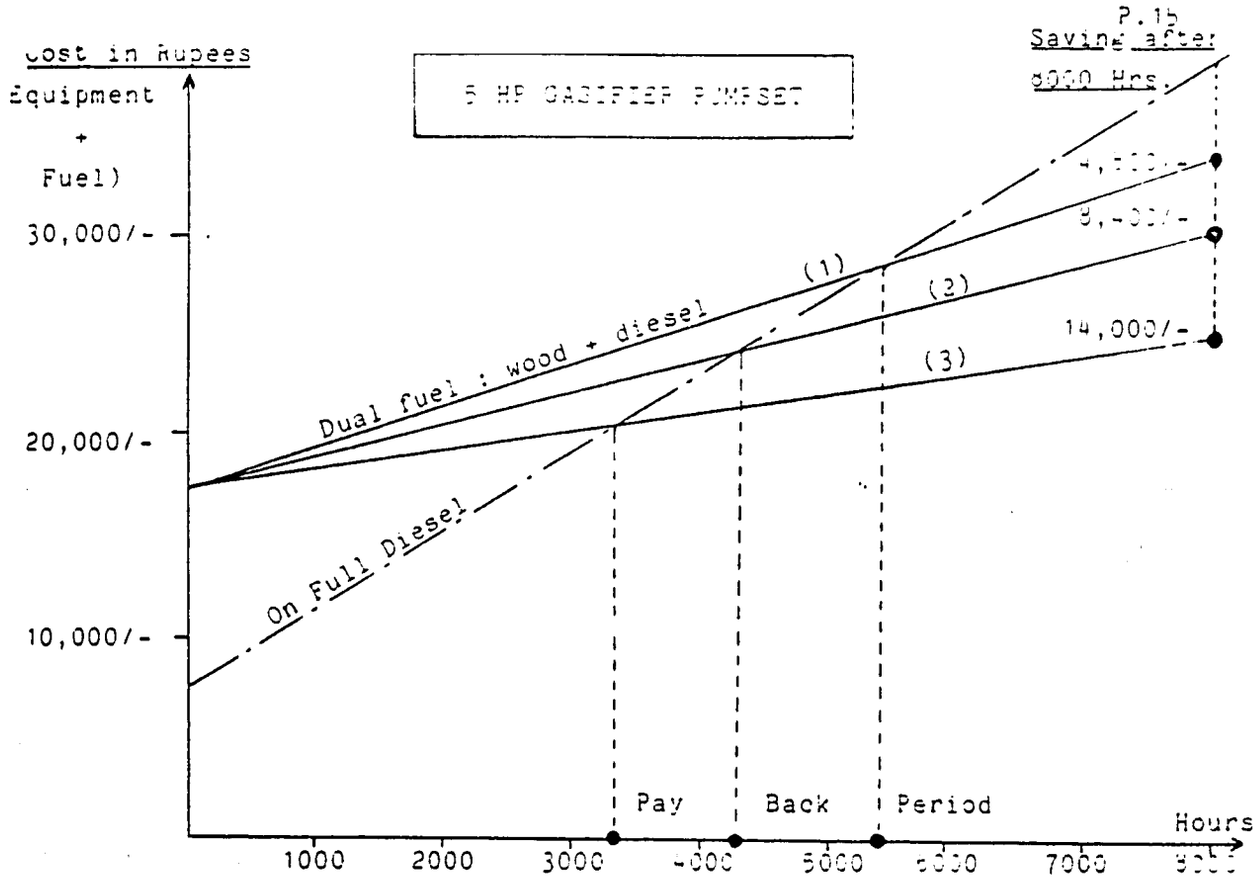
To feed the engine, gas is mixed with air and enters the inlet manifold with no further modification of the diesel engine. The governor by itself reduces the diesel injection down to 20% (according to the gas contribution) with no derating in power.

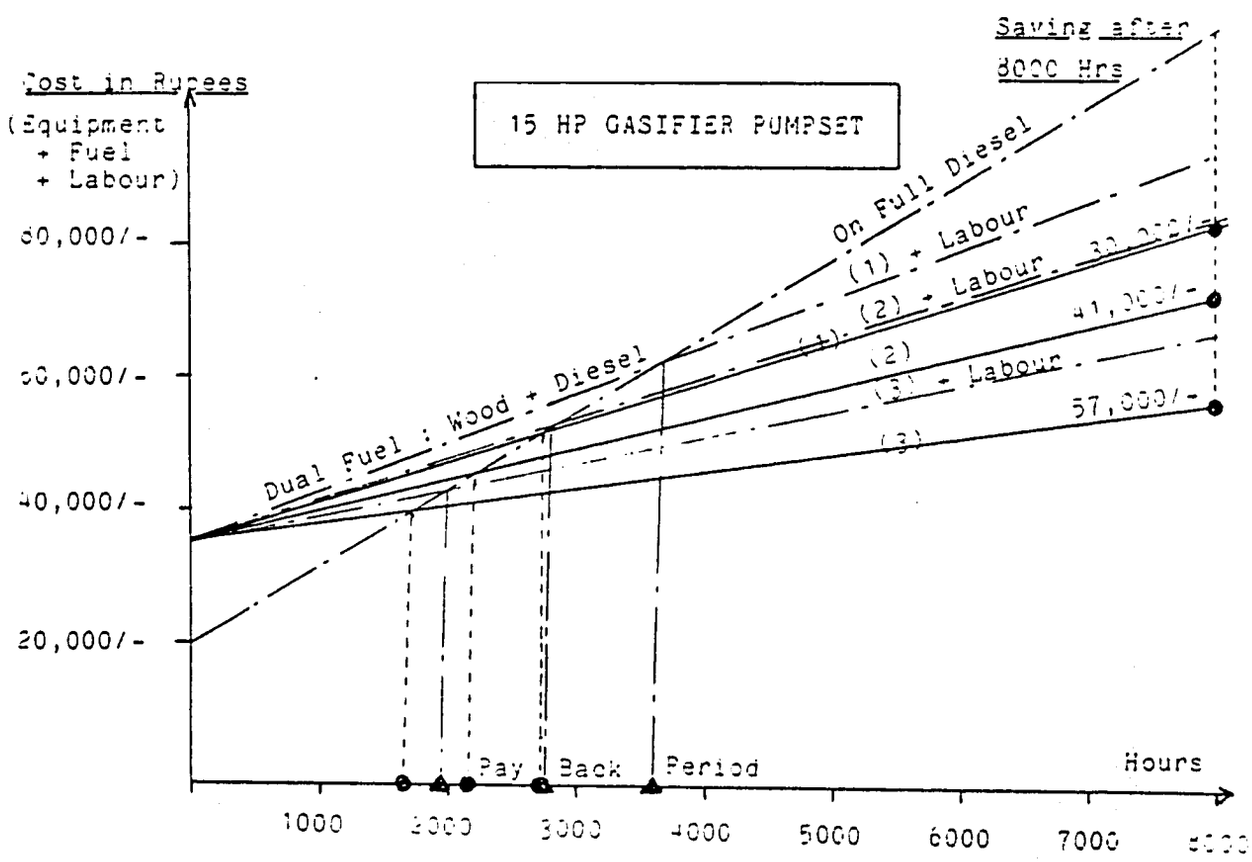
DIESEL FUEL SAVING

Running on wood gas, a 5 HP diesel pumpset consumes about 0.3 litre diesel and 3.5 kg wood per hour, thus saving 0.8 litre/hour diesel

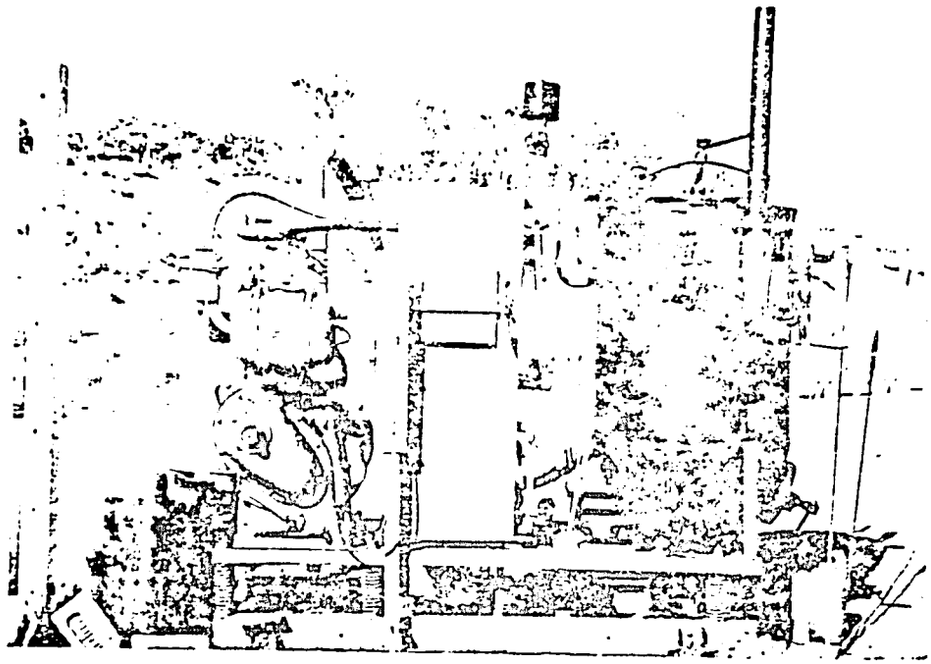
FURTHER INFORMATION

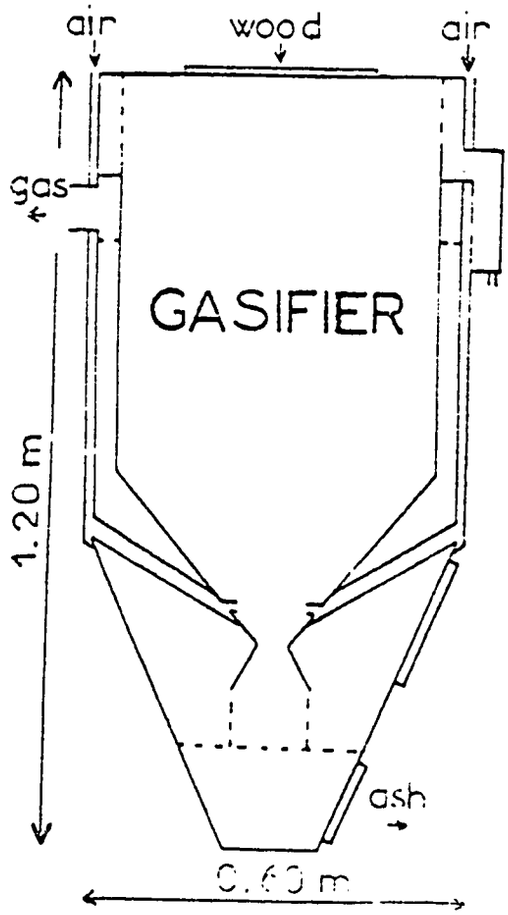
A wood-based gasifier with a 5 HP pumpset is installed for demonstration at Jyoti Solar Energy Institute. Any further nformation and technical data can be provided on visit or on

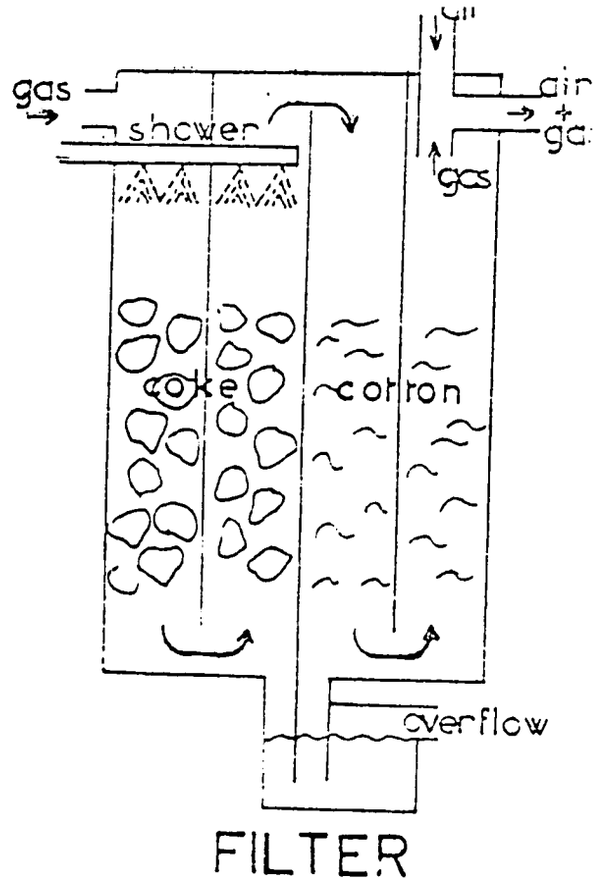

5 HP GASIFIER PUMPSET
Cost in Rupees
Equipment
+
Fuel)
30,000/-
20,000/-
10,000/-
Saving after
8000 Hrs.
14,000/-
(1)
(2)
(3)
Dual fuel : wood + diesel
On Full Diesel
Pay
Back
Period
Hours
1000
2000
3000
4000
5000
6000
7000
8000


15 HP GASIFIER PUMPSET
Cost in Rupees
(Equipment
+ Fuel
+ Labour)
60,000/-
50,000/-
40,000/-
20,000/-
Saving after
8000 Hrs
On Full Diesel
(1) + Labour
(2) + Labour
(3) + Labour
(1)
(2)
(3)
41,000/-
57,000/-
Dual Fuel : Wood + Diesel
Pay
Back
Period
Hours
1000
2000
3000
4000
5000
6000
7000
8000

5 Hp Wood-based Gasifier Pumpset







DETAILED WORK PLAN FOR PROPOSED PROJECT
FOR SUPPORT UNDER U.S. AID GRANT PROJECT
ALTERNATIVE ENERGY RESOURCES DEVELOPMENT

(386 - 0474)

PART-I. GENERAL INFORMATION

1. Title of Project : Research and Development of Reliable Wood-Based Gasifier Coupled with Internal Combustion Engines for Field Implementation (Field unit will be located at Karamsad, Taluka Anand, District Kheda, Gujarat).

2. Subject Area : Biomass Conversion.

3. Sponsoring Institution Agency and Ministry/ Department Administratively concerned with it. : Jyoti Solar Energy Institute (BVM Engineering College) Vallabh Vidyanagar (Gujarat) Pin:388 120 INDIA.

[A brief note about the Jyoti Solar Energy Institute (JSEI) is attached herewith at Enclosure-A].

PART-II. INVESTIGATORS - THEIR QUALIFICATIONS & EXPERIENCE

4. Name & Designations of Principal & Other Investigators :

- Dr.Surendra Kumar
  Principal Investigator
  Deputy Director
  Jyoti Solar Energy Institute
  Vallabh Vidyanagar.
- Dr.M.A. Date
  Principal
  BVM Engineering College
  Vallabh Vidyanagar.
- Dr.B.C. Jain
  Technical Advisor.
- Mr.M. Farcy
  Visiting Scientist.
- Mr.V. Butin
  Visiting Scientist.
- Dr.F. Vyarawalla
  Consultant.
- R.N. Pandya
  Senior Mechanical Engineer.

(Details about their qualifications, research experience and publications related to the above project are attached at Enclosure-B).

5. Projects already in hand with investigators : Design and Development of a 25 kW Biomass Gasifier.

PART-III. PROJECT DESCRIPTION

6. Objective : Research and Development of Reliable Wood-Based Gasifiers Coupled with Internal Combustion Engines for Field Implementation

This objective has been sub-divided into the following areas :

a) To develop reliable wood-based gasifier and gas clean-up system suitable to fuel internal combustion engines.

b) To conduct field trials for demonstrating its applications in the rural areas.

c) To collect and analyse relevant field operating data for facilitating wider rural implementation in the size range of 5 HP to 30 HP.

d) To carry out relevant R&D work in support of the proposed demonstration activity.

e) To exchange scientific and technical information in the above areas.

7. Summary Description of Project : When combustion of organic matter like coal, wood or agricultural residues is carried out in a limited supply of oxygen, combustible gaseous products like carbon-monoxide and hydrogen are produced which can be used to replace diesel in operating an engine. Some modifications are required to run existing engines on such a gas (producer gas).

The gasifier unit will consist of four elements - A gasifier, a filter box, an air-gas mixer and an ordinary engine-pump set. Specific features of our design will be as follows :

a) Use of stainless steel (SS 310, SS 312, SS 316) for nozzles and combustion cone.

b) Condensation of moisture inside the hopper.

c) Use of 5 or 6 nozzles for even distribution of high temperature in the combustion zone.

d) Use of loose grates to allow free flow of ashes,

e) Use of outside layer of charcoal for heat insulation and completion of reduction.

f) Use of vibrations from the engine to shake the gasifier to help movement of wood in the gasifier.

All the above modifications will be tried out in the field implementation. Gasifier will be installed at Karamsad - a village near the Institute in Gujarat. Extensive field trials will be carried out and a field operations, maintenance and safety manual will be prepared.

8(a) Detailed Description (Work Plan)

Methodology : With the said objectives in view, the program is proposed to be divided into undermentioned stages. These stages may or may not bear a separate temporal identity in which case the division would just underscore the tasks to be carried out -

a) Perfecting the design of a reliable 5 HP gasifier.

b) Modifications of a 5 HP engine to run on the gas produced by the 5 HP gasifier.

c) Trials and laboratory demonstration of the 5 HP gasifier and internal combustion engine system.

d) Field demonstration of the 5 HP system

e) Field implementation of the 5 HP system

f) Development of 100% producer gas engine

Organisation of Work Elements : The program will be carried out in the following three phases of one year duration each -

PHASE 1 : Gasifier Development and Work Pertaining to Field Trials.

PHASE 2 : Monitoring of Field Trial Unit and Relevant R&D Work.

PHASE 3 : Finalization of R&D Work and Concluding Field Trials.

Time Schedule of Activities Giving Milestones : The time schedule of phases, tasks, and activities alongwith the milestones achieved will be as follows -

(A bar diagram is appended at Enclosure-C).

PHASE-1 : GASIFIER DEVELOPMENT AND WORK PERTAINING TO FIELD TRIALS

Task 1.1 : Develop site selection criteria for installation of field trial units

Activities

1.1.1 : Proximity to the Institute (Jyoti Solar Energy Institute)

1.1.2 : Willingness of the people to record the tests

1.1.3 : Availability/need for irrigation

1.1.4 : Geographic reasons

1.1.5 : Availability of trained people

1.1.6 : Availability of existing irrigation pumps

Task 1.2 : Fabrication, assembly and initial testing of field trial units

Activities

1.2.1 Assemble the system

1.2.2 : Initial start-up

1.2.3 : Short term tests

1.2.4 : Site preparation

1.2.5 : Preliminary operator training

Task 1.3 : Initial start-up operations

Actitivies

1.3.1 : Start-Up

1.3.2 : Short-term test

1.3.3 : Long-term test

1.3.4 : Operating the system under field conditions

1.3.5 : Determine load-following capability

1.3.6 : Record local fluctuations in load in the field

1.3.7 : Look for waste water management system

1.3.8 : Determine performance

<u>Task 1.4</u> : Undertake safety measures

<u>Activities</u>

1.4.1 : Identify required safety measures

1.4.2 : Notify and prescribe safety measures

1.4.3 : Prepare safety procedure manual

<u>Task 1.5</u> : Evolve field trial procedures

<u>Activities</u>

1.5.1 : Develop fuel specifications

1.5.2 : Develop test methods for periodic check-up

1.5.3 : Determine operating duration consistent with site requirements and equipment capability

1.5.4 : Identify type of data to be collected and recording procedures for R&D feedback

<u>Task 1.6</u> : Detailed study of the effect of various parameters on gas composition and tar content

<u>Activities</u>

1.6.1 : Study effect of air flowrate

1.6.2 : Determine effect of moisture content

1.6.3 : Identify the type of feed

1.6.4 : Analyse size of feed

1.6.5 : Investigate cleaning and cooling of gas

Task 1.7 : Identification of temperature zones

Activities

1.7.1 : Determine oxidation zone

1.7.2 : Find out reduction zone

1.7.3 : Locate pyrolysis zone

Task 1.8 : Spark ignition engines coupled with gasifiers

Activities

1.8.1 : Study spark ignition engines coupled with gasifiers

1.8.2 : Interact with development of engine project carried out at the IIT, Delhi

PHASE-2 : MONITORING OF FIELD TRIAL UNIT AND RELEVANT R&D WORK

Task 2.1 : Continued monitoring of the field trial unit and personnel training

Activities

2.1.1 : Collect data

2.1.2 : Train local personnel

2.1.3 : Develop operating and maintenance schedule

2.1.4 : Prepare training manual

2.1.5 : Analyse data

Task 2.2 : Determine methods of cleaning the gas

Activities

2.2.1 : Investigate wet method of cleaning the gas

2.2.2 : Try out dry method of cleaning the gas

Task 2.3 : Measurement of air in-flowrate and gas out-flowrate

Activities

2.3.1 Measure air in-flowrate

2.3.2 : Measure gas out-flowrate

Task 2.4 : Study fuel combustion characteristics

Activities

2.4.1 : Determine flash point and ignition point from literature

2.4.2 : Study self-ignition on compression in various percentage mixtures of producer gas and diesel

Task 2.5 : Testing of other engines

Activities

2.5.1 : Test petrol engine

2.5.2 : Test engine on kerosene

Task 2.6 : Develop designs of other gasifiers

Activities

2.6.1 : Couple gasifier and engine to an electric generator

2.6.2 : Scale upto larger sizes of 5 HP to 30 HP

Task 2.7 : Carry out further field trials at other sites

Activities

2.7.1 : Select other sites

2.7.2 : Install gasifiers at four other selected sites

2.7.3 : Test new design variations

Task 2.8 : Catalysis of pyrolysis

Activities

2.8.1 : Try out various substances such as finely divided nickel, copper, etc. as catalysts.

PHASE-3 : FINALISATION OF R&D WORK AND CONCLUDING FIELD TRIALS

Task 3.1 : Material handling and fuel preparation problems

Activities

3.1.1 : Study material handling problems

3.1.2 : Evolve material handling procedure

3.1.3 : Identify fuel preparation needs, if any

Task 3.2 : Effects of vibrations on grate design and ash disengagement

Activities

3.2.1 : Study effects of vibrations on grate design

3.2.2 : Determine effects of vibrations on ash disengagement

Task 3.3 : Heat losses from gasifier by radiation

Activities

3.3.1 : Study heat losses by radiation from the gasifier

Task 3.4 : Continuous operation of field gasifier units

Activities

3.4.1 : Study the operation of gasifier on pelletised biomass

3.4.2 : Study the operation of gasifier on powdery biomass

Task 3.5 : Effects of different feed sizes

Activities

3.5.1 : Study the effects of different feed sizes on gasifier operations

Task 3.6 : Continued monitoring at the sites

Activities

3.6.1 : Testing of large size gasifiers

3.6.2 : Continue R&D activity

Task 3.7 : Rural electricity generation with gasifiers

Activities

3.7.1 : Trials on rural electricity generation with gasifier

3.7.2 : Increase reliability of the system

Task 3.8 : Preparation of field implementation manual and Project Report

Activities

3.8.1 : Documentation of experiences and results obtained from field trials

3.8.2 : Preparation of field operations and maintenance manual

3.8.3 : Preparation of final Project Report

8(b) Nature and Extent of U.S. Collaboration/Assistance

i) Name of the U.S. Collaborating Institution : USAID

ii) Names of U.S. Co-investigators : Not applicable

9. Duration of Project : Three years

i) Date of Commencement: The date on which funds will be received

ii) Date of Completion : Within three years of the date of commencement

10. Budget (Details attached vide Enclosure D, E, F, G, H & I)

Sr. No.	DESCRIPTION	U.S. BUDGET IN DOLLARS U.S. DOLLAR COSTS				LOCAL COSTS	INDIAN BUDGET IN RUPEES			
		First Year	Second Year	Third Year	Total		First Year	Second Year	Third Year	Total Rs.
1.	Staff salaries/U.S. Consultants Fees	25,000	20,000	20,000	65,000		1,40,000	1,53,000	1,71,000	4,64,000
2.	Equipment	40,000	30,000	-	70,000		1,75,000	1,25,000	-	3,00,000
3.	Spares/Materials,etc.	-	-	-	-		20,000	15,000	15,000	50,000
4.	Study tours/visits, etc. to and from USA by Investigators,etc.	13,000	10,000	7,000	30,000		-	-	-	-
5.	Local travel including U.S. Consultants	-	-	-	-		16,000	12,000	12,000	40,000
6.	Contingencies	5,000	5,000	5,000	15,000		15,000	10,000	10,000	35,000
7.	Inflation (15%)	11,000	10,000	5,000	26,000		-	-	-	-
	T O T A L :-	94,000	75,000	37,000	2,06,000		3,66,000	3,15,000	2,08,000	8,89,000

	U.S. BUDGET IN $	LOCAL COSTS	INDIAN BUDGET (Rs.)
FIRST YEAR	94,000	Nil	3,66,000
SECOND YEAR	75,000	Nil	3,15,000
THIRD YEAR	37,000	Nil	2,08,000
GRAND TOTAL :	$ 2,06,000	Nil	Rs. 8,89,000

PART-IV SOCIO-ECONOMIC INFORMATION

11. How project is connected with rural develoment in social and cultural context, etc.

An alternative method of utilisation of biomass is its gasification to produce a combustible gas (producer gas) which can be used for running an internal combustion engine which can be coupled to an irrigation pump or to an electric power generator system or can be used for providing motive power to any mechanical device.

Biomass gasifiers are appropriate in all senses of the word: Technology required for their fabrication, operation and maintenance is the appropriate technology; they are relatively less expensive; they are efficient in small sizes; they can utilize a variety of biomass and other resources.

The efficiences of biomass gasifier systems compare well with other means of utilising biomass. On the basis of these efficiencies and estimated calorific value of feed material at approximately 3500 kcal/kg. about 1.3 kg of biomass input will be necessary to produce one kwh (1 unit) of energy.

It is sometimes argued that any scheme for utilising local resources is bound not to succeed as these resources are not waste in literal sense, they being put to some use in a system. For example, rice straw, though generally considered as waste, is used for thatching of roofs and for stocking boilers in Punjab. Use of rice straw in biomass gasifiers would, therefore, make it unavailable for thatching, for which no immediate substitute is locally available. However, in Gujarat it is available in Kheda District where experiments would be conducted. Further, it has been shown that the extra agricultural waste production as a result of the increased yield due to irrigation and by adoption of other modern practices made possible by availability of more power would alone be sufficient to meet the requirements of fgasifiers. In addition, if gasifier program is coupled with social forestry, the requirements of feed for biomass gasifiers could be met from additional firewood that would be available.

Development and demonstration of viability of gasifiers compatible with the properties of available resources and with the requirements of the area under consideration thus becomes very desirable. Jyoti Solar Energy Institute with its experience and committment to the task proposes to make a beginning in this direction by launching a development and demonstration project for biomass gasifiers and internal combustion engine systems

for use in Indian villages. It is believed that such a system could go a long way in overcoming the constraint of availability of energy in development of these villages.

12. Cost/Benefit Ratio (to be given to the extent feasible)

From the experience gained and data collected so far, the expected diesel replacement by producer gas would be to the tune of 80%. 3.5 kg of wood will thus replace 1 litre of diesel on full load of engine. 1.3 kg. of wood will produce about 1 kwh (1 unit) of energy. Gasification efficiency will be about 70%. Assuming that a diesel engine consumes 220 ml/HP hour and considering the price of diesel as Rs.3.20 per litre, and considering the following three prices of wood for comparison :

(A) Rs. 0.50 per kg.

(B) Rs. 0.25 per kg.

(C) "Zero Cost"

	Diesel Only Rs.	A Rs.	B Rs.	C Rs.
Diesel cost/HP hour	0.70	0.20	0.20	0.20
Alternate fuel cost/ HP hour	-	0.25	0.15	-
Total fuel cost/ HP hour	0.70	0.45	0.35	0.20
Saving / HP hour	-	0.25	0.35	0.50

For a 5 HP Pump Set Running 1500 hours/year :

	Diesel Only Rs.	A Rs.	B Rs.	C Rs.
Fuel cost per year	5250	3375	2625	1500
Saving per year	-	1875	2625	3750
Payback period if cost of gasifier is Rs.8,000/-	-	4.5 yrs.	3 yrs.	2.3 yrs.

The payback period of a gasifier would be about 3 to 5 years and its life could be reasonably expected to be about 10 years (although it has not been tested for such a duration so far).

If bigger units of 10 to 30 HP are considered then the fuel saving will be 2 to 6 times that of a 5 HP unit. But the capital cost will increase only marginally. Thus, for larger units the payback period may be 1 to 2 years only which may even allow for the wages of an operator.

However, the above consideration do not take into account the savings accrued in foreign exchange due to the resulting lesser consumption of petroleum products which are imported in large quantities, as well as the utilisation of rural resources and creation of new employment opportunities due to absorption of appropriate technology.

13. Potential for Providing Near or Medium Term Benefits to the Rural Population

The proposed project is almost in the take-off stage. The gasifier technology is the appropriate technology for our rural areas. The project implementation will result in the following near and medium term outputs/ benefits to the rural population :

(a) Substitution of biomass for petroleum derived fuels in the rural sector

(b) Self-sustaining energy cycle in the rural areas

(c) Availability of energy for the growth of rural industry

(d) Reduction in dependence on conventional fuels

(e) Providing reliable means for irrigation as required for improved cultivation thus enhancing food production

14. Utilisation of Research Results and Suggested Plan of Action

The research results will be utilized in the following areas in a phased manner :

(a) Providing and building technical infrastructure including training of personnel to promote small scale gasifier technology in the rural areas.

(b) Developing enterpreneurial activities by creating confidence in the use of gasifier technology

(c) Wide dissemination of gasifier design, operating, maintenance and safety precedures to prospective enterpreneurs and users

(d) Availability of micro-level gasifier technology for its wide application in developing countries

(e) Availability of design and operating data on micro-level gasifier technology for the use in the USA and other developed countries

The suggested plan of action and implementation would be to make available gasifiers off-the-shelf at the Institute to the progressive farmers and other interested organisations at the cost price. The Institute also undertakes the responsibility to train local industries to manufacture such gasifiers for large-scale use. In fact, the Institute has already received a large number of such requests from small farmers to giant Government Organizations like the Steel Authority of India about the gasifier technology. There is a bright future and great scope for this technology provided a proper and reliable gasifier is developed and made available.

Certified that :

(a) This Institute/Organization will provide the basic facilities and other administrative support for undertaking the proposed project to the Investigators.

(b) An Internal Monitoring Committee will be constituted for implementation of the Project as also for its long-term development.

SKumar

Prof.SURENDRA KUMAR
Signature of Principal Investigator

28th October, 1983

Prof.M.A. DATE
Principal BVM Engineering College and Honoraty Director, JSEI.

Signature of Head of Institute/Organization

28th October, 1983

..... Enclosure 'A'

Enclosure 'A'
(Refer to Para 3)

JYOTI SOLAR ENERGY INSTITUTE (JSEI)
VALLABH VIDYANAGAR, (GUJARAT) 388 120
INDIA

HISTORY

With the increasing population and a rise in peoples' standard of living, the conventional energy sources are rapidly being used up. A day may come in the near future when all the reserved conventional fuel may not be there to make our life comfortable. Even now one can at times feel the scarcity of wood and coal.

Jyoti Solar Energy Institute (JSEI) established in 1979 by a reputed educational trust (the Charutar Vidya Mandal) has as its basic aim, the promotion of use of non-conventional sources of energy. JSEI, started with a munificent grant of Rs five lacs from Jyoti Limited, Baroda, was inaugurated by Honorable Shri H.M. Patel, the then Union Minister of Home, Government of India.

The Institute is located at Vallabh Vidyanagar near Anand in Kheda District of Gujarat at the latitude of 22° North and the longitute of 73° East, a good location for Solar energy work from the geographical point of view.

Since its inception, JSEI has been extensively engaged in research and development of new and renewable sources of energy such as Solar, biogas, biomass gasification and wind. The projects of JSEI have been funded by organizations like Department of Science and Technology, Department of Non-conventional Energy Sources and Commission for Additional Sources of Energy, Government of India, Gujarat Energy Development Agency, Baroda, Commissioner for Industries, Government of Gujarat, Ford Foundation, New Delhi, Jyoti Limited, Baroda, etc.

RESEARCH PROJECTS

A brief account of various research and development projects of the Institute is given below :

1. Hot Air Drying of Agricultural Produces and Casein

   Processing of different agricultural produces using various Solar driers was studied. As about 40% of casein produced in Gujarat is from Kheda District, utilization of Solar drier for this purpose was also studied.

2. Solar Thermal Power Generation System

The Institute is working on a project to generate 5 kW of power for irrigation and other needs of remote rural areas. The project funded by the Department of Non-conventional Energy Sources, Government of India, New Delhi, is being put up near the Institute campus.

3. Solar Cooker Monitoring Programme

JSEI, through its 18 service personnel, monitors, the Solar cookers marketed by the Gujarat Energy Development Agency in Gujarat State. Gujarat State has half the total number of Solar cookers in use in the whole country.

4. Solar Cooling System

The Institute is working on the project "Solar Cooling Through Cycles Using Microporous Solid Absorbents". A refrigerator working on zeolite - water cycle is being fabricated.

5. Solar Tracking System

An automatic tracking system is being developed and this system is to be attached with a paraboloidal concentrator.

6. Biogas Generation

The Institute has carried out substantial amount of pioneering work on biogas production through anaerobic fermentation of agricultural wastes like banana stem, chido (Cyperus rotundus; Linn), dharo (Dynodon dactylon; Linn), tandaljo (Amaranthus virdis; Hook), kuwadio (Cassia tora; Linn), congress grass (Parthenium), eucalyptus leaves, kutch grass, rice straw and wheat straw, industrial wastes like sugarcane bagasse, aquatic wastes like water hyacinth (Eichhornia crassipes) and animal wastes like cattle dung, chicken droppings. Bench scale and pilot plant models were constructed for various wastes and methane generation was studied in the mesophilic as well as thermophilic range of temperatures. Field trials of biogas plants are being conducted now and a 10 cubic meter plant working on banana stem as feed material is being set up in the Institute.

7. Biomass Gasification

The work on biomass gasification was started at the Institute in January 1982 with financial assistance

from Ford Foundation, New Delhi. The French Government deputed two of their engineers to carry out work in the area of small-size gasifiers. As a result of extensive work in this field, gasifiers of 3.5 kW are being developed. The wood-based gasifiers are coupled to conventional diesel engines and are used for water pumping. The gasifiers being developed here are found to replace about 80% of diesel consumption in diesel engines used for the purpose of irrigation.

8. Basic Research

JSEI is doing basic research in the areas like Solar water heating, air heating, desalination of water, Solar sterilisation of water, design of wind mills, cooking, applications of Solar cells, drying of agricultural and industrial products, etc.

PROJECTS COMPLETED

1. Study of Parameters for Optimum Selective Coating Properties for Black Nickel and Black Chrome Surface.

2. Monitoring of Experimental-cum-Demonstration Solar Hot Water System in a Textile Mill

3. Study of Parameters for Optimum Generation of Methane from Plant and Animal Wastes

4. Biogas Production from Kutch Grass

5. Air Pollution and Rural Biomass Consumption in Developing Countries

6. Pilot Study of Fuel Consumption in Chulahs and Occupational Hazards

LABORATORY AND TEST FACILITIES

The Institute has the following facilities :

1. Meteorological Station : For collecting daily insolation and other data

2. Solar Thermal : Hot water system with flat plate collectors as well as concentrating collectors, Winston collectors, Solar green house, Solar grain dryers, hot air system, cookers of oven and paraboloid type, water still, Solar sterilizer, testing facilities according to National Bureau of Standards, Solar cell based pesticide sprayers, etc.

3. Wind Energy : Wind tunnels (suction type and blower type) for testing models of different shapes of wind generation, horizontal and vertical axis wind mills.

4. Electrodeposition : For use of selective coating of different surfaces

5. Bio-conversion : For investigations in the area of biogas production using animal, agricultural and aquatic wastes

6. Gasification : Down draft gasifiers, dual-fuel type engines with pump set

EXTENSION WORK

The Institute has successfully erected an experimental-cum-demonstration Solar hot water system in a textile mill at Ahmedabad from a grant made available by Department of Industries, Government of Gujarat. The system was monitored for a period of two years and is found to be working satisfactorily.

Similarly, Department of Non-conventional Energy Sources, Government of India, has given the Institute funds to install an experimental-cum-demonstration Solar hot water system of capacity 6000 litres and Solar desalination system of capacity 250 litres per day for a modern hospital. The Institute has provided such a system at Charutar Arogya Mandal Hospital at Karamsad.

The Institute is studying the percentages of energy and fertilizer requirements for a banana plantation and recovery of energy and fertilizer from banana stem through biogas plant. This is studied at a farm under a project of Agricultural Wastes-to-Biogas Plant-to-Fuel and Fertilizer for Agricultural Cycle funded by Jyoti Limited, Baroda.

EDUCATIONAL ACTIVITIES

JSEI is attached to the reputed and recognised BVM Engineering College, S.P. University, Vallabh Vidyanagar. It is a unique Institute in the country which is exclusively devoted to research, development and teaching in the area of non-conventional energy sources. A two-semester elective course on the Alternative Sources of Energy was introduced at the final year B.E. level from the academic year 1979-80. The Institute also conducts a two-semester Post-Graduate Diploma Course on Solar Energy Systems. In order to bring multi-disciplinary approach to the course, the admission requirements have been laid down in such a manner that any Post-Graduate in Science with Physics, Chemistry or Biology or any Agricultural Engineering or any other Engineering Graduate is eligible for admission. The Institute is also starting a three-semester Post-Graduate Degree Course in Solar Energy Systems.

PLAN FOR FUTURE WORK

It is proposed to take up the following additional work on:

1. Installation of Solar hot water system at pilgrimage centres.
2. Monitoring of experimental-cum-demonstration Solar hot water system for a hospital
3. Design and fabrication of Solar powered refrigeration plant
4. Design and fabrication of biomass-based cold storage
5. Installation of community biogas plants in rural areas
6. Studies on the practical application of producer gas from agricultural residues as supplementary fuel for diesel engines
7. Catalysis of biomass methanation
8. Demonstration and extension of wood-based gasifiers and dual-fuel engines in hilly and rural areas
9. Research and development on biomass gasification
10. Biogas production from guayule shrub (Parthenium argentatum) and extraction of rubber from the digested slurry
11. Biogas production from congress grass (Parthenium)
12. Seasoning of secondary timber in Solar kilns
13. Development of a Solar pond

MANAGEMENT

The Institute is managed by a Board of Management whose members are reputed scientists, engineers, and high dignitaries of the country including Professor MGK Menon, Fellow of Royal Society, U.K. and Member, Planning Commission, Government of India. Professor M.A. Date, FIE, Principal BVM Engineering College, is the Secretary of the Board of Management and Honorary Director of the Institute. Dr.B.C. Jain who is a national figure in the field of renewable energy sources in the country, is the Technical Advisor of the Institute. Mr.N.B. Amin, a renowned industrialist and distinguished technocrat, is the Founder of the Institute.

Enclosure 'B'
(Refers to Para 4)

I - BIODATA OF PROF.SURENDRA KUMAR PRINCIPAL INVESTIGATOR

Prof.Surendra Kumar, 45, was born on 21 November, 1938. He secured first class throughout his educational career. He was conferred upon the degree of PhD in 1965 and MBA in 1981. He possesses extensive research, development and teaching experience of about 23 years including that as a Professor teaching postgraduate (ME) engineering classes. Currently, he is working as the Deputy Director of the Jyoti Solar Energy Institude, Vallabh Vidyanagar, where he is responsible for conducting post graduate teaching programs in non-conventional energy sources. He is also responsible for the work on biomass gasification in his Institute. He has done significant work in the utilisation of non-conventional energy sources at high attitudes. He has made significant contribution in the area of energy. He has vast project management experience and is responsible for running the Institute.

Address: Deputy Director
Jyoti Solar Energy Institute
Vallabh Vidyanagar (Gujarat)
Pin: 388 120

II - BIODATA OF PROF.M.A. DATE

Prof.M.A. Date, 59, is the Principal of the BVM Engineering College, Vallabh Vidyanagar (Gujarat), India, and Honorary Director of the Jyoti Solar Energy Institute. He is actively engaged in research, development and teaching work in the field of non-conventional energy sources. He has research and teaching experience of about 35 years. He is a Fellow of the Institution Engineers (India). His current area of interest is the use of gasifier engine sets for the generation of electricity.

III - BIODATA OF DR.B.C. JAIN

Dr.B.C. Jain did his basic Mechanical Engineering Degree from BITS, Pilani (1971) where he was a Gold Medalist. He joined M.I.T. Cambridge, USA. immediately after that where he did his Master's

and Doctorate Degrees in Mechanical Engineering as well as his Master's in Business Management from the prestigious Sloan School of Management.

Among the various projects that he worked on while in the United States were :

Development of a highly efficient, multi-fuel automotive engine, Steam powered automotive vehicles for reduced environmental pollution, Novel methods for combustion and spray painting.

The multi-fuel automotive engine for which a complete performance model was developed by him as part of his doctoral thesis, is now being produced by a big oil company for the U.S. Army because it can accept any fuel like petrol, kerosene, diesel or alcohols. The engines for which special burners were developed by him are now being used by the U.S. Bureau of Mines.

He joined Jyoti's R&D Centre in January 1977 and is currently responsible for research and development in the area of energy as well as for manufacturing and marketing of the products of Jyoti's Energy Division.

A few of the most prestigious projects currently being handled by them are some large Solar Powered Cold Storages, Solar Steam Generation Systems for cooking in industrial canteens and Solar systems for a variety of processes in a number of industrial units in the country. The division also offers systems based on wind energy and biomass including a variety of Wind Energy Conversion Systems and Biomass Gasifiers, etc. for decentralized power generation in remote, rural areas.

IV - BIODATA OF MR.M. FARCY

Mr.M. Farcy is the French Engineer working on the gasifier project at JSEI. He is a Chemical Engineer by training. He has considerable experience in gasifier hardware. He is a keen and enthusiastic engineer.

V - BIODATA OF MR.V. BUTIN

Mr.V. Butin is the French Engineer working on the gasifier project at JSEI. He has experience in the area of replacement of oil by producer gas. He has good theoretical background besides having practical experience of gasifier technology.

VI - BIODATA OF DR.F. VYARAWALLA

Dr.F. Vyarawalla did his basic Chemical Engineering degree from I.I.T., Kharagpur and thereafter went on to complete his Doctorate from the same Institute.

After his doctorate he had been on the teaching faculty of the BITS, Pilani for twelve years. Among the various projects he has worked on are : Continuous carbonation of hydrated lime in spray absorber, Development of centrifugal gas-absorbers, Mechanism of mass transfer in liquid drops in spray columns - pulsed and impulsed, etc.

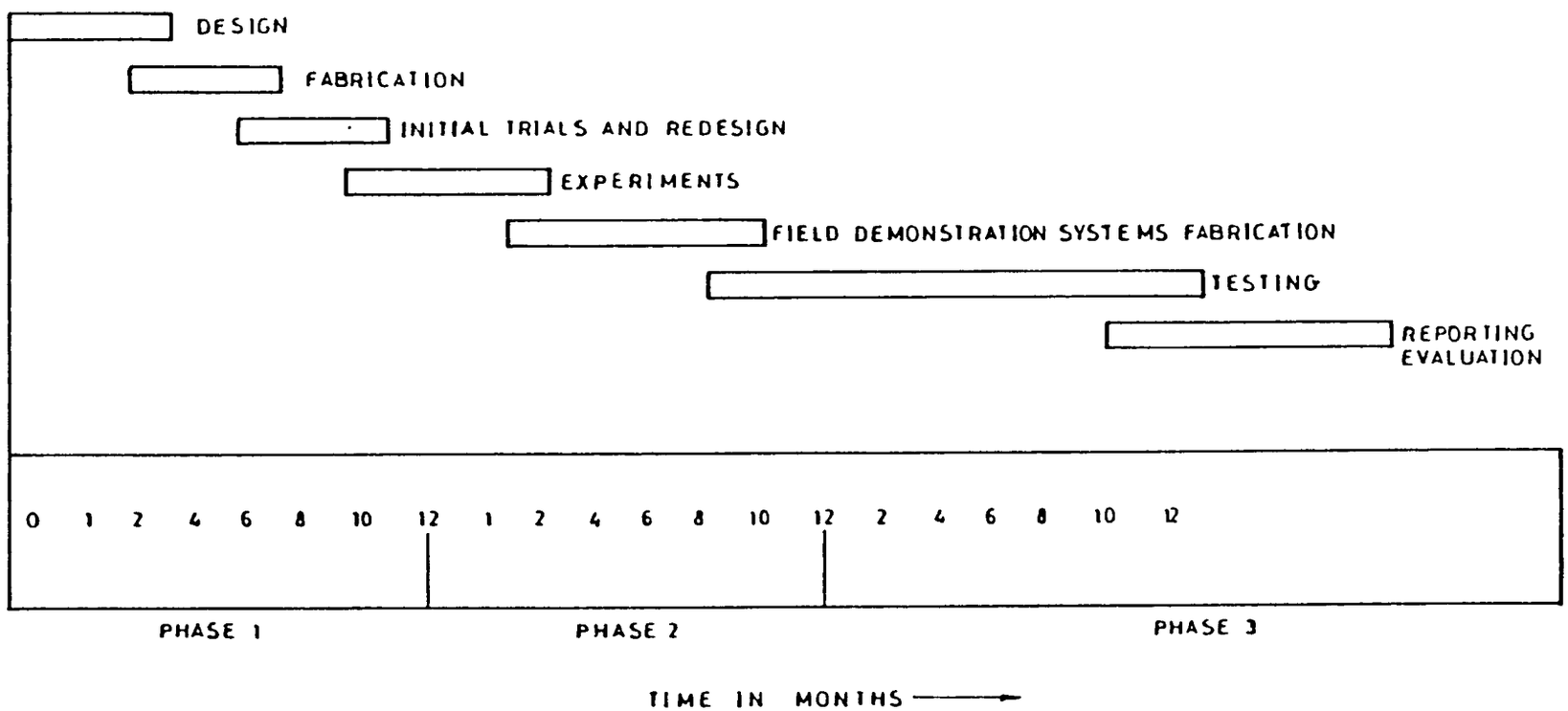
He joined the Energy Division of Jyoti Limited in 1982 and since past one year he has been working in the development of the Gasifier-Engine systems.

VII - BIODATA OF MR.R.N. PANDYA

Mr.R.N. Pandya is a graduate Mechanical Engineer. He is currently engaged in the design and fabrication of gasifiers and has got good experience in gasifier hardware.

ENCLOSURE – C

BIOMASS GASIFICATION-ENGINE SYSTEM DEMONSTRATION



Enclosure 'D'
(Refers to Para 10)

U.S. BUDGET STAFF SALARIES

The amount of $ 65,000 will be required to defer the salary costs of U.S. consultants whose expertise will be necessary for proper and speedy implementation of the Project.

Enclosure 'E'
(Refers to Para 10)

INDIAN BUDGET - STAFF SALARIES

SR. NO.	CATEGORY	REQUIRE-MENT	QUALIFICATIONS	FIRST YEAR Rs.	SECOND YEAR Rs.	THIRD YEAR Rs.	TOTAL AMT. Rs.
1.	Senior Mechanical Engineer	One	M.E./M.Tech/Ph.D. in I C Engines	25,000	27,000	30,000	82,000
2.	Senior Chemical Engineer	One	M.E./M.Tech/Ph.D. in Combustion	25,000	27,000	30,000	82,000
3.	Mechanical Engineer	One	B.E./B.Tech.	20,000	22,000	25,000	67,000
4.	Electrical Engineer	One	B.E./B.Tech.	20,000	22,000	25,000	67,000
5.	Agricultural Economist	One	M.A./Ph.D. in Agro-Economics	20,000	22,000	25,000	67,000
6.	Technicians	Three	I T I Diploma Holder	30,000	33,000	36,000	99,000
			TOTAL AMT. Rs.	1,40,000	1,53,000	1,71,000	4,64,000

Enclosure 'F'
(Refers to Para 10)

REQUIREMENTS OF U.S. BUDGET EQUIPMENT

NOMENCLATURE OF ITEM	PURPOSE	ESTIMATED COST (IN DOLLARS)
1. Piezoelectric pressure transducer with charge amplifier	For obtaining P-V characteristics of engine under test	1,800
2. Storage oscilloscope (with system to record angular position of engine)	For coupling to the transducers	2,400
3. Multichannel digital temperature indicator with probes, for range 0 to 1500 °C	For obtaining temperatures in - a) Combustion zone b) Reduction zone c) Various states of cooling d) Engine exhaust	4,400
4. Non-contact digital RPM indicator Range : 0-999 rpm Accuracy: 1 rpm	For monitoring engine RPM	2,500
5. Torque transducer with digital torque display (Full set of equipment to carry out complete engine testing)	For load testing of engine	3,000
6. Turbine flow meters with digital display (two)	For monitoring air and gas flowrates to the engine	8,000
7. a) Fuel efficiency monitor b) CO Monitor (continuous) c) H_2 Monitor (continuous)	For determining O_2 CO and H_2 contents in the inlet and exhaust gases	6,000
	C/F :-	28,100

NOMENCLATURE OF ITEM	PURPOSE	ESTIMATED COST (IN DOLLARS)
	B/F :-	28,100
8. Data Logger for temperature, flowrate and pressure	For continuous recording of temperature, flowrate and pressure drops	10,7000
9. Portable temperature indicator with surface probe	For spot checking surface temperatures of gasifier and other parts of the system	1,500
10. Gas chromatograph with digital display	For analysis of gas from the gasifier and calorific value measurement	12,000
11. Bomb calorimeter	Analysis of the wood used in gasifier	3,000
12. Density meter	For determining density of wood	1,000
13. Moisture meter	For determining moisture content in wood	1,000
14. Junkler's calorimeter (with gas flow meter)	To determine calorific value of the gas	2,500
15. Wood chopping machine	For preparing wood for gasifier	1,000
16. Electric wood saw	For preparing wood for gasifier	100
17. Vibration analyser	For detecting engine and system vibrations	2,500
18. Pelletizer	For briquetting agro-wastes	3,000
19. CO Sensor	For safety measures	100
20. CHN Analyser	For material analysis	2,500
21. Viscometer	For determining viscocity of lubricating oil used in engines	1,000
	DOLLARS :-	70,000

Enclosure 'G'
(Refers to Para 10)

REQUIREMENTS OF INDIAN BUDGET EQUIPMENT

NOMENCLATURE OF ITEM	PURPOSE	ESTIMATED (COST Rs.)
1. Vacuum pump	To connect gas chromatograph to gasifier	30,000
2. Blue-print machine	For making blue prints of drawings	25,000
3. Electro-photo copier	For production and dissemination of information and reports	1,00,000
4. Air-conditioner	For the air-conditioning of gas chromatograph and electro-photo copier	40,000
5. Slide projector	For general use	5,000
6. Hardware (gasifiers)	For trials	1,00,000
	TOTAL AMT :-	Rs. 3,00,000

Enclosure 'H'
(Refers to Para 10)

STUDY TOURS/VISITS ETC.TO AND FROM USA BY INVESTIGATORS ETC

An amount of $ 30,000 is envisaged in the budget to defray the cost of visits of Investigators to the USA and of U.S. Consultants to India. As this Project is of immediate importance and is in the take-off stage, so there is a provision of important investigators. Providing a modest amount of 5,000 dollars for one visit of each specialist and taking into account the location of the Institute in the remote rural area (in contrast with the convenient location of IIT, Delhi) an amount of 30,000 dollars is envisaged in the budget. It is intended to invite Dr.Abu Talib and Professor V.J. Flanigan or Dr.Peter Rogers as U.S. Consultants to the Project. They are specialists in the field and their consultancy will be crucial in the implementation of the Project as will be the visits of the Principal Investigator to the U.S.A.

Enclosure 'I'
(Refers to Para 10)

INDIAN BUDGET

LOCAL TRAVEL INCLUDING U.S. CONSULTANTS

As the Jyoti Solar Energy Institute is located in the remote rural area of the country, where sophisticated equipment is not available locally, one has to make frequent trips to big cities for procurement of such equipment. Moreover, some bare minimum expenses will also have to be incurred on the visits of U.S. Consultants. Therefore, an amount of Rs.40,000/- has been budgeted for this purpose in the Project.

TECHNOLOGY DEVELOPMENT THROUGH BIOMASS GASIFICATION

M. K. SARKAR

TECHNOLOGY DEVELOPMENT THROUGH GASIFICATION OF BIOMASS

Prof.M.K. Sarkar
Chemical Engineering Department
Indian Institute of Technology
New Delhi-110016, INDIA

INTRODUCTION:

In view of energy crisis of the recent past and rapid depletion of fossil fuel reserves, a great deal of research has been initiated on recovery of energy and feedstock from renewable resources such as agricultural and forest wastes. Voluminous literature have appeared on studies involving liquefaction, gasification, hydrogasification, pyrolysis, etc. and combination of these catalytic and non-catalytic processes for conversion of agricultural and wood wastes into char, oil and combustible gases. The present paper reports a brief summary of significant results obtained through extensive study (1977-1982) of catalytic and non-catalytic steam gasification of biomass with projection for Technology Development for a developing country like India with Rural Bias.

Biomass resources in a country like India could come from agricultural and Forest wastes, and also from energy plantation ept which is rapidly gaining ground in some parts of the

country. Development of high technology, based on similar lines as coal conversion, appears to be immediately unattractive because of highly scattered nature of the raw material (biomass) with associated high cost of collection and transport, as well as diverse physical and chemical nature of the material. Some of the visible active programmes of biomass conversion and utilization in and around the country are:

(i) Generation of biogas by fermentation where gas could be used for rural energy supply (cooking, lighting and irrigation pumps through gas engines), and residue for organic manure.

(ii) Direct gasification with air (with or without steam) for generation of lean gas with development of lean gas engines for application in irrigation pumps, refrigeration in cold storage, power generation, etc.

(iii) Partial charring of biomass and conversion of the char to briquetted fuels as substitution of coal and coke.

(iv) Improvement of burning appliances for direct combustion of biomass for higher efficiency or to make combustion possible for those which are difficult to burn in conventional appliances.

All these developments are highly useful and have tremendous potential for localized and zonal applications depending on circumstances. However, there are some basic drawbacks in most

of these applications causing diversity of opinions and lacking universal appeal. Some of these drawbacks are:

(i) Normally low efficiency of energy utilization with higher initial cost compared to fossil fuel equivalents, based on original fuel value of biomass.

(ii) Not having any potential for high value products, there is no generation of wealth near the source causing no improvement in the lots of rural poor. Instead, in some cases they deprive the rural poor of some of the free materials they could use.

Based on the above reasons, the development strategy of the present research scheme has been to produce some high value products such as hydrocarbon oils which can be stored and easily transported at the village level itself. Part of the oil can be stripped of kerosene kind of fuel for village level application, and the rest can go through district and state level refineries for large scale petroleum substitution. The value for this crude oil can be shared at all levels according to scheme shown in Fig.1. Further value can be added to the process, depending on circumstances, by producing activated charcoal and/or other valuable products, if possible. Energy for the process can be obtained by combustion of part of the gas and/or char, or partial combustion of biomass itself. Some of logic and arguments for the scheme have been presented elsewhere (1).

Laboratory Studies:

With saw dust and wood chips as standard biomass, extensive steam gasification studies (2-7) have been made using a micro batch reactor under isothermal conditions. Details of reaction techniques, product analysis, product distribution and kinetics analysis have been published, presented and also under various stages of communication. Significant results of the above study are summerized below:

(i) Non-catalytic steam gasification produces conversion of sawdust from 60% at 350°C to 85% at 650°C with gas yields from 50 ml/gm. to 340 ml/gm. respectively. Combustible fuels appear in the gas only beyond 500°C. Volatile products (on carbon basis) were observed to be mainly liquid upto 500°C. (48% beyond which only gaseous yields increased from 10 to 30% at the expense of solid residue). At the highest temperature (650°C) the molar ratio of carbon monoxide to hydrogen was approximately 2:1.

(ii) Steam gasification of sawdust catalyzed with 5% potassium carbonate was observed to yield similar level of overall conversion, the product gas having more hydrocarbon content (methane) with lowered contents of carbon monoxide and hydrogen.

(iii) Steam gasification of sawdust, catalysed with Zinc Oxide, calcium oxide and a mixture of both yielded 80-90% gasification at 700°C with 50% converted carbon appearing in gas. Also ratio of carbon monoxide and hydrogen was significantly altered. With particular combination of catalyst and residence time, it was possible with fair reproducibility to obtain gas with carbon monoxide and hydrogen in the ratio of 1:3.

Projection of Technology Development:

Along with the above observations in catalytic steam-gasification of biomass, another significant observation with one of our coal liquefaction programe (8) was that coal when catalysed with zinc oxide, and devolatilized in an atmosphere of steam and carbon monoxide (with some hydrogen), yielded gas with not only altered ratio of carbon monoxide and hydrogen through shift reaction, but also much higher quantity of liquid volatiles through hydro-cracking type of reaction on coal molecules (possibly under the influence of rascent hydrogen). From these experimentally observed facts, the following technology projections can be made:

If liquid hydrocarbons have to be the main product, two routes can be followed:

(i) Direct catalytic gasification at 700°C or above, to produce gas with carbon monoxide/hydrogen ratio as 1:2.5-3.

Since most of the biomass mattrials have negligible sulphur, the gas after removal of carbon dioxide, can be directly converted into liquid hydrocarbons by Fisher-Tropsch reaction. Suitability of the reaction with gas from laboratory gasifier has been tested with a cobalt-based catalyst giving very clean liquid hydrocarbons in temperaturerange 180-220°C, with some initial induction period. All the reactions being under atmospheric pressure, rural based application should not be difficult. Supplying heat to the system would pose some problem. Injection of air into the system would have some disadvantage of handling large volume of inerts in gas with consequent heat loss; but it would be somewhat advantageous in the highly exothermic Fisher-Tropsch reaction. Other alternatives are, supplying indirect heat which is possible at the level of 700°C, by burning part of the gas or by operating the whole gasifier in fluidization mode, recirculating part of the char through an external combustion loop. The scheme is shown in Fig. 2.

(ii) The second alternative for optimising liquid products is similar to a scheme developed for coal liquefaction as shown in Fig.-3. This system has got a shaft reactor, where the bottom zone acts as a high temperature gasifier generating carbon monoxide and hydrogen, and the top

zone acts as a pyrolyzer in atmosphere of carbon monoxide, steam and hydrogen. If biomass is properly catalysed, most of it could be converted to liquid hydrocarbons. As zinc oxide is one of the most suitable catalyst, the char being treated with zinc oxide and steam, can make a valuable byproduct in the form of activated carbon.

In case, only high value gas is desired, both the liquefaction reactor systemscan be optimised for gas, having carbon monoxide and hydrogen in the ratio of 1:3. This gas, after removal of carbon ~~mo~~dioxide can then be methanated to give a high value gas (substentively Methane). A scheme suitable for coal (9) as shown in Fig.-4 is applicable to biomass also.

Current Status:

The shaft reactor, as shown in Fig.-3, suitable for handling 1 Kg. per hour of dry biomass (or 1-5 Kg. coal per hr.) has been set-up and under trial. Hydrocracking facility for up-grading liquid fuels has been in operation since two years.

Fluidized bed biomass gasifier, Fischer-Tropsch reactor and a methanator to suit the system are under construction. Recirculation of char/coke with ash with external air oxidation loop for a fluidized bed system is under developmental stage through experimental cold models. A packaged demonstration plant, optimizing liquid fuels, is also under construction

for rural application in collaboration with Centre for Rural Development and Appropriate Technology, I.I.T. Delhi.

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Acknowledgements:

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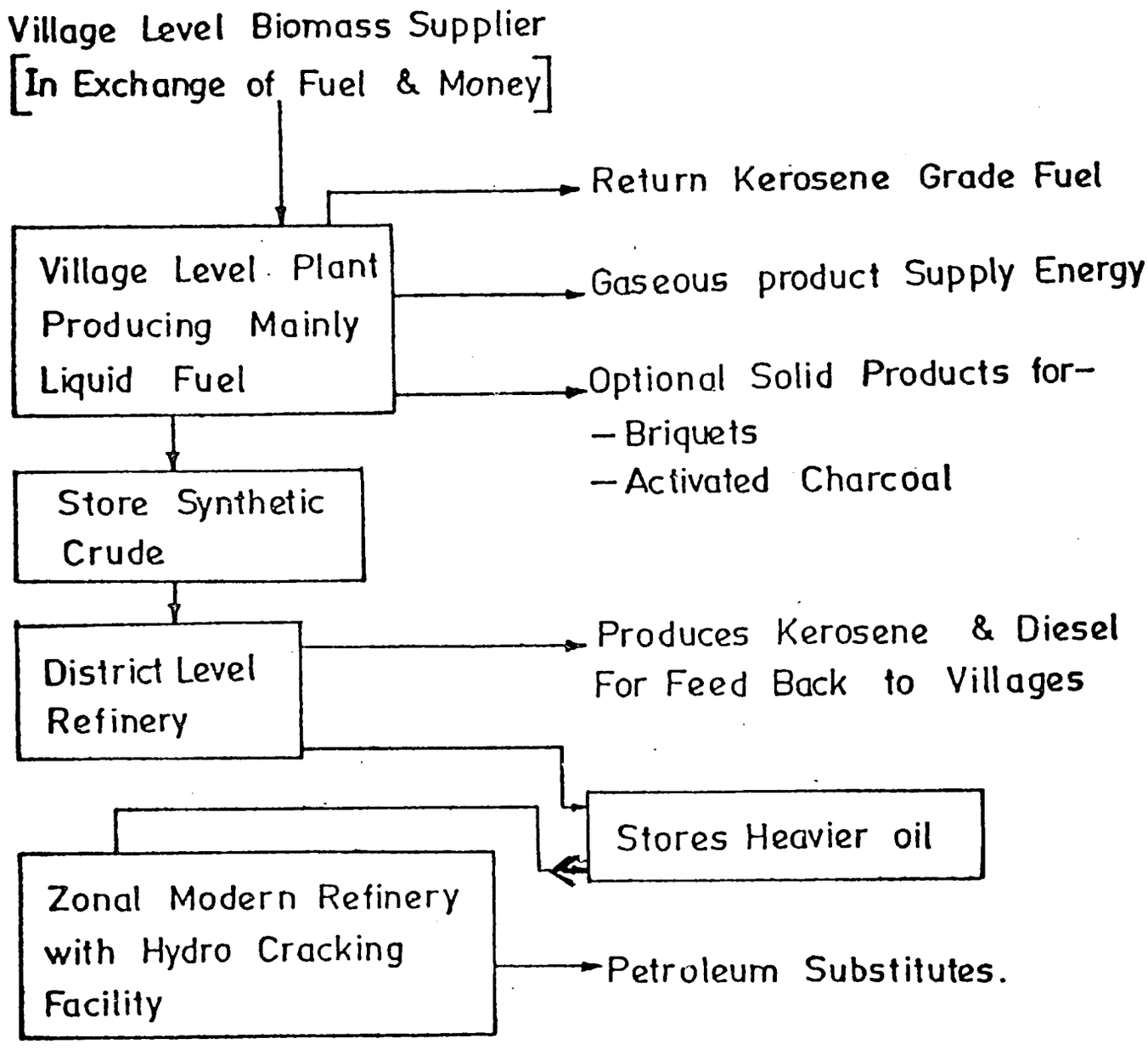

FIG.1. A PROPOSED MODEL OF RURAL TECHNOLOGY THROUGH BIOMASS GASIFICATION / LIQUEFACTION.

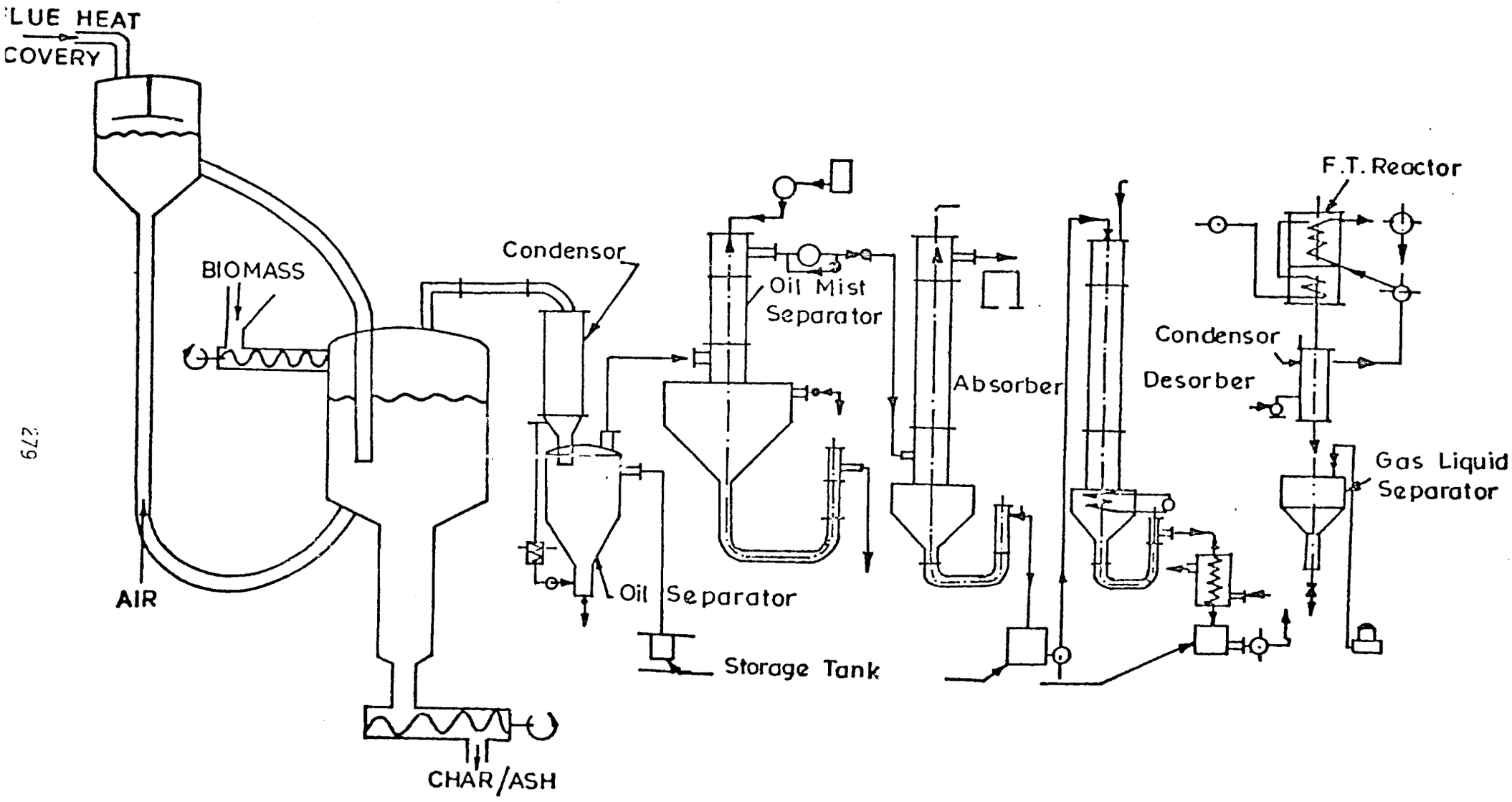

FIG.2. PLANT FOR BIOMASS GASIFIER/ LIQUEFIER.

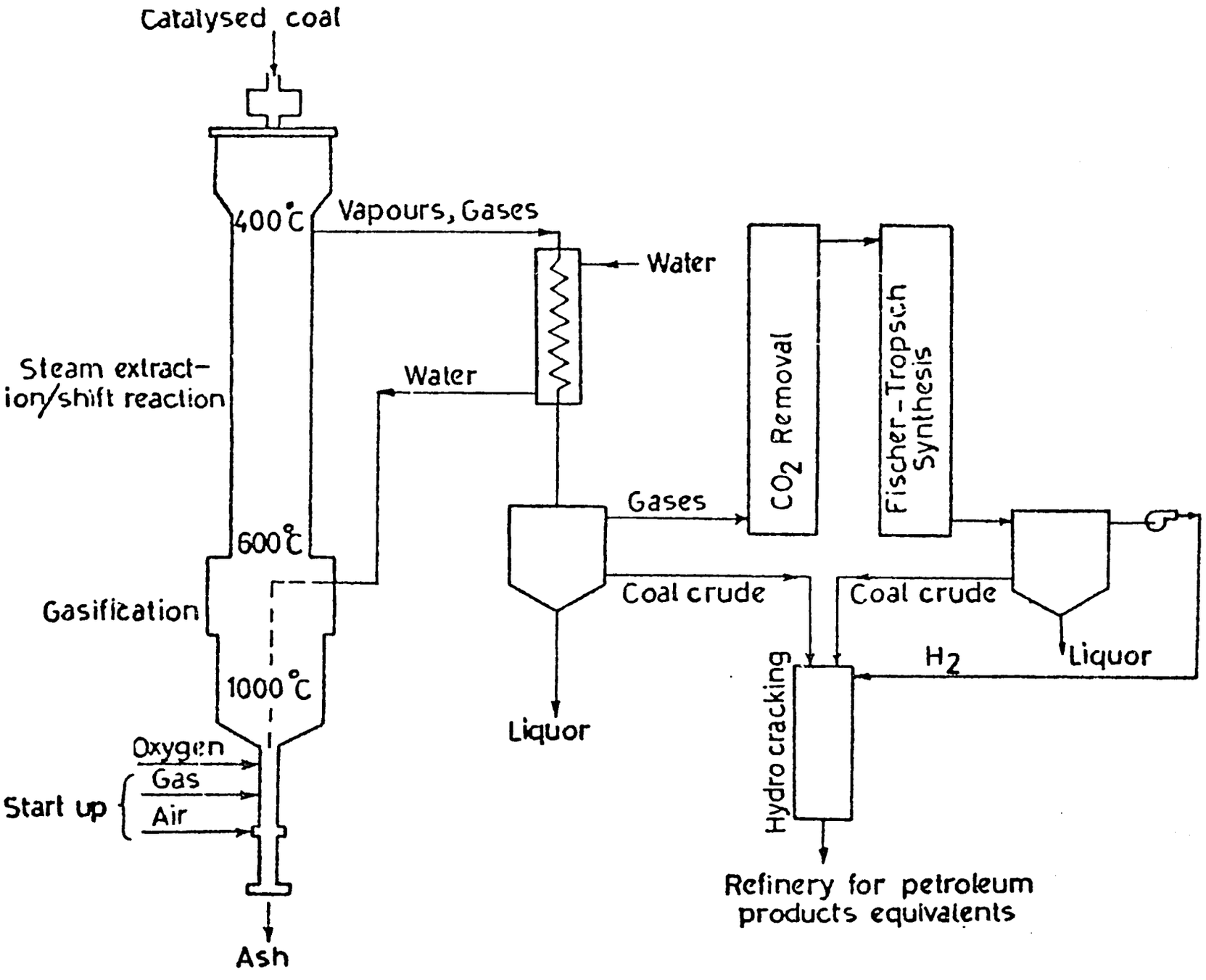

FIG. 3 PROPOSED COAL LIQUEFACTION PROCESS

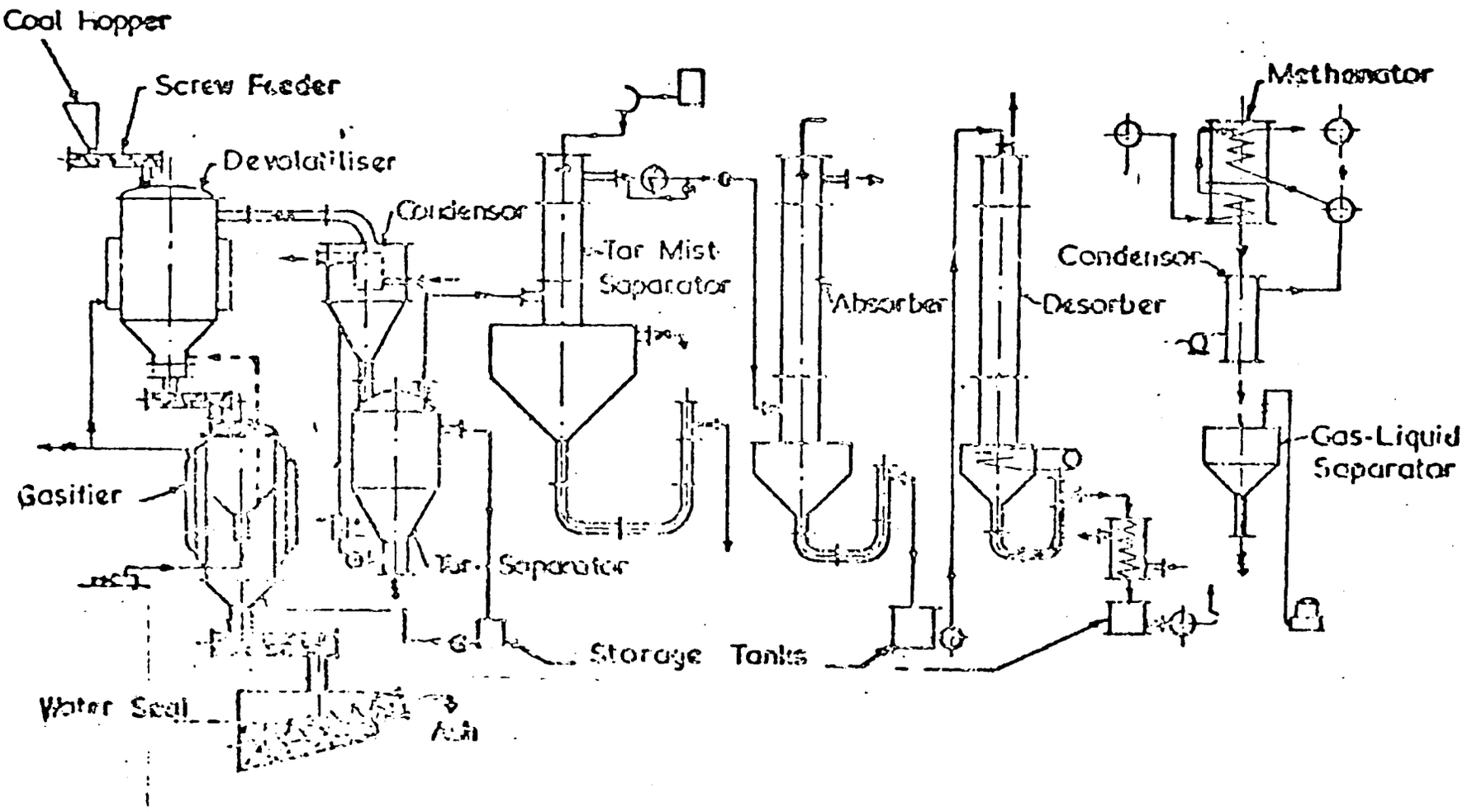

FIG.4. FLOW SHEET FOR COAL BASED GAS PLANT (WITH AIR).

ON THE COMBUSTION OF CORNCOBS IN FLUIDIZED BED

A. K. DRONA

ON THE COMBUSTION OF CORNCOB IN FLUIDIZED BED

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ABSTRACT

A study is being conducted to examine the potential of Corncob as a commercial fuel and to develop a highly efficient fluidized-bed combustor (FBC) for the purpose. In the present study maximum bed temperatures have been reported for varying feed rates and the steam temperatures and bed temperatures at different time intervals have been reported for four levels of sand beds. The bed temperatures have also been reported for varying feed rates of the fuel. It has been found that Corncob can be burnt efficiently in a FBC and high operating bed temperatures of the order of 1000° to 1300°C can be obtained.

SCOPE

The realization of decreasing fuel reserves and the uncertainties in fuel oil supplies and their rising costs have made it necessary to seriously consider potential options for the existing fuels. Another driving factor for finding viable alternate energy resources is the pollution caused by the emission of abnoxious exhausts and the residual wastes from the existing fuels.

The FBC, one of the most promising coal utilizing techniques, has been intensively research in various countries. In the last few years a number of pilot plants have started operation, and now commercial plants are being constructed. It can be safely said that the coal-fired FBC boiler has now entered the phase of practical applications. However, FBC boilers fired by low grade fuels, such as agricultural waste, forest waste and timber industry waste seem to have not been studied much.

The present study to develop a highly efficient FBC system utilizing corncob (agricultural waste), an alternate energy source, is an attempt toward generating appropriate technology for the rural masses.

EXPERIMENTAL SETUP

The experimental setup consisted of combustion chamber, heat exchanger section, constant head water tank, reducer and feeding hopper. The FB Combustor consisted of a combustion chamber fabricated from 750 mm x 150 mm x 8 mm seamless G.I. pipe. The chamber had two 9.375 mm diameter holes drilled at a height of 120 mm and 72.5 mm from the base of the pipe for the insertion of thermocouple probes. Another hole of 100 mm diameter was provided at 675 mm from the base for feeding the fuel. Two more holes were drilled on the pipe diametrically opposite to accommodate inlet and outlet ends of the heat exchanger tube. Glass wool packing was fixed around the

combustion chamber with the help of an outer casing of M.S. The base of the pipe was joined to the reducer with the help of flanges. A grid or distributor was fixed between the above two flanges for supporting the sand and fuel bed. The grid (200 mm x 1 mm) circular M.S. plate had holes of 1.5 mm diameter drilled at 5 mm square pitch within a diameter of 150 mm. The joint was sealed for any loss of heat and air leakage. The sand bed consisted of sand with particle size ranging between 0.425 mm and 0.500 mm. Four bed heights of 30, 45, 60 and 70 mm were selected.

The reducer was fabricated from 1 mm thick M.S. sheet with a circular top (150 mm diameter) and rectangular base to match the delivery pipe of the blower. The reducer had a slit (150 mm x 75 mm) with a sliding cover for bypassing the air from the blower for adjusting the superficial air velocity through the bed.

The heat exchanger was a helical tube of 100 mm inside diameter with three complete turns fabricated out of a steam pipe of 12.5 mm outer diameter. After placing the helical tube at appropriate position, it was joined to the walls of the combustion chamber with the help of shoulder couplings.

Chromel-alumal thermocouples were used for the temperature measurement of bed, the exit of the combustion chamber and the exit of the heat exchanger delivery pipe. The ambient body temperature and the inlet water temperature were measured by mercury thermometer. Annemometer was employed to measure the superficial air velocity for fluidization. The velocity was measured before the start of combustion.

TEST MATERIAL

The test material (corncob) was procured from Crop Research Centre, G.B. Pant University, Pantnagar, India. The average size of the corncob stocks was 125 mm x 20 mm. This was reduced to 50 mm x 20 mm for the test purpose. The percentage composition of corncob by weight: Carbohydrate, 80; Protein, 10; Oil, 4.5; Fibre, 3.5 and Minerals, 2.0. The percentage composition of corncob ash by weight: C, 7.91; NaOH, 1.1; Na_2CO_3, 12.4; NaCl, 2.38; Na_2SO_4, 2.60; Na_2S, 0.1 and insolubles, 68. The source of the above composition is Department of Chemistry, College of Basic Sciences and Humanity, G.G. Pant University, Pantnagar.

TEST PROCEDURE

Upon setting of steady fluidization of the sand bed, the combustion process was initiated by kerosene-soaked corncob. After the sand bed has attained the ignition temperature of corncob, feeding of kerosene-soaked corncob was stopped. Manual feeding of unsoaked corncob was done at a steady rate by noting down the time of feeding for a given quantity of fuel. Corresponding maximum bed temperatures were recorded for varying feed rates. Further, for a fixed feed rate, steam temperatures and bed temperatures were recorded at different time intervals. These observations have been recorded for four bed depths of sand, i.e., 30, 46, 60 and 70 mm.

RESULTS AND DISCUSSION

Bhattacharya et al[1] who have used a rectangular cross section FB have reported a choking problem. This has not been observed in the present case. Circular section of the FB with uniform fuel distribution over the bed seems to be the reason for the absence of choking. The sized corncob sticks easily ignited on attaining the ignition temperature. The burning was initially fast which slowed down as it reached the core of the corncob. The initial fast burning might have been due to the fluffy fibrous exterior of the kernel due to high oxygen availability and low material density on the exterior. This fast burning of the exterior creates a high degree of pre-heating of the inner hard core. The preheated inner core material, which is found to contain certain oil and minerals, gets ignited as soon as the burning reaches the core. This autoprocess helped in efficient self-ignition and continuous burning of the inner core. The flame tongue of 1.5 m height was an indicator of efficient burning of the fuel. No ash accumulation has been observed at the end of the test, which must have helped in non-occurrence of choking.

The circular cross-section, larger pore size and closer spacing of the grid have been able to provide uniform air flow all over the bed, which in turn have reduced the effect and height of dead zones.[5] The thin film of glass wool spread over the pores of the grid helped in attaining negligible sand bed losses due to leakage and dumping.[2]

It is observed from Fig. (2) that the temperature of the bed and steam generated follow the pattern of feed rate for a given bed depth. The maximum bed temperatures and the steam generation temperatures and the flue gas temperatures recorded are given in the Table below:-

Bed Depth (mm)	Maximum Bed Temperature (°C)	Temperature of Steam Generated (°C)	Flue Gas Temperature (°C)
30	1250	107	560
45	1292	235	570
60	1171	230	552
70	998	212	543

From the above Table it is clear that a sand bed height of 45 mm gave the best results. The low steam generation temperatures recorded compared to very high bed temperatures were due to the fact that the heat exchanger tube has been placed above the sand bed. It is expected that higher steam generation temperatures can be achieved by placing the exchanger in the sand bed itself.

The flue gas temperatures recorded are approximately half the maximum bed temperatures. The high temperature flue gases can be used to preheat the feed water or to further superheat the steam.

It has been observed that, after attaining steady state, the bed temperatures could be maintained with lower fuel feed rates. Increasing the fuel rate further only tended to choke the combustion process. This phenomenon was observed for all the four bed depths.

The increase in bed depths resulted in lower temperatures for the same feed rates. The added heat requirement to maintain the temperature of the increased sand bed volume seems to have lowered the temperatures recorded.

CONCLUSION

It can be concluded that a 45 mm sand bed will result in the best performance of the FB. The optimum range of fuel feed rate was found to lie within 15 to 20 #/h. The ash coming out of this FBC can be used as a detergent because of its highly alkaline nature.

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GASIFICATION AND PYROLYSIS OF BIOMASS FUELS

V. FLANIGAN

GASIFICATION AND PYROLYSIS OF BIOMASS FUELS

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UNIVERSITY OF MISSOURI-ROLLA

TO REVIEW SEVERAL PROCESSES OF INTEREST IN CONVERTING BIOMASS FUELS INTO USEFUL ENERGY OR POWER. SPECIAL EMPHASIS WILL BE ADDRESSED TO FLUID BED GASIFICATION TECHNOLOGY AND CHARRING SYSTEMS.

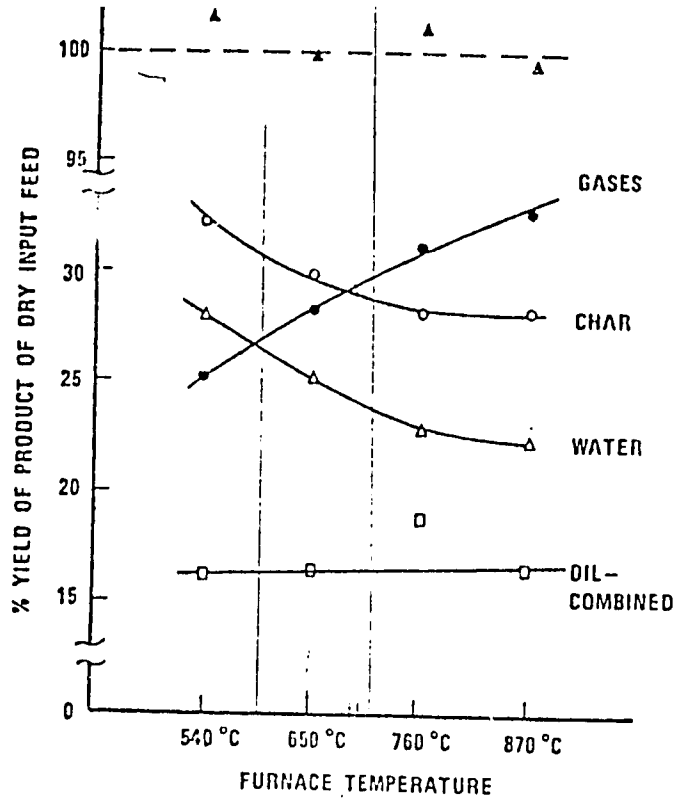
DEFINITIONS

GASIFICATION: THERMAL DECOMPOSITION OF ORGANIC MATERIALS IN THE PRESENCE OF CONTROLLED AND LIMITED AMOUNTS OF AIR, OXYGEN, OR STEAM PRODUCING THREE DISTINCT PRODUCTS; GAS, LIQUIDS, AND CHAR.

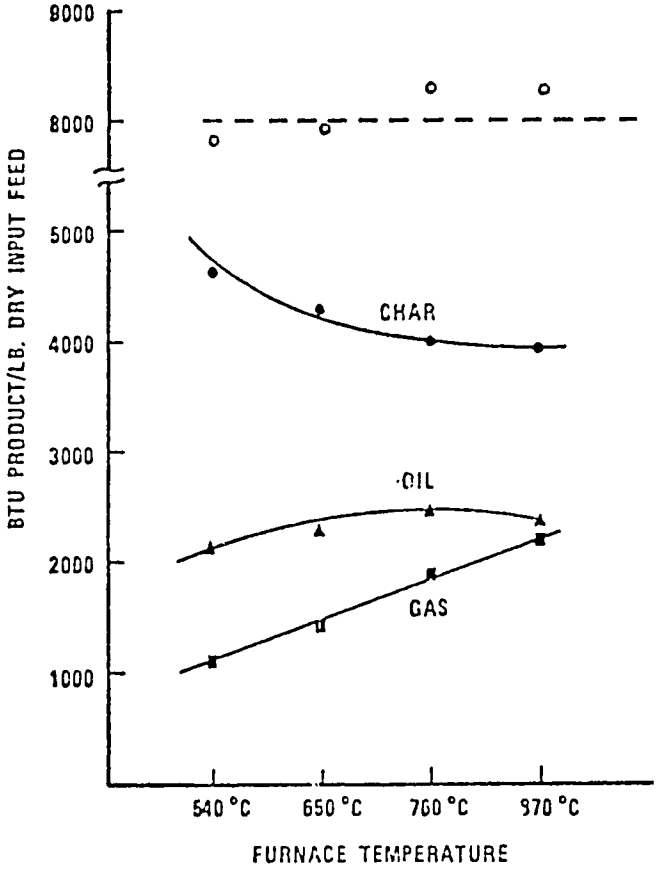
PYROLYSIS: THERMAL DECOMPOSITION OF ORGANIC MATTER IN THE ABSENCE OF OXYGEN. HEAT CAN BE APPLIED EXTERNALLY OR THE CHARCOAL INDUSTRY COMBUSTS SOME OF THE FUEL TO START PYROLYSIS PROCESS.

CHARRING PROCESS

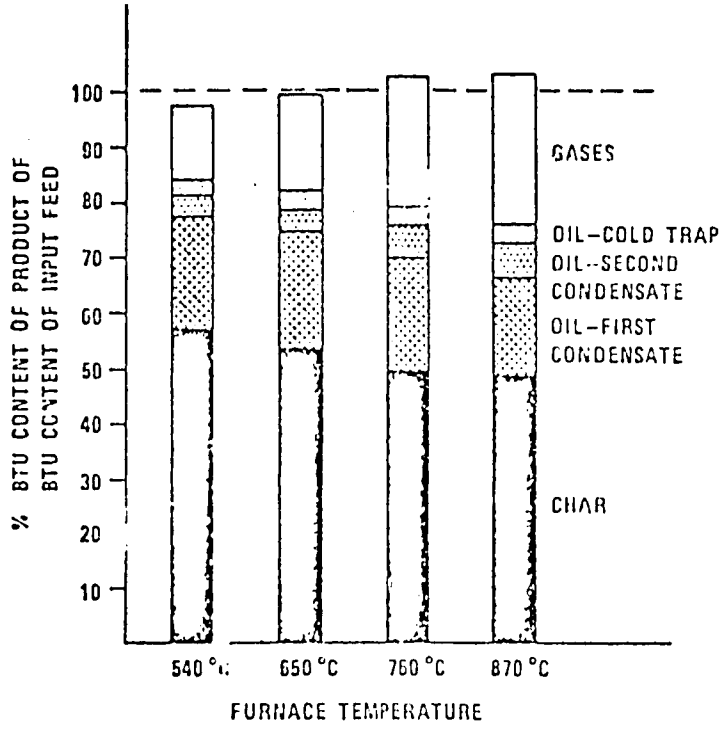
MAJOR FACTORS ENFLUENCING YIELDS MOISTURE CONTENT AND TEMPERATURE OF CONVERSION PROCESS



Yields of the four major pyrolytic products versus temperature.



Heat available from pyrolytic products.



Percentage of recovery of the pyrolytic products of the input feed.

KILN PROCESS

SPECIFICATION (CHARCOAL - BRIQUETTING)

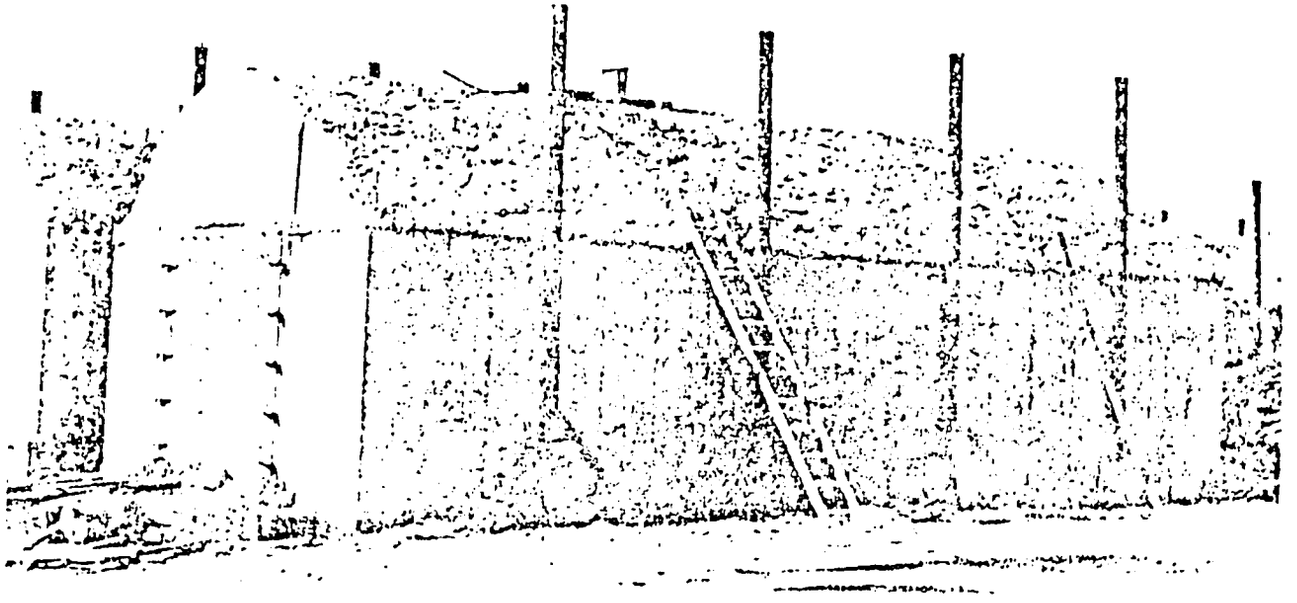
MOISTURE	2.4%
VOLATILES	18-23%
ASH	1-4%
FIXED CARBON	74-81%

YIELDS LB/LB
MIXED OAK AND HICKORY - 27 to 32%

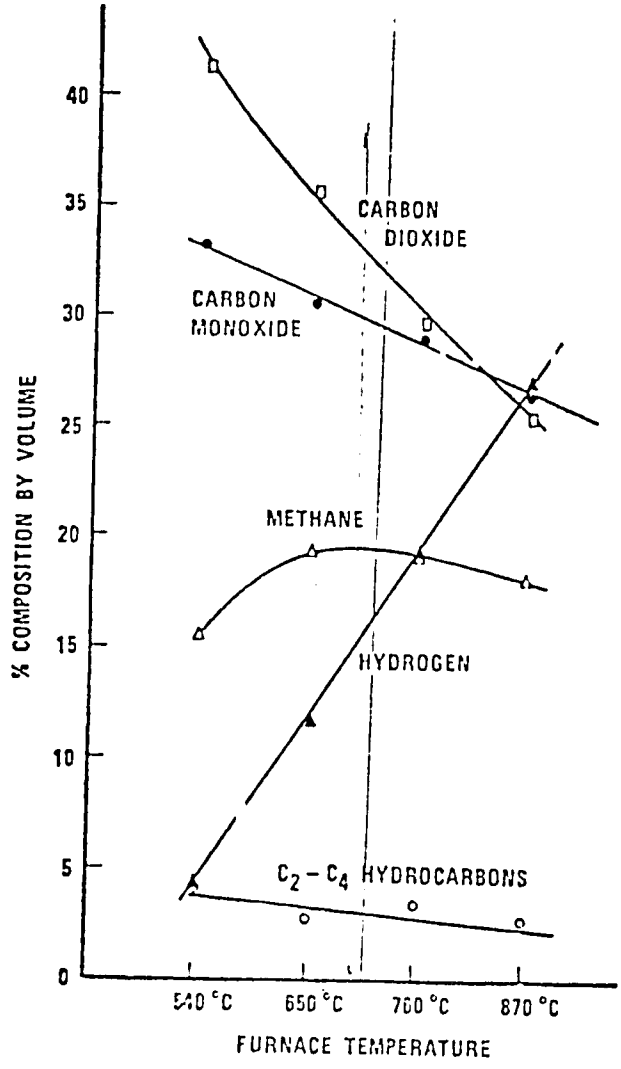
TYPICAL WOOD ANALYSIS

MOISTURE	25%
CARBON	38.1
HYDROGEN	4.8
OXYGEN	31.35
ASH	0.75

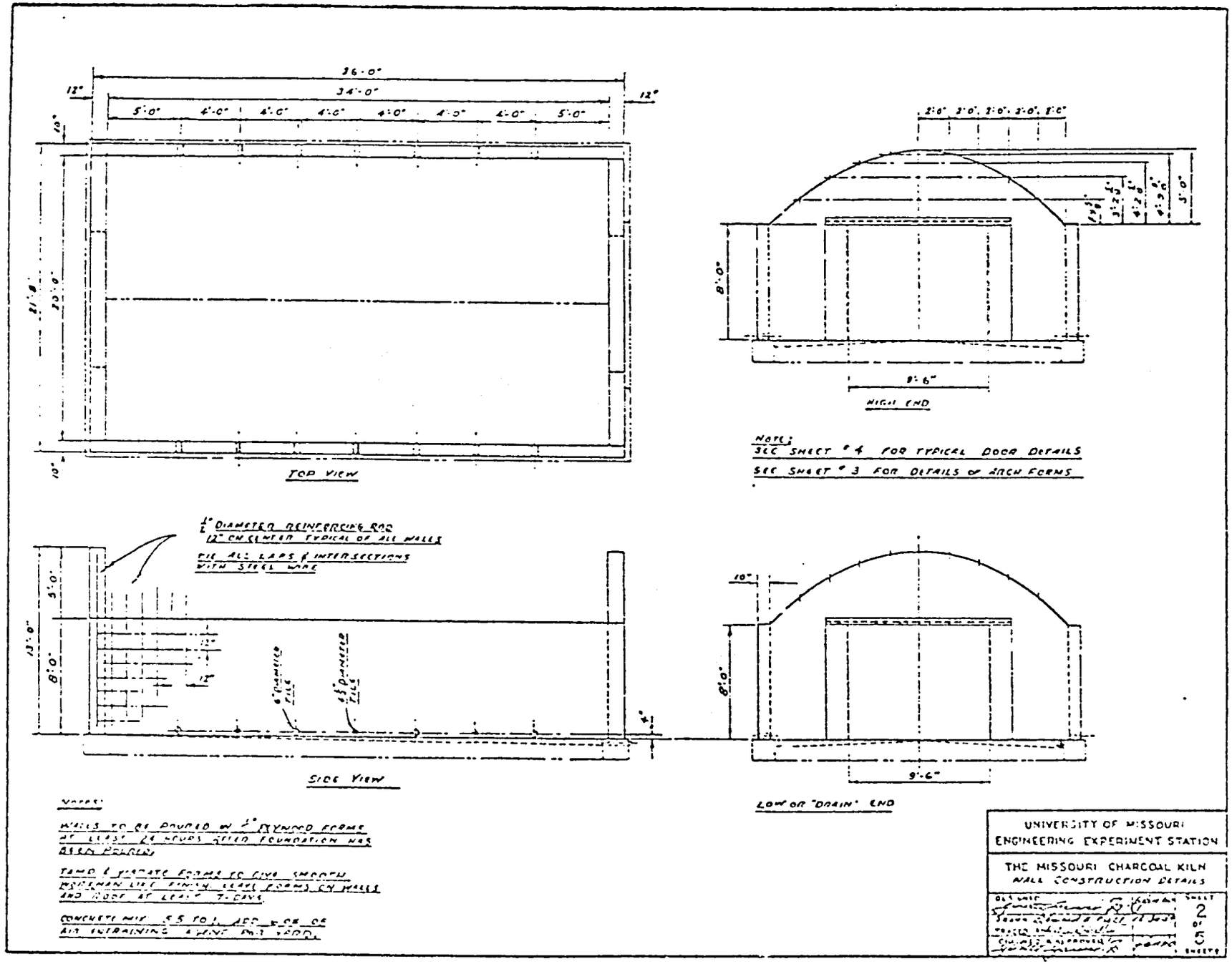
MOISTURE	25%
FIXED CARBON	14.55
VOLATILES	58.95
ASH	1.5



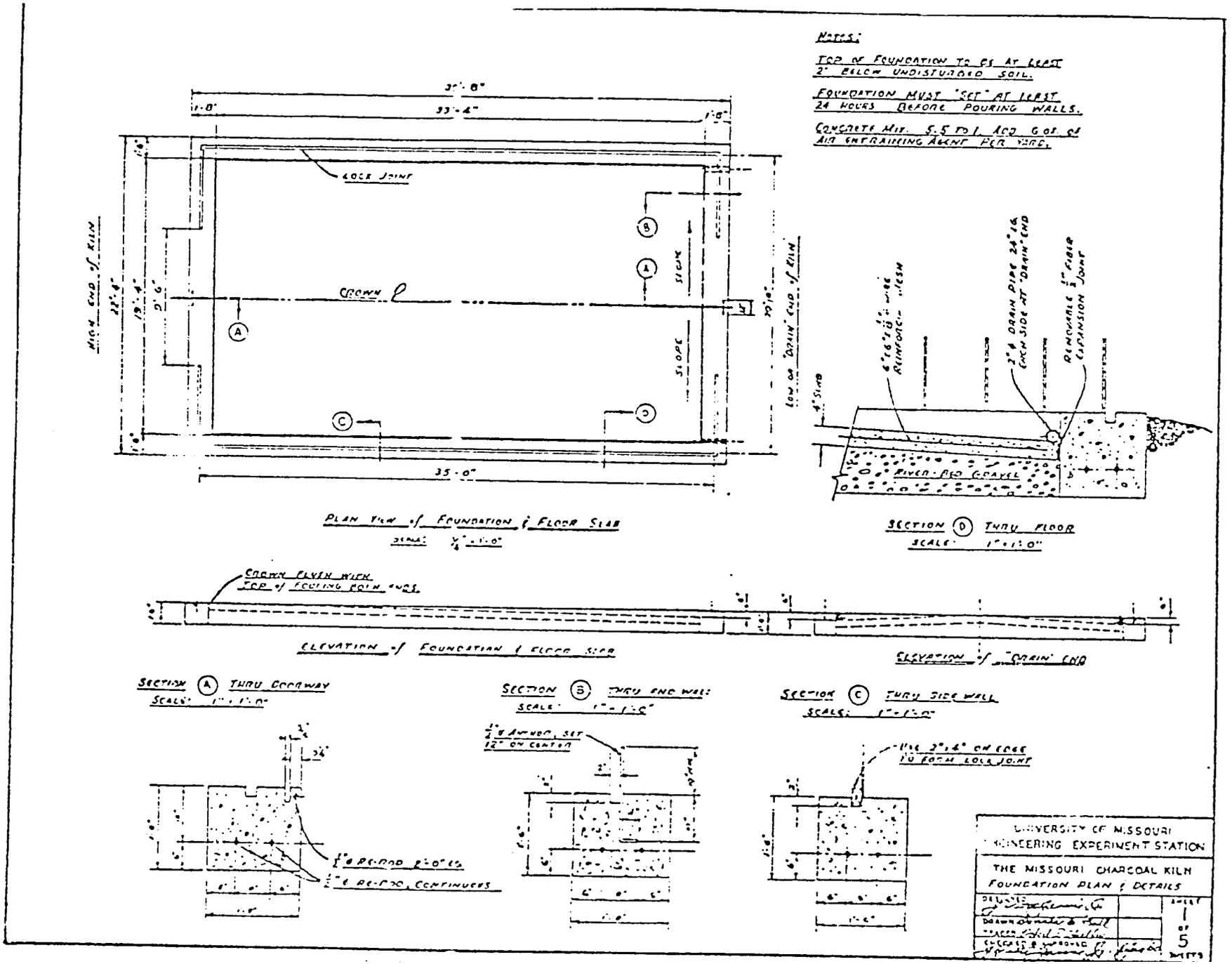
Missouri type batch kiln (Photo courtesy of Bob Massengale, Missouri Department of Conservation)



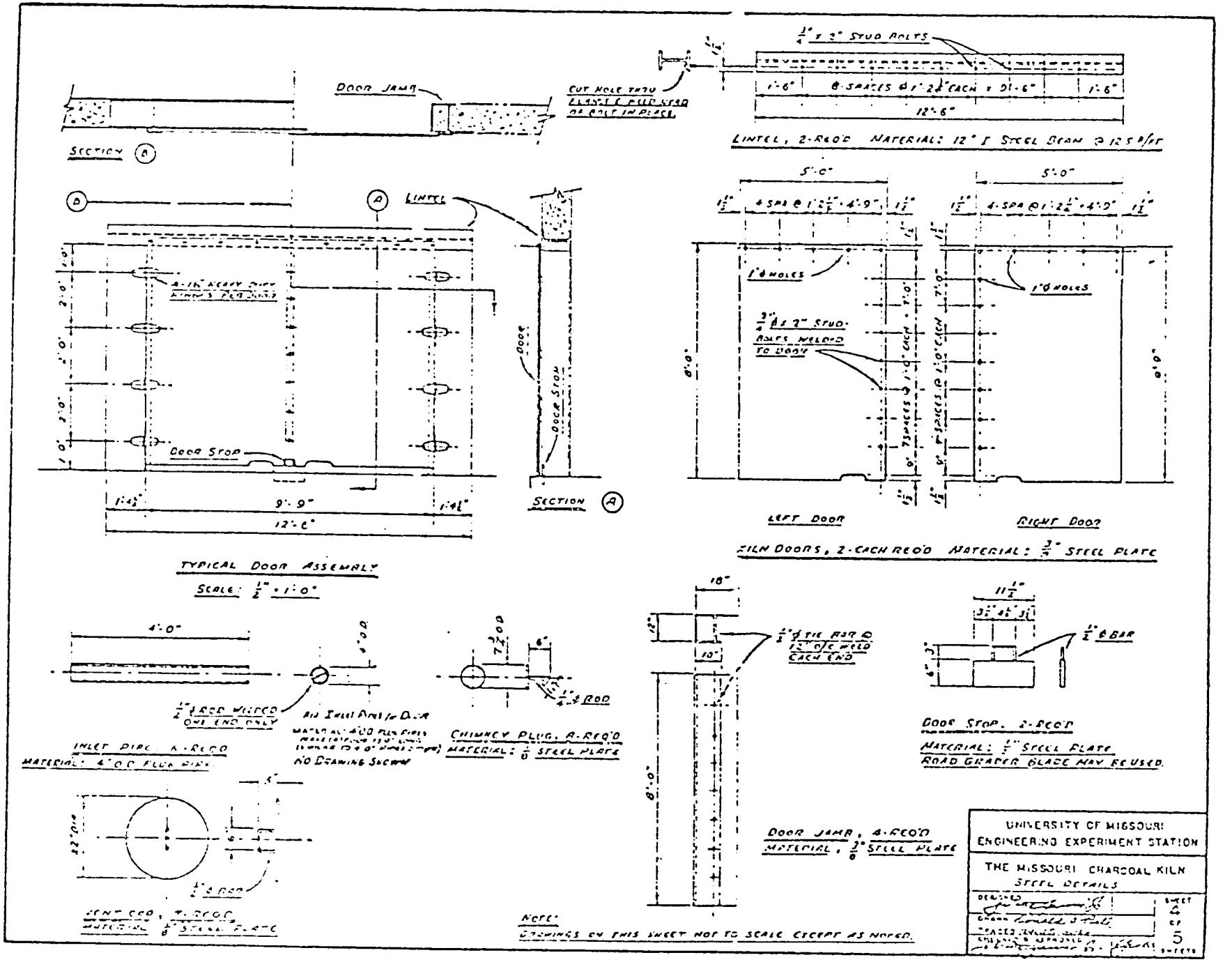
Variations of yields of the major gases.



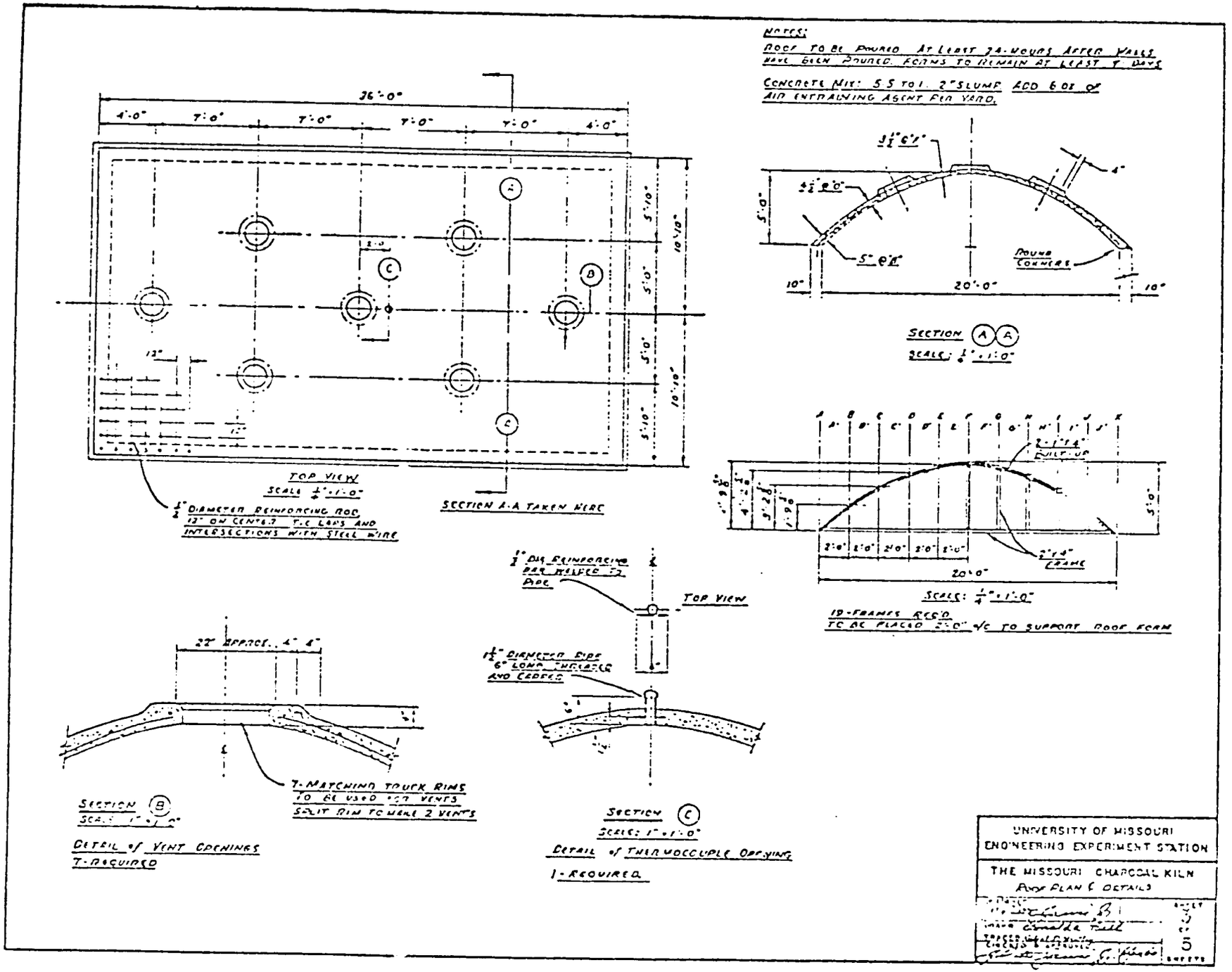
The Missouri Charcoal Kiln. Wall Construction details



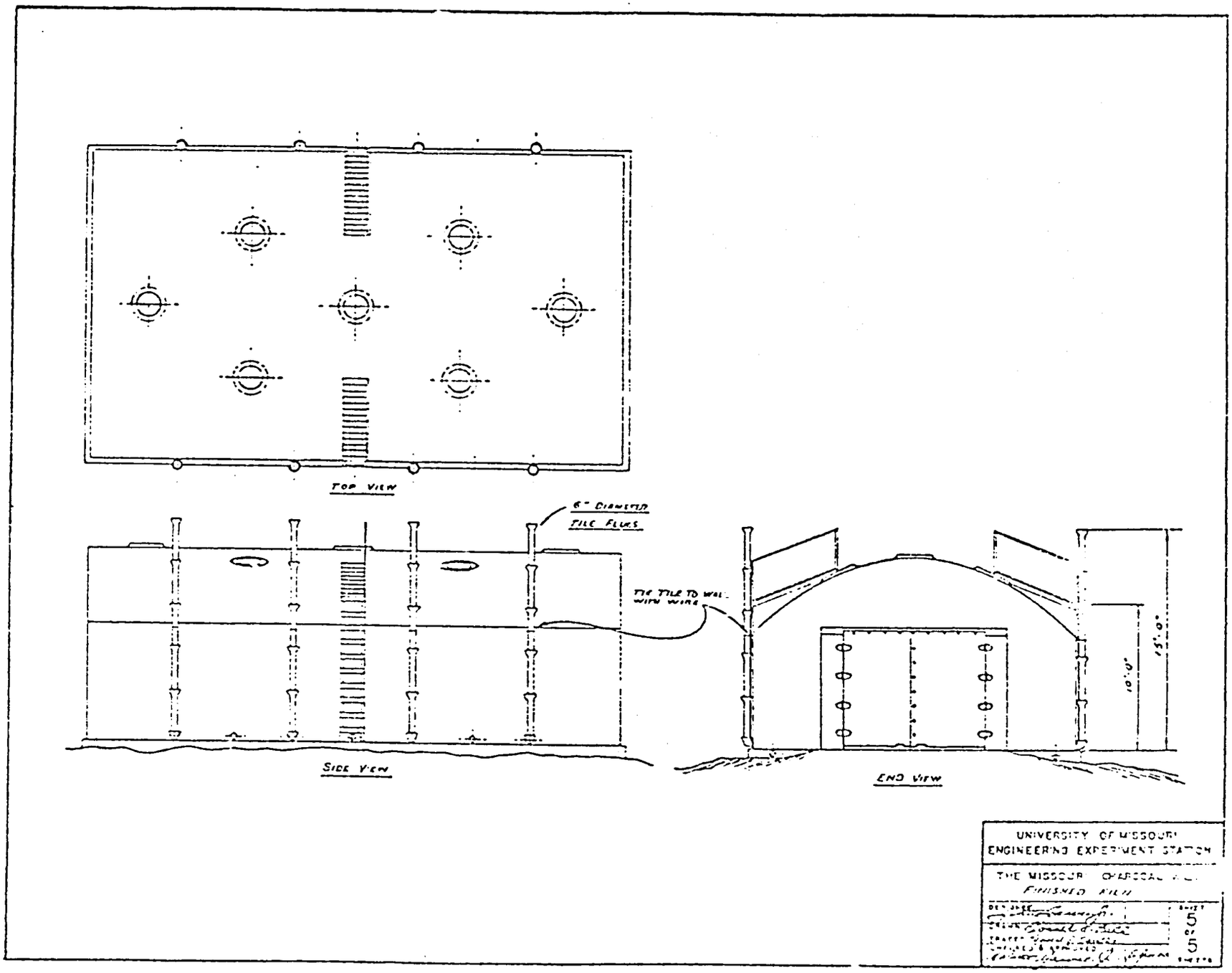
The Missouri Charcoal Kiln. Foundations Plan and details.



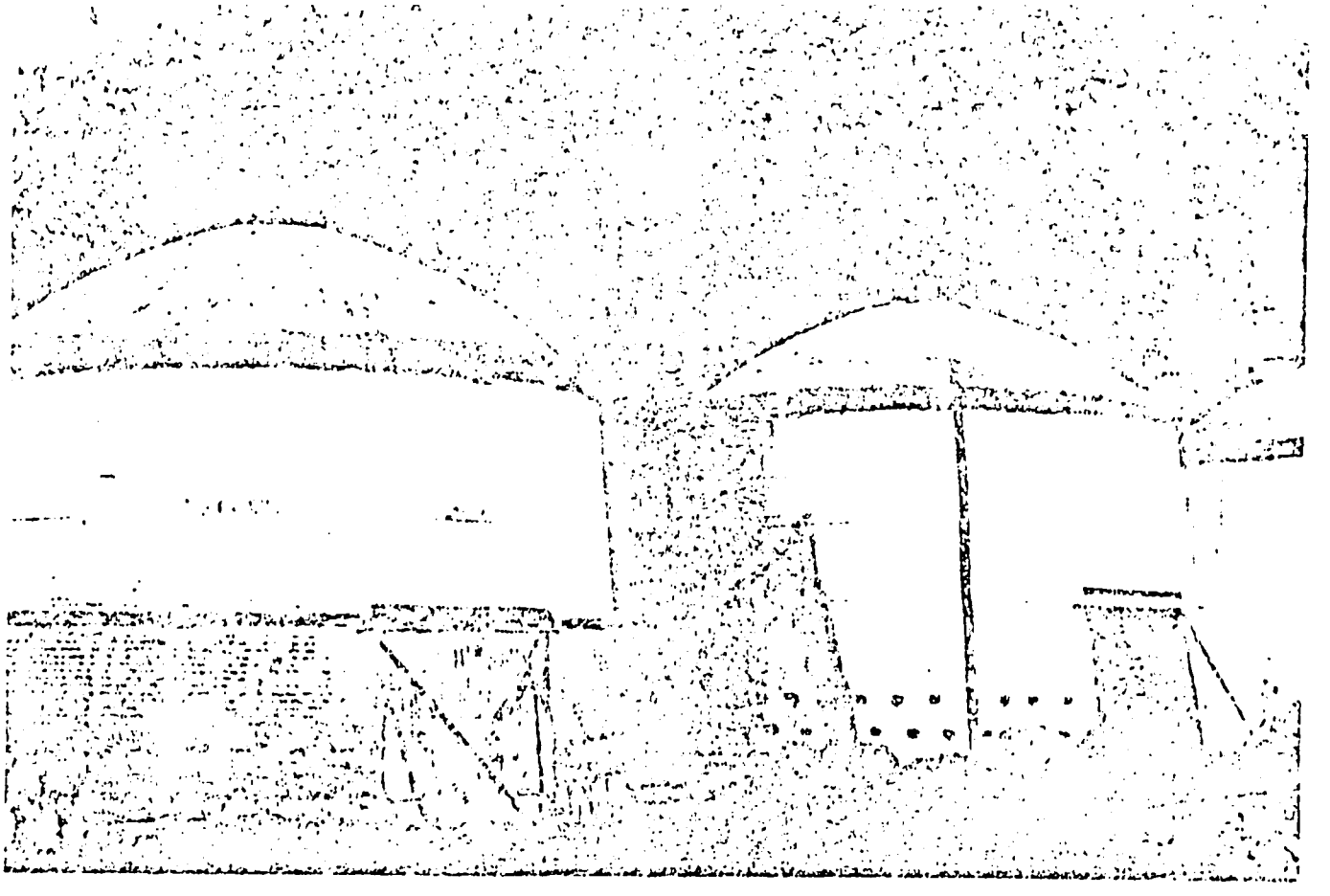
The Missouri Charcoal Kiln. Steel details.



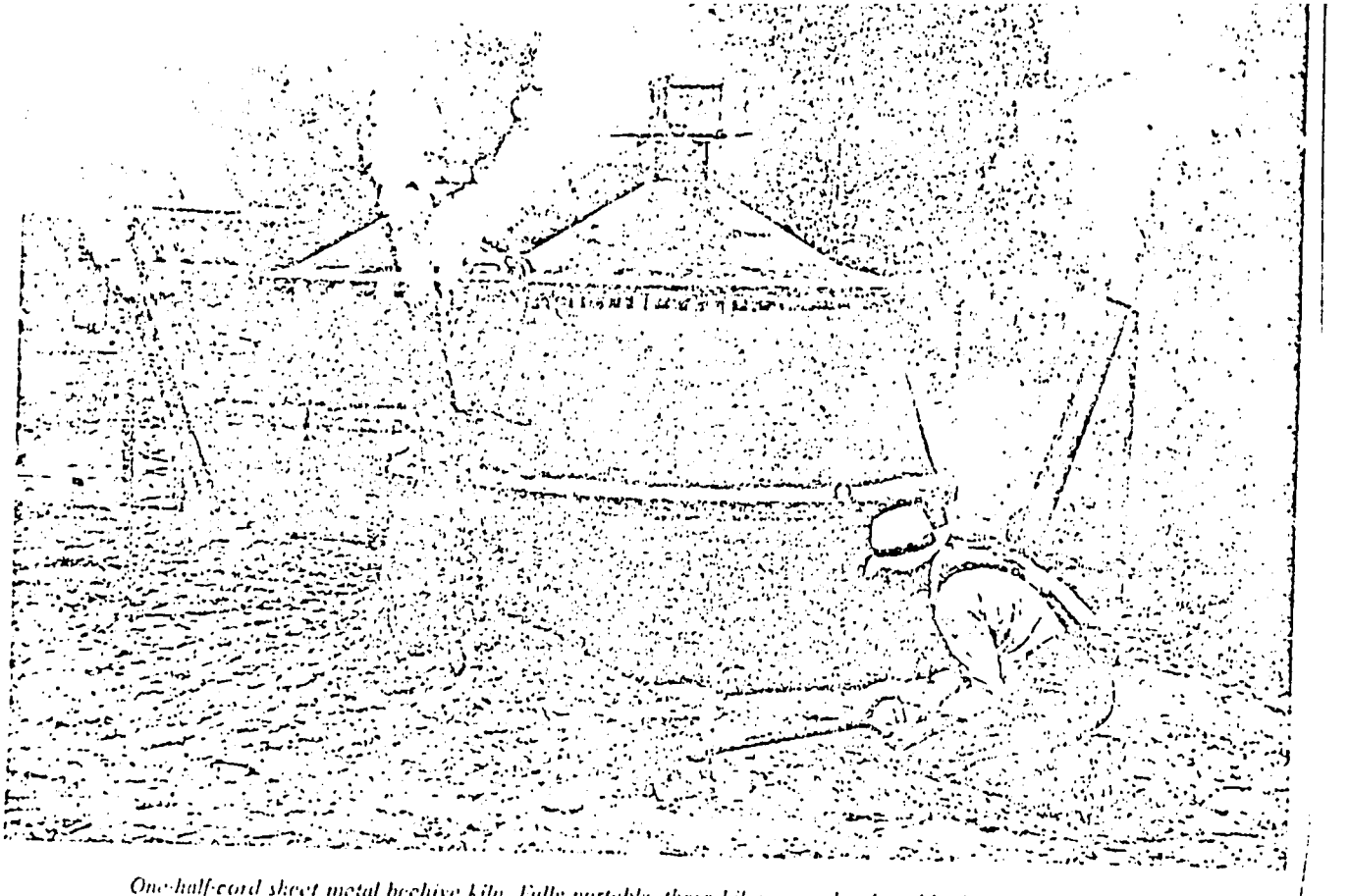
The Missouri Charcoal Kiln. Roof Plans and details.



The Missouri Charcoal Kiln. Finished Kiln.



Brick beehive kilns--large-scale conversion of low-grade wood.



One-half-cord sheet metal beehive kiln. Fully portable, these kilns were developed in the 1930's and were still in use in the 1960's. The kiln shown here is in the coaling phase. (Photo from Page and Wyman 1969.)

HERRESHOFF (BRANDESVILLE,MISSOURI)

INPUT: 10 TONS/HR 240 TONS/DAY

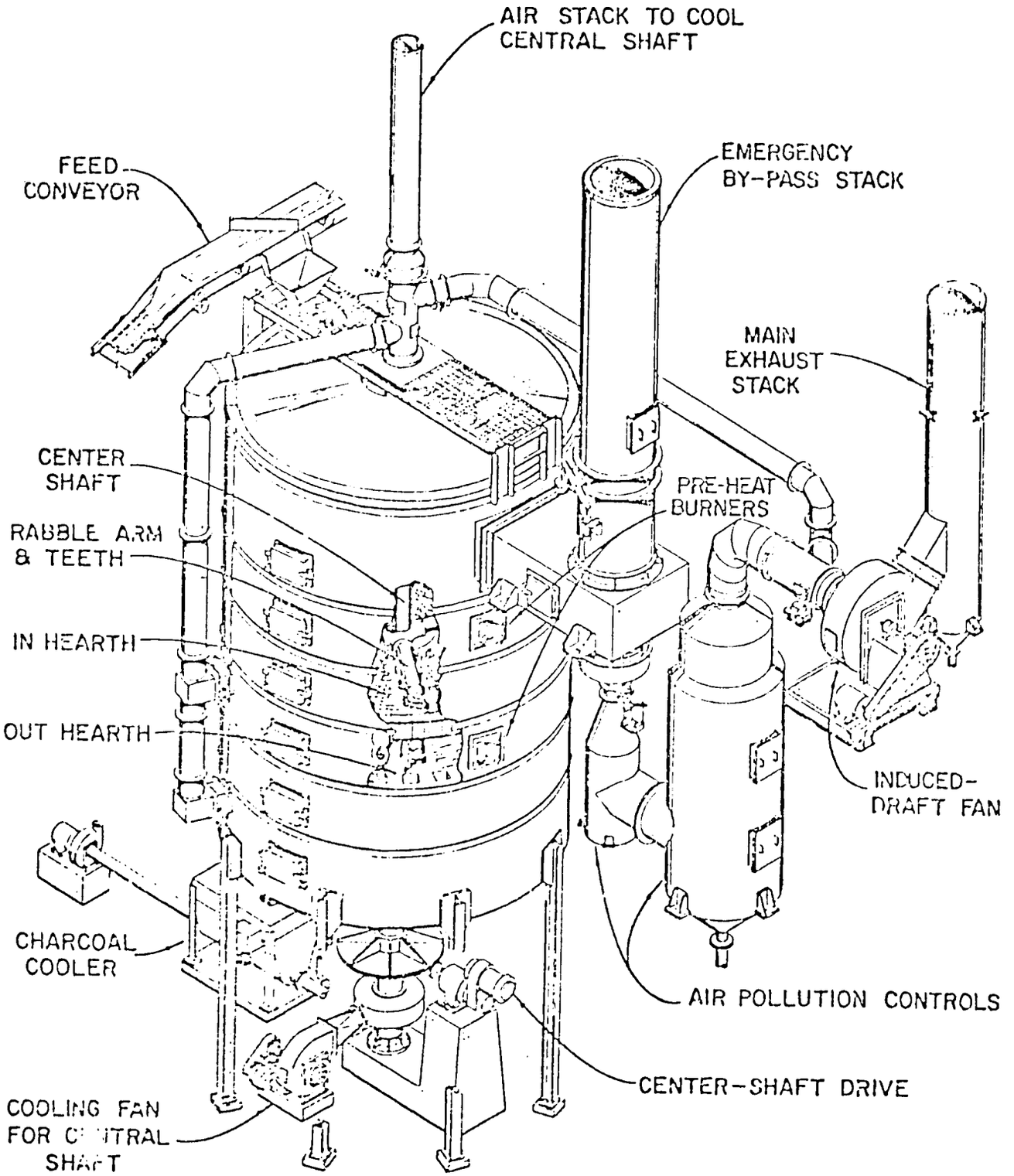
OUTPUT: CHAR 2500 LB/HR (1¼ TONS/HR) 30 TONS/DAY

WOOD (AS RECEIVED)		CHAR (DRY)
MOISTURE	30.97	
ASH	2.74	16.27
VOLATILES	59.04	18.24
FIXED CARBON	7.25	65.49
SULFUR	.03	.05
HEAT COMBUSTION	5,948	12,151

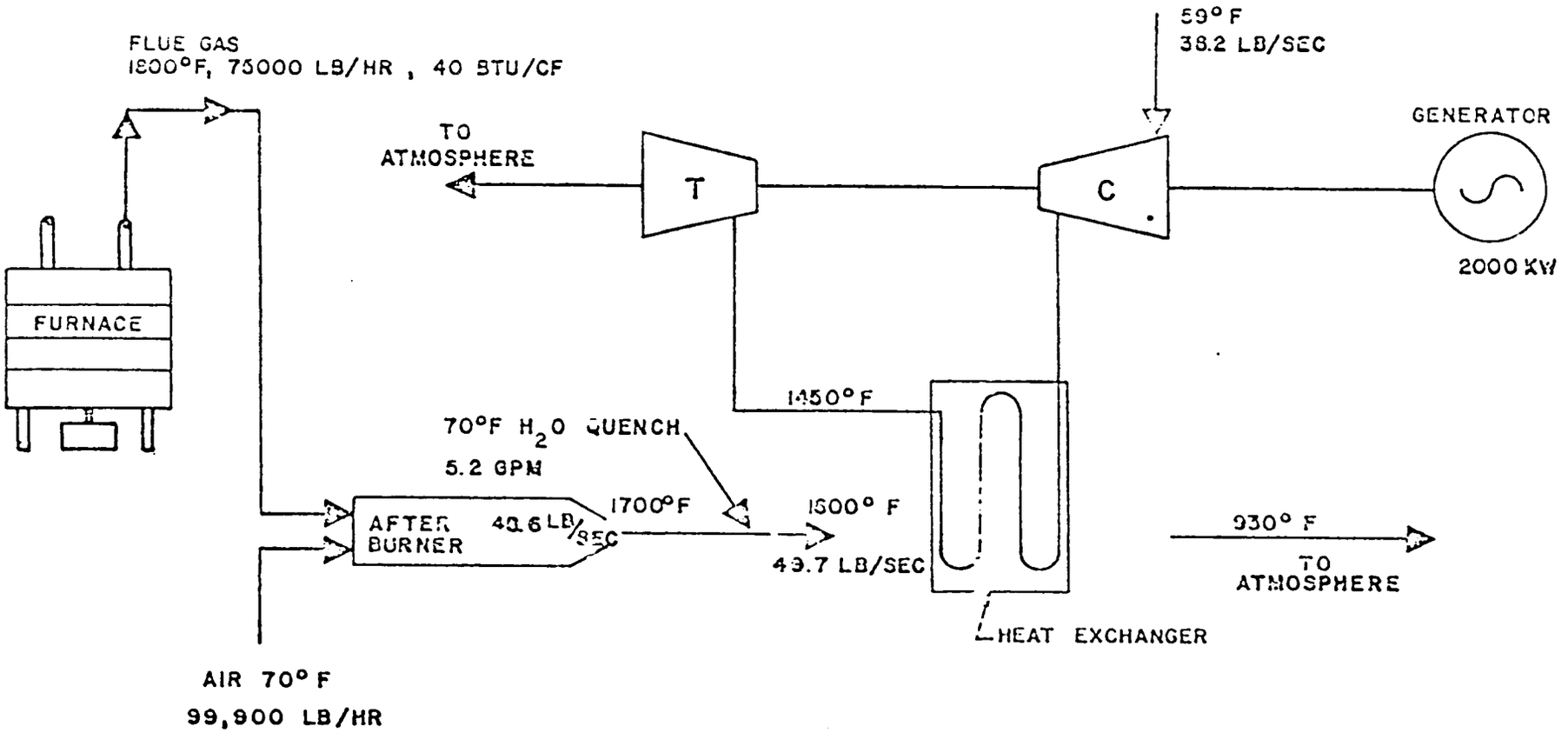
ENERGY IN 1.19×10^8 BTU/HR

ENERGY OUT (CHAR) 22,132,500
(FLUE GAS) 96,000,000

POSSIBLE GENERATION (SOLAR INDIRECTED FIRED GAS TURBINE) 4000 KW (14% EFF)



Nichols-Herreshoff multiple hearth furnace for the production of wood charcoal. (Drawing from Nichols Engineering and Research Corporation.)



ENGINEERING APPLICATIONS INC.	EXHIBIT 10 INDIRECT TURBINE CYCLE

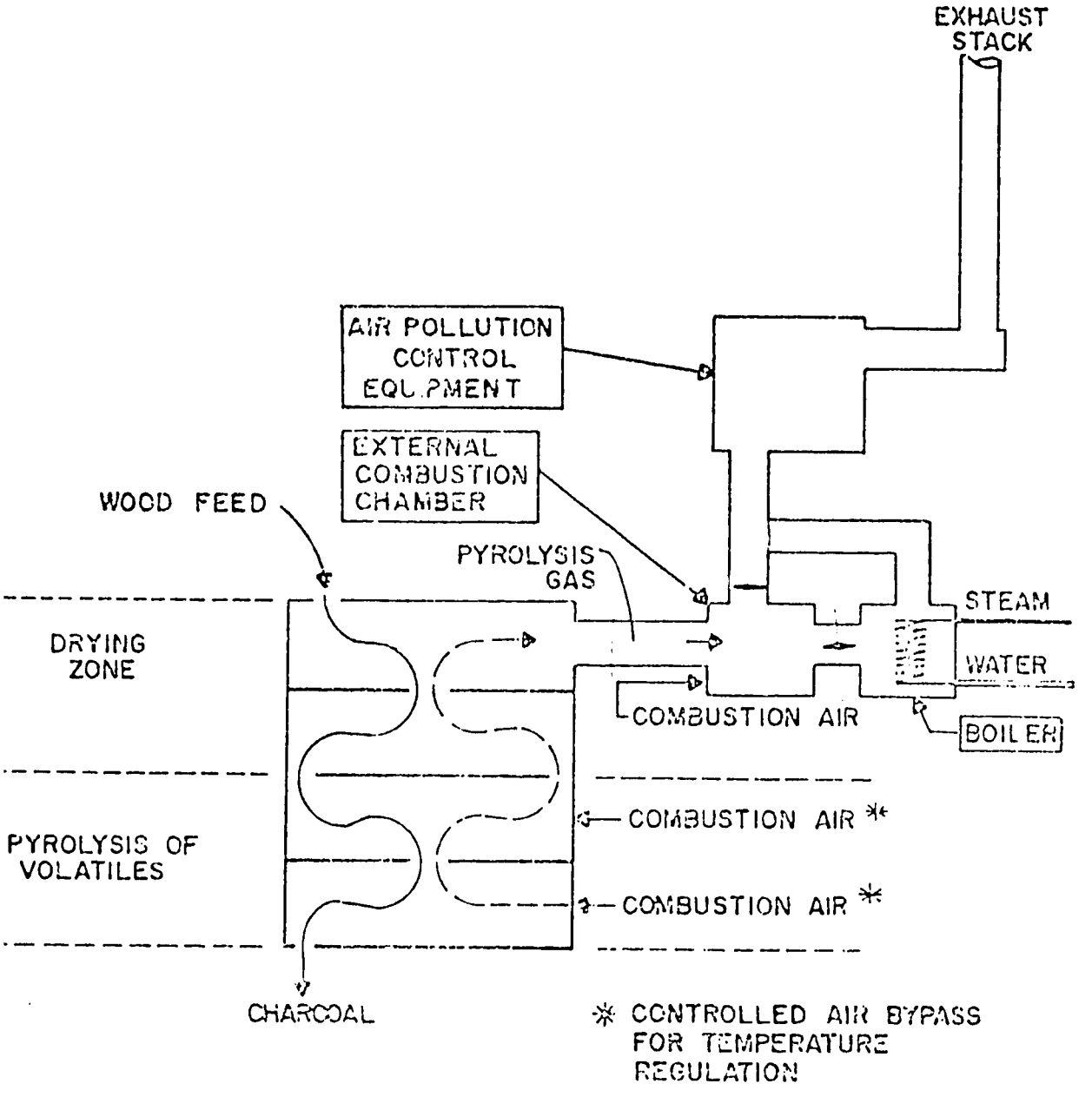
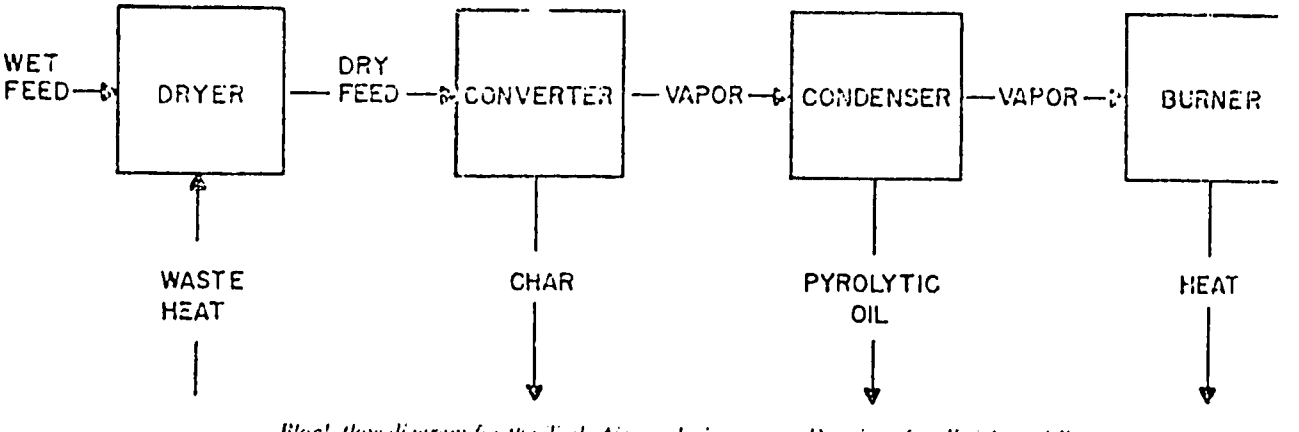


Figure 5-3.—Feed and gas flow diagram for the Nichols-Herreshoff multiple hearth furnace.



Block flow diagram for the Tech-Air pyrolysis system. (Drawing after Knight and Bowen[9])

RICE HULL DATA SUMMARY RAF 10-24-83

1) FEED RATES (AS RECEIVED)

TOTAL - 2571 LB/HR = 30.85 TON/DAY
RICE HULLS 750 LB/HR = 9 TON/DAY
ASH 250 LB/HR = 3 TON/DAY

2) REDUCTION (RICE HULLS) 33% (AS RECEIVED) 35.12%(DRY)

3) ASHING DATA

A) FEED STOCK	5.5% WET	7% DRY
B) RICE HULLS	18.94% WET	20.47% DRY
C) ASH	56.75% WET	57.95% DRY

4) FIXED CARBON CONVERSION EFFICIENCY 7.41%

5) HEAT LOSS DUE TO CARBON IN ASH 31.75% DRY
34.32% AS RECIEVED

6) "SCALE-UP" TO 100% RICE HULLS
FEED 30 TON/DAY
ASH 10 TON/DAY
ENERGY AVAILABLE 10.3×10^6 BTU/HR
ASSUME 20% MORE LOSSES IN BOILER = 8.24 -10^6BTU/HR (BOILER=246 HP)

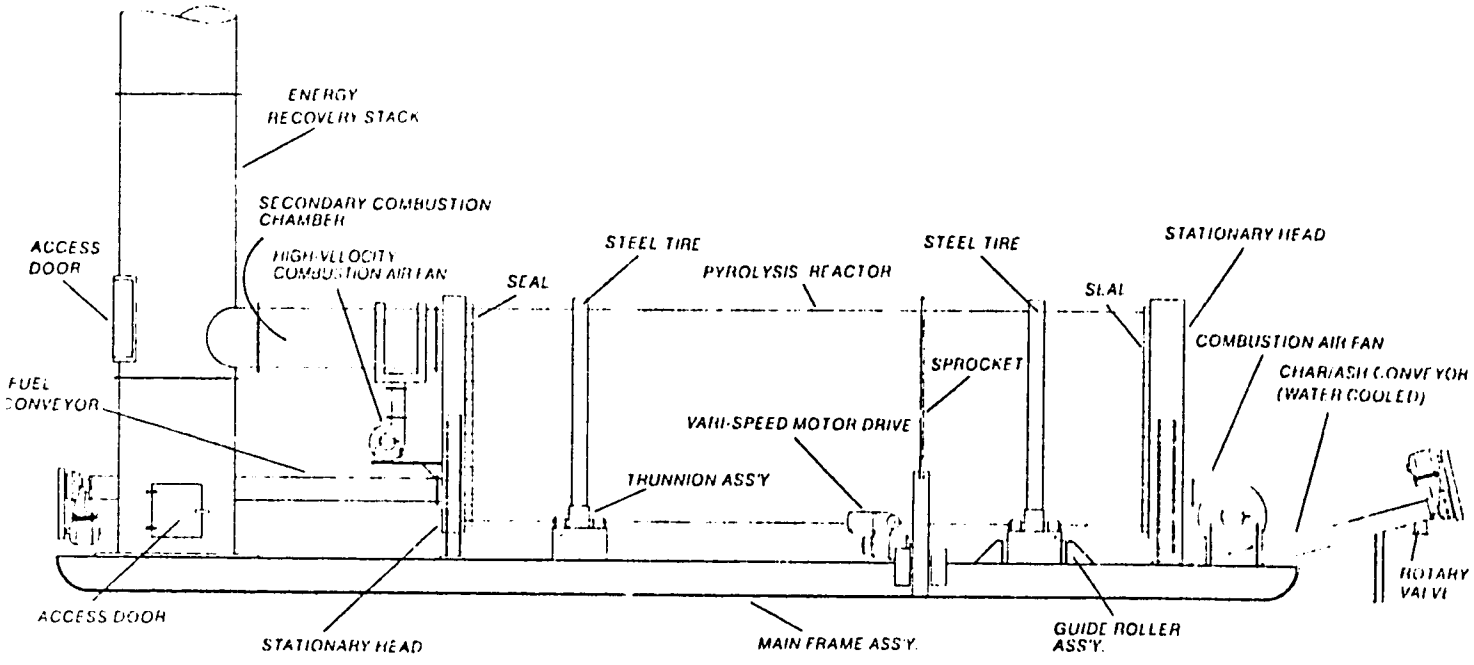
7) RICE HULL DATA DENSITY 9.38 LB/FT^3

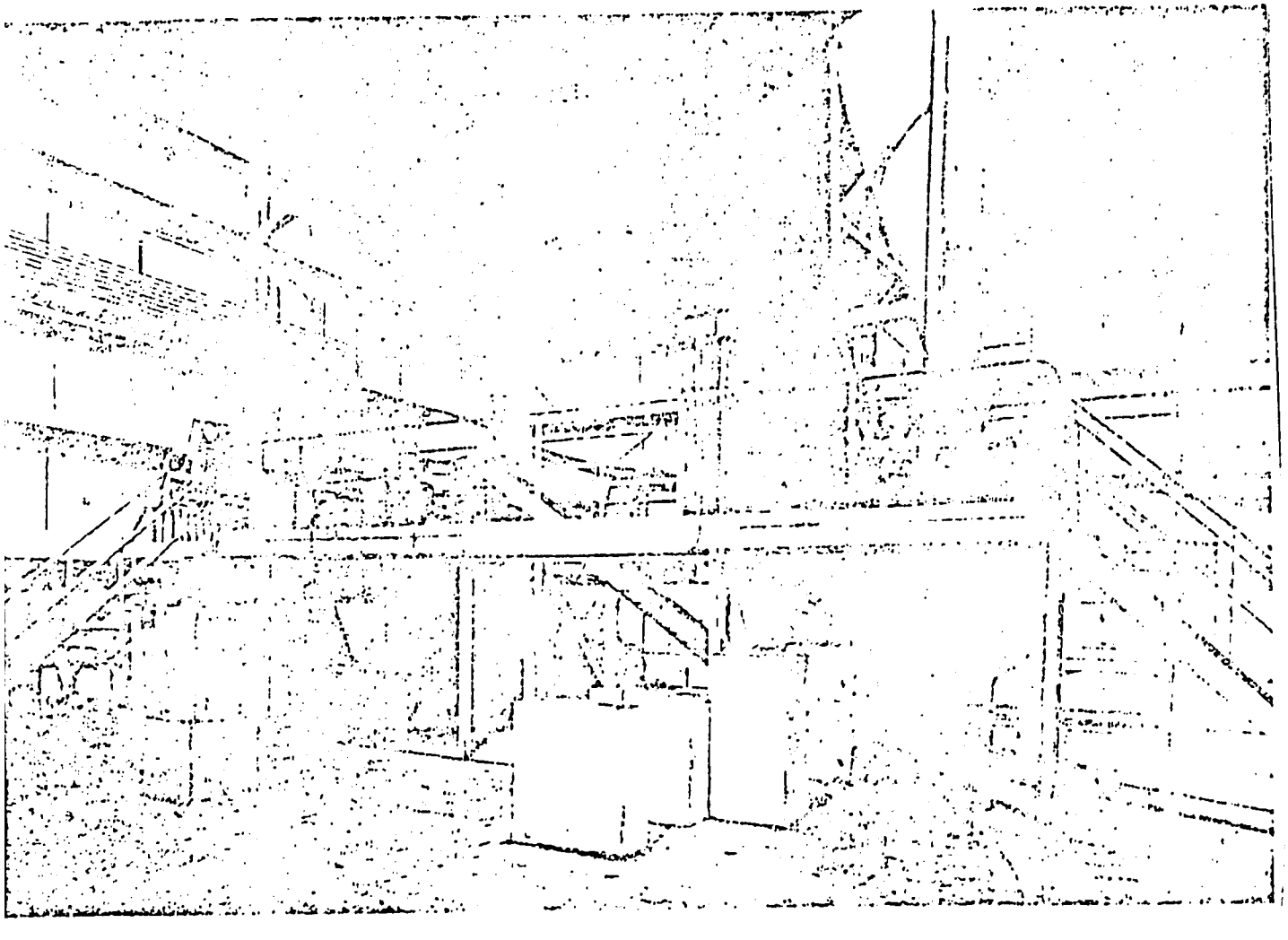
PROXIMATE	AS - RECEIVED	DRY
M	7.48%	
V.M	58.84%	63.60%
F.C	14.74%	15.93%
ASH	18.94	20.47%
HHV	6.274 BTU/LB	6.781 BTU/LB

ULTIMATE (DRY)

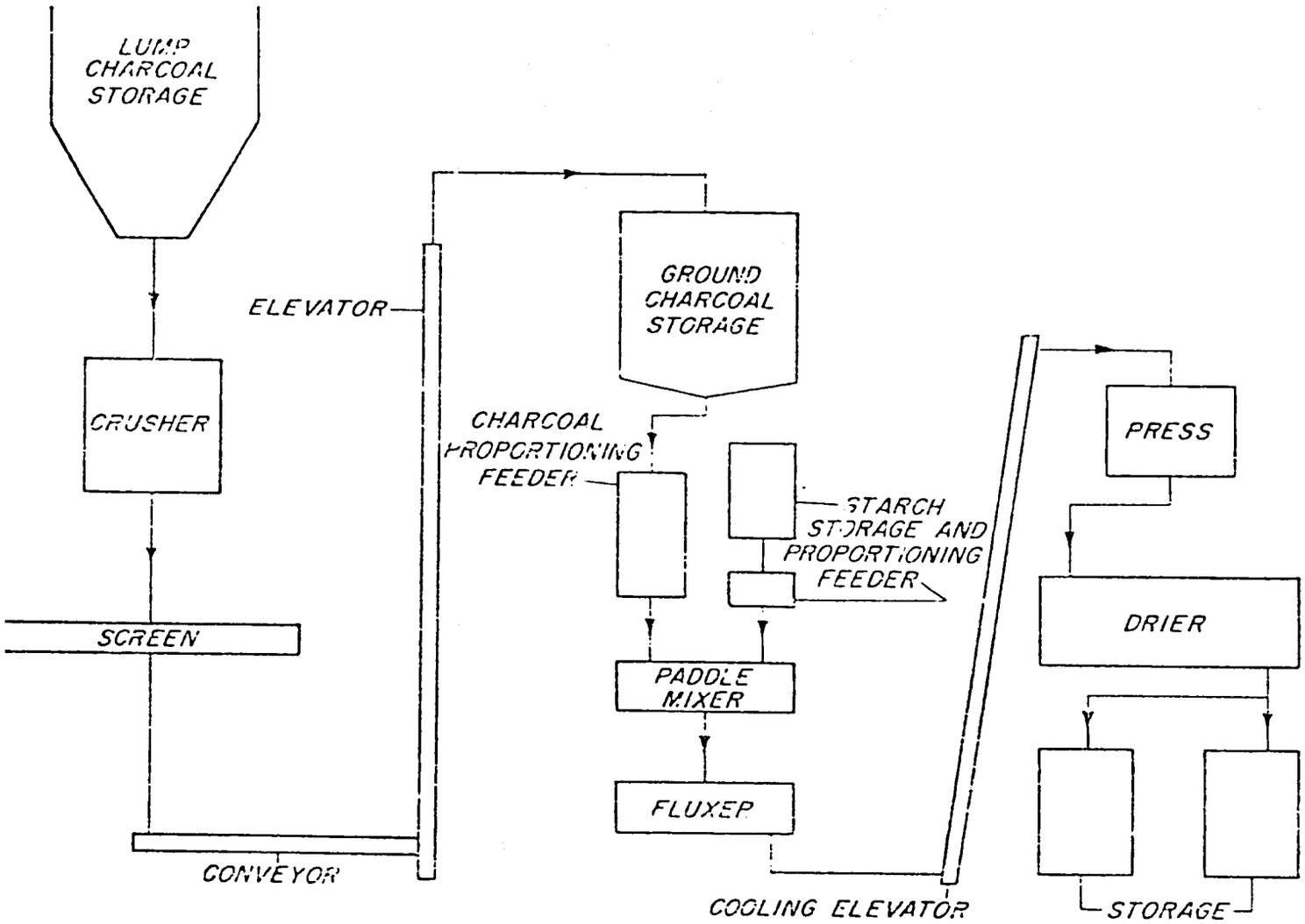
CARBON -	39.47%	OXYGEN	35.71%
HYDROGEN	4.01%	Nitrogen	.30%

ROTARY FURNACE PYROLYSIS/COMBUSTION SYSTEM

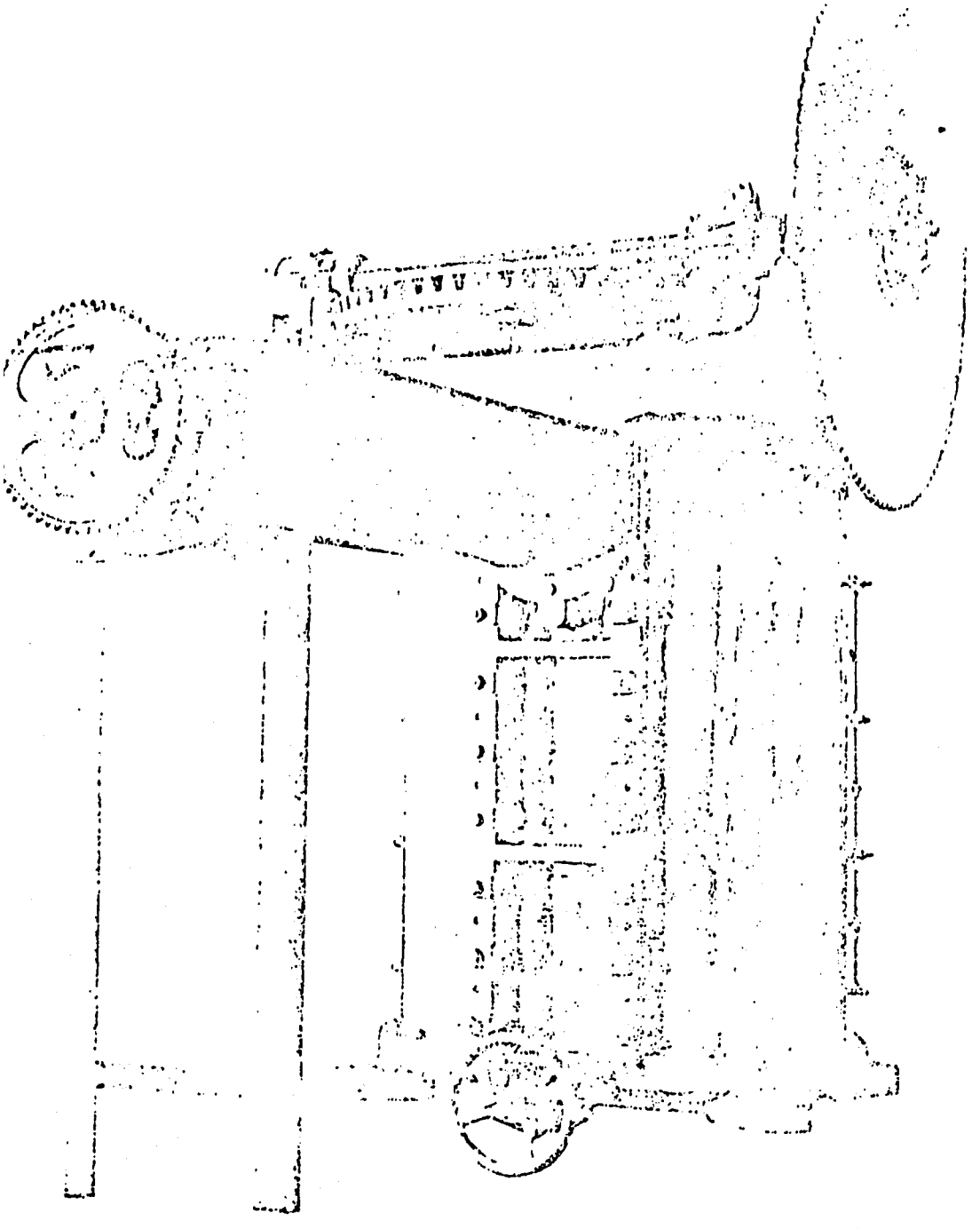




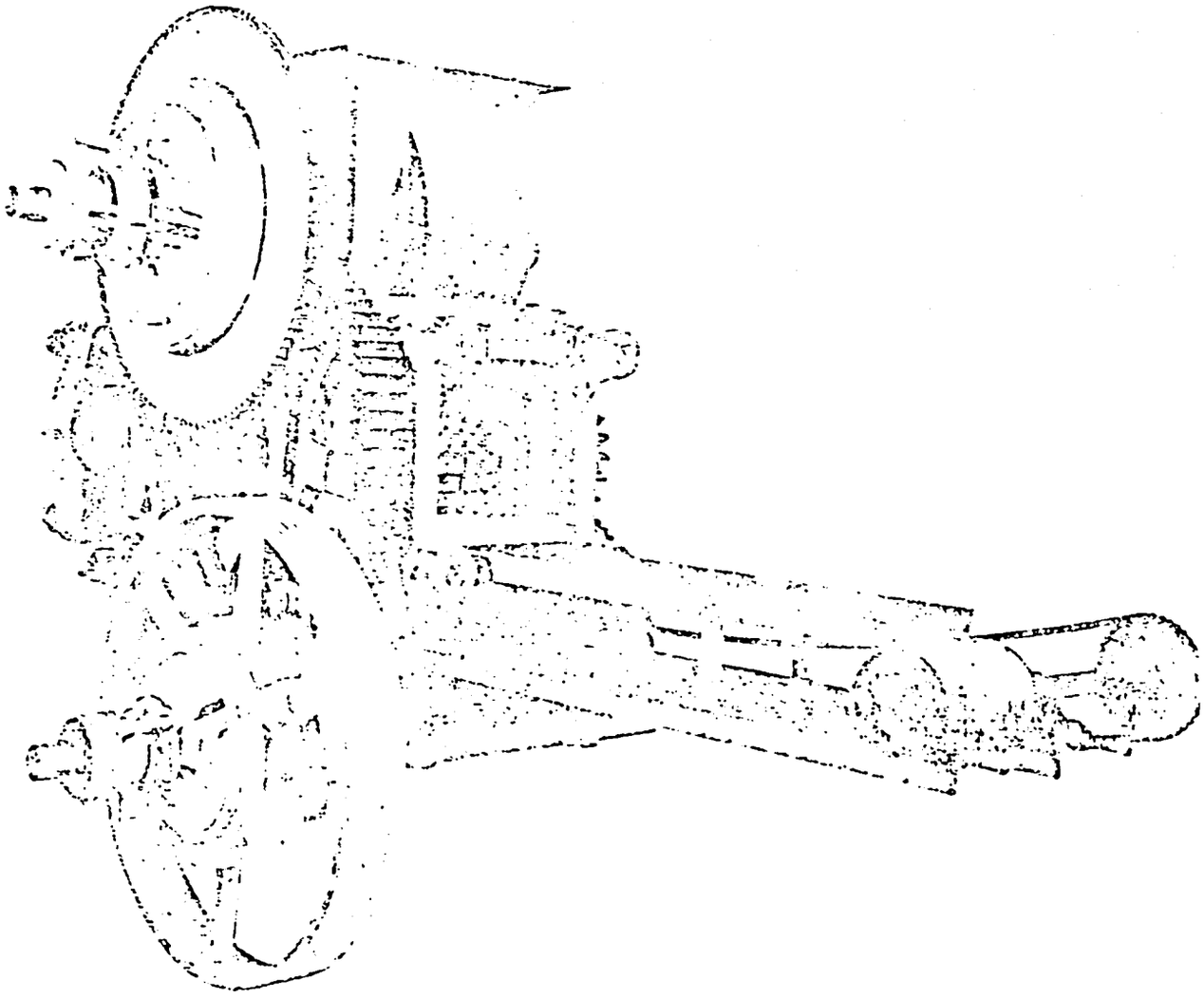
Charcoal briquetting plant.



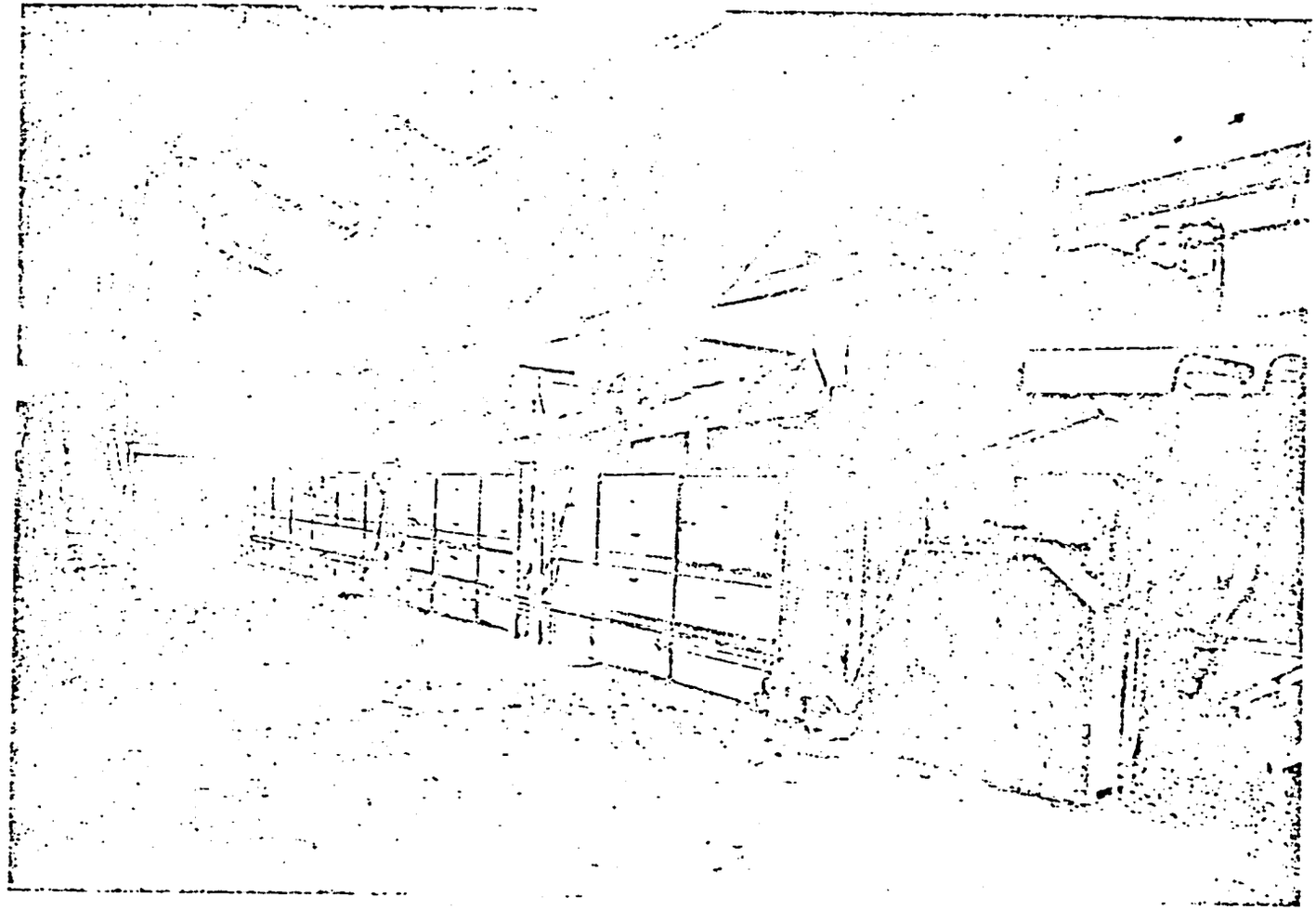
Flow diagram of a commercial process for the manufacture of charcoal briquettes.



Two-shaft, vertical fluxer and paddle mixer.



Charcoal briquette press.



Charcoal briquette drier.

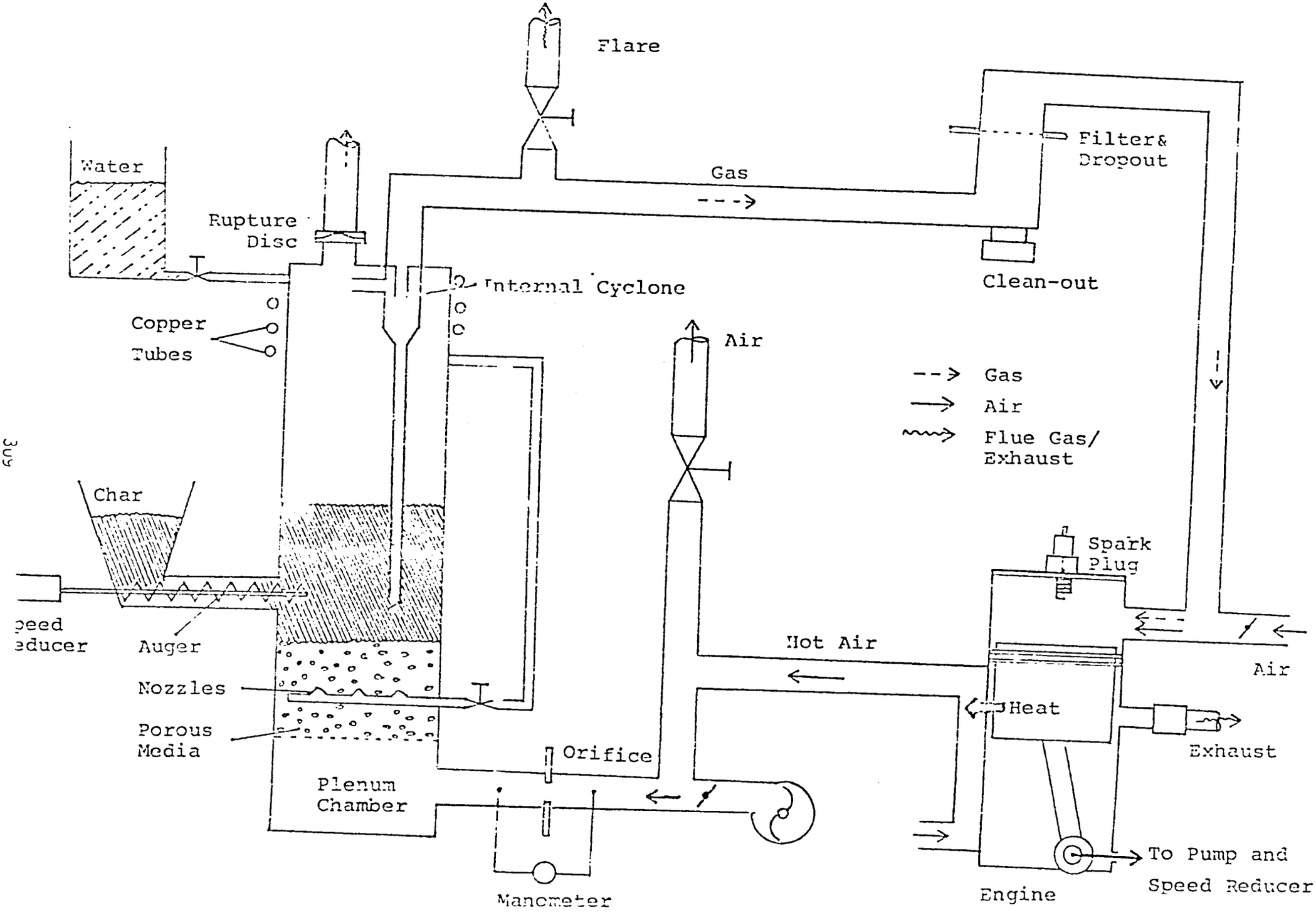
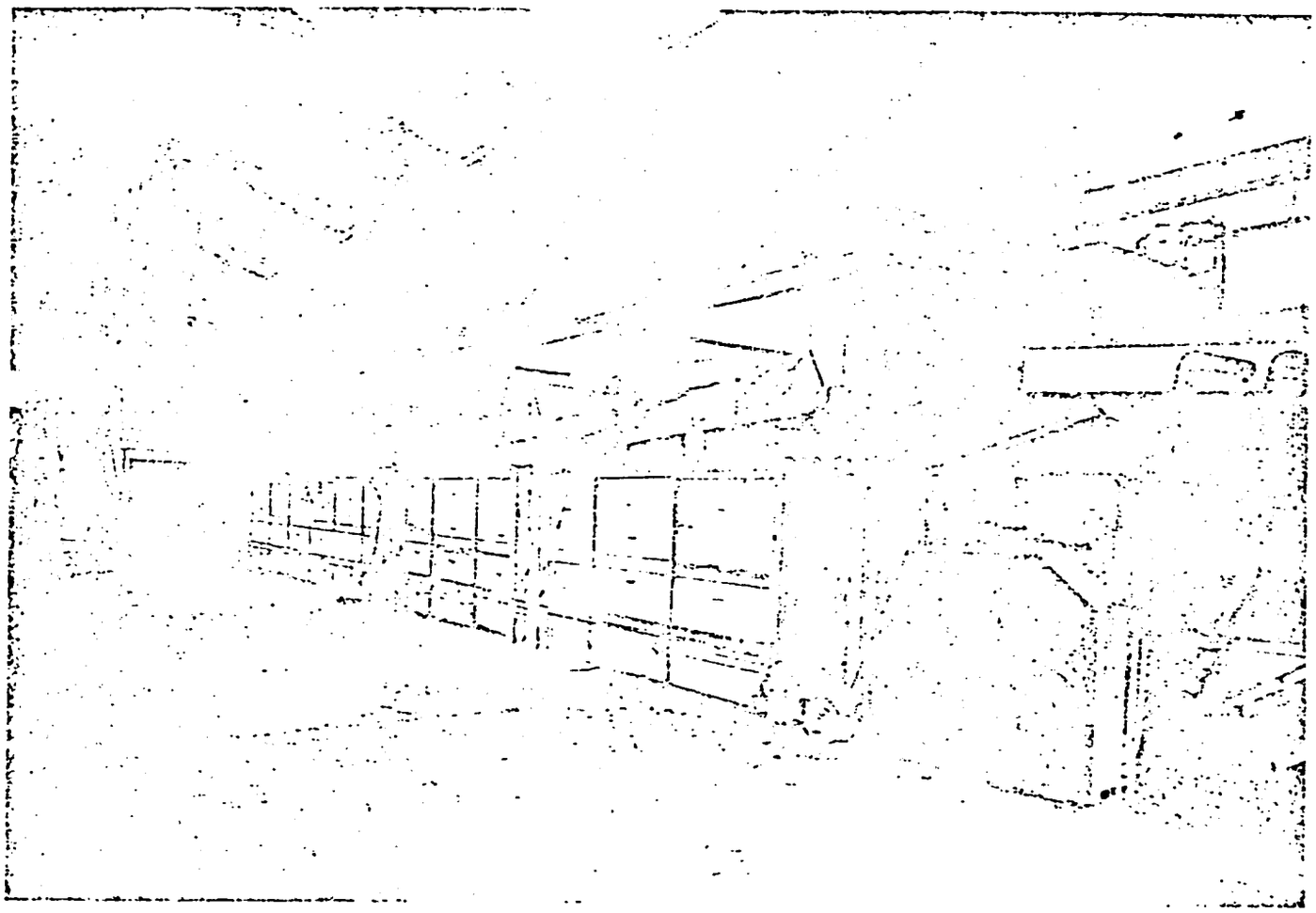


Figure 4. Fluidized Bed Gasifier - Engine Set



Charcoal briquette drier.

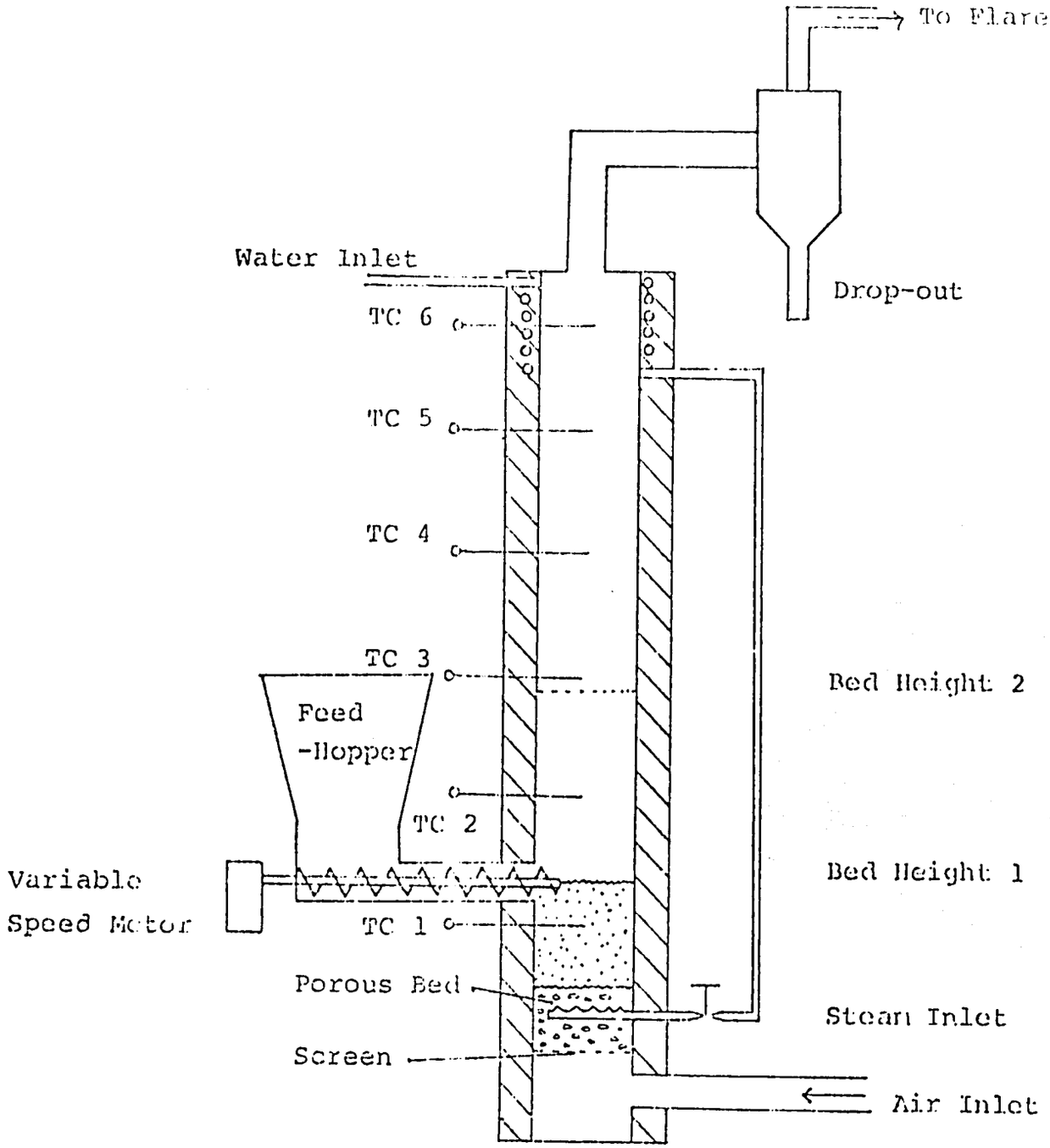


Fig. 1 4" Fluid-Bed Char Gasifier

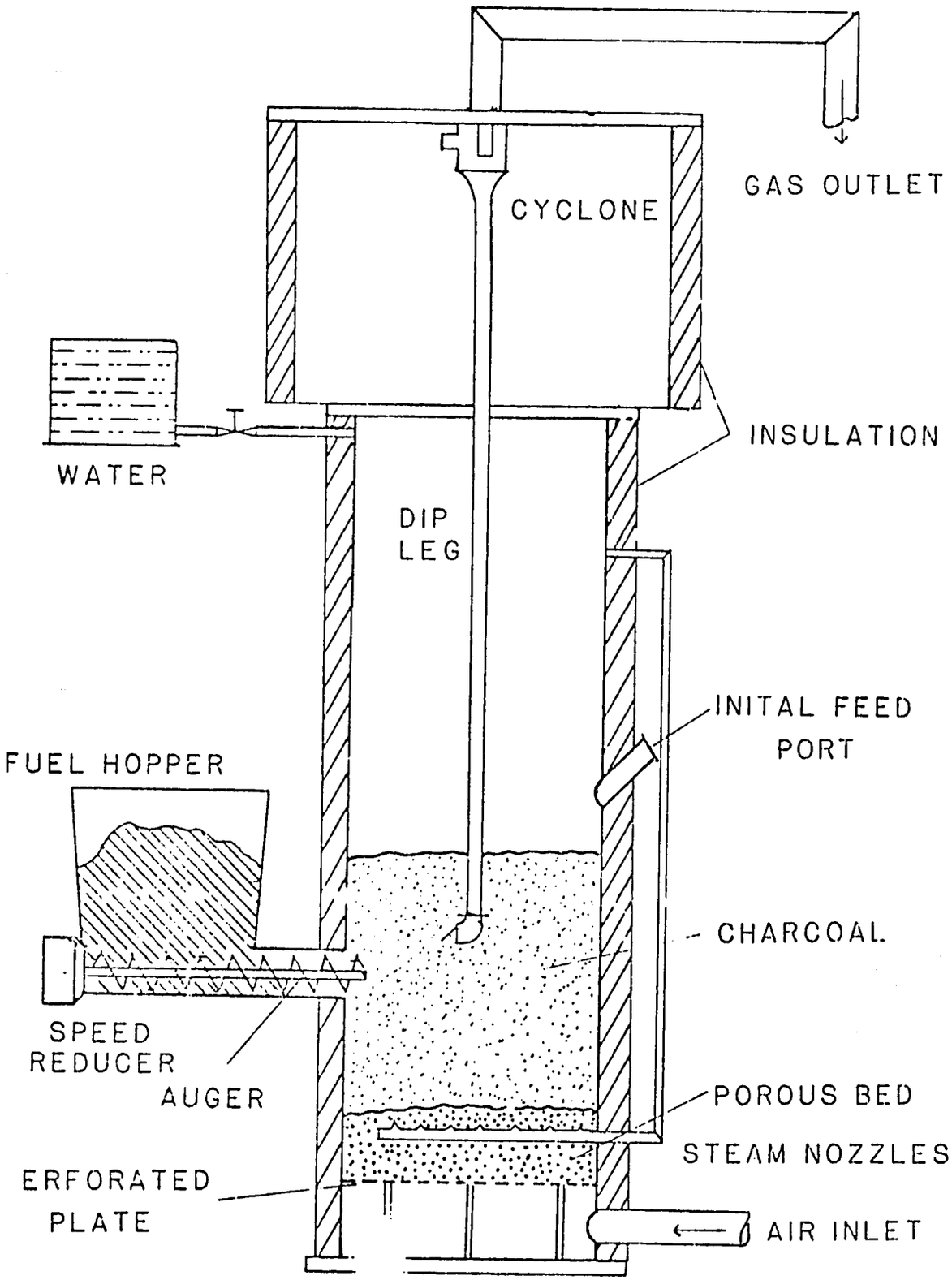


FIGURE 4 – 4" FLUIDIZED BED REACTOR

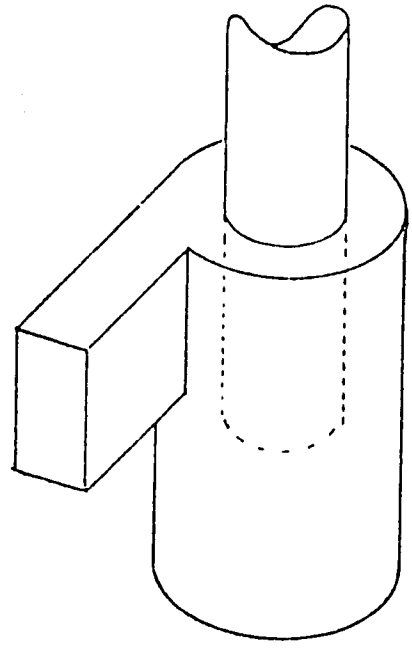


FIGURE 5 - 2" CYCLONE

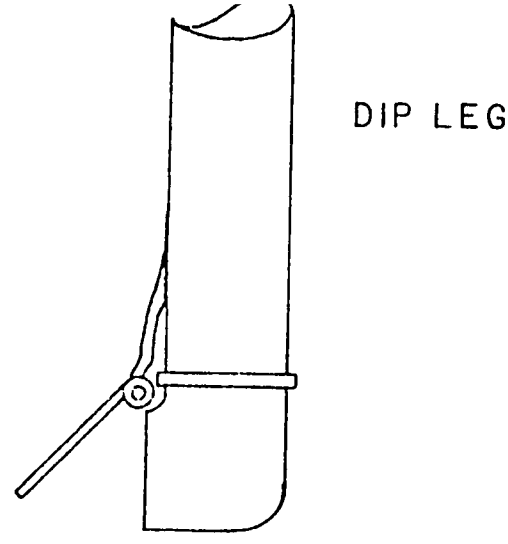


FIGURE 6 - TRICKLE VALVE

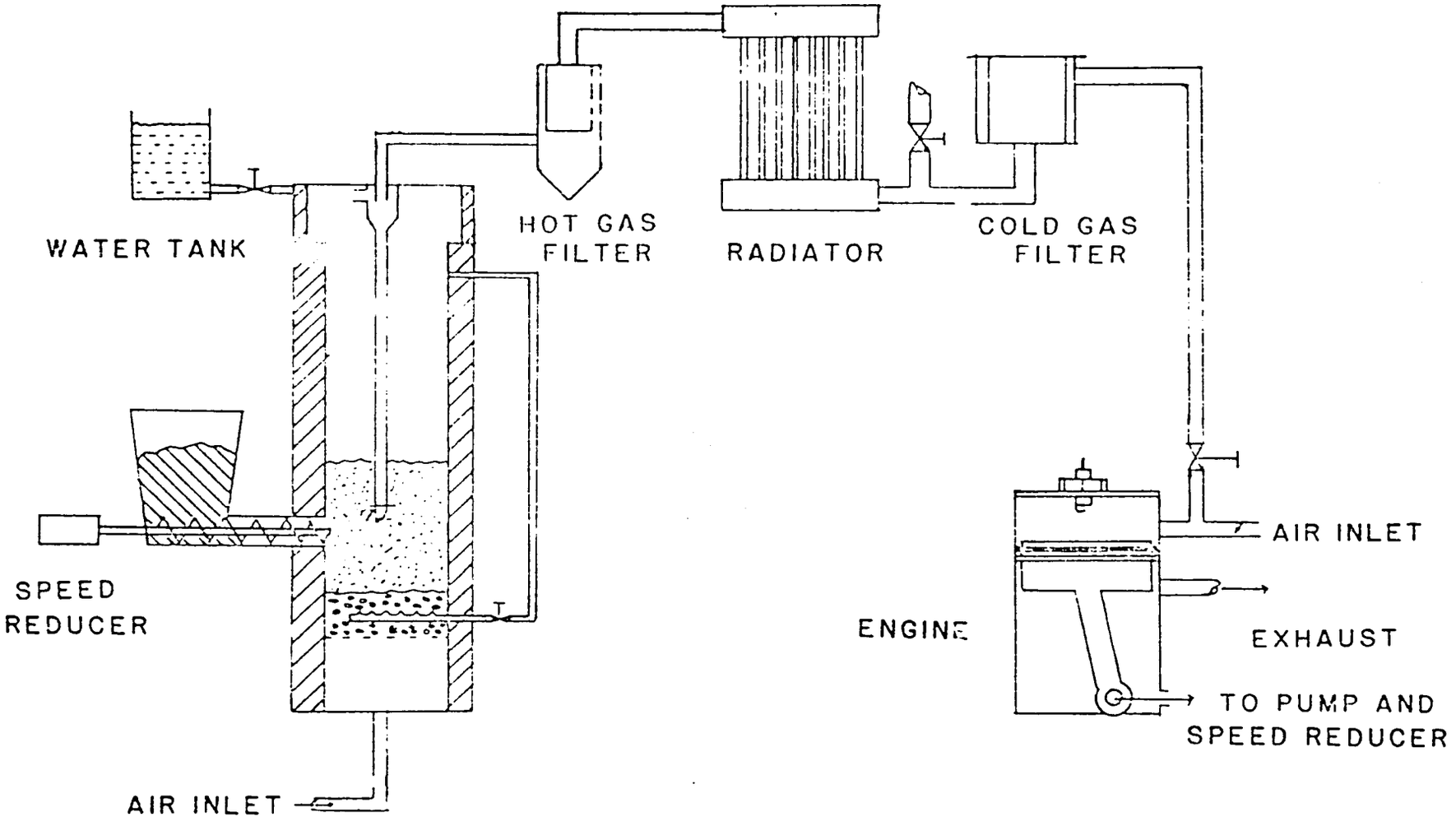


FIGURE 10 – 4" FLUIDIZED BED GASIFIER–ENGINE SYSTEM

TABLE IV

ANALYSIS OF THE CHARCOAL USED IN THE

4" FLUIDIZED BED REACTOR

Fixed Carbon	66.16
Volatile Matter	21.36
Ash	8.74
Moisture	3.74

TABLE V

ANALYSIS OF THE CHAR PRODUCED IN THE

4" FLUIDIZED BED REACTOR

	Run #10	Run #12
Fixed Carbon	78.91	55.14
Volatile Matter	10.09	-
Ash	10.09	40.30
Moisture	0.91	4.56

TABLE I.

ANALYSIS OF CHARCOAL USED BY

NATIONAL RESEARCH COUNCIL OF CANADA (%)

Fixed Carbon	71.1
Volatile Matter	21.0
Ash	2.1
Moisture	5.8
HHV, Btu per lb.	12,690

TABLE II.

ANALYSIS OF CHARCOAL USED BY

TROPICAL PRODUCTS INSTITUTE (%)

Fixed Carbon	79.7
Volatile	11.4
Ash	2.3
Moisture	6.6
HHV, Btu per lb.	12,977

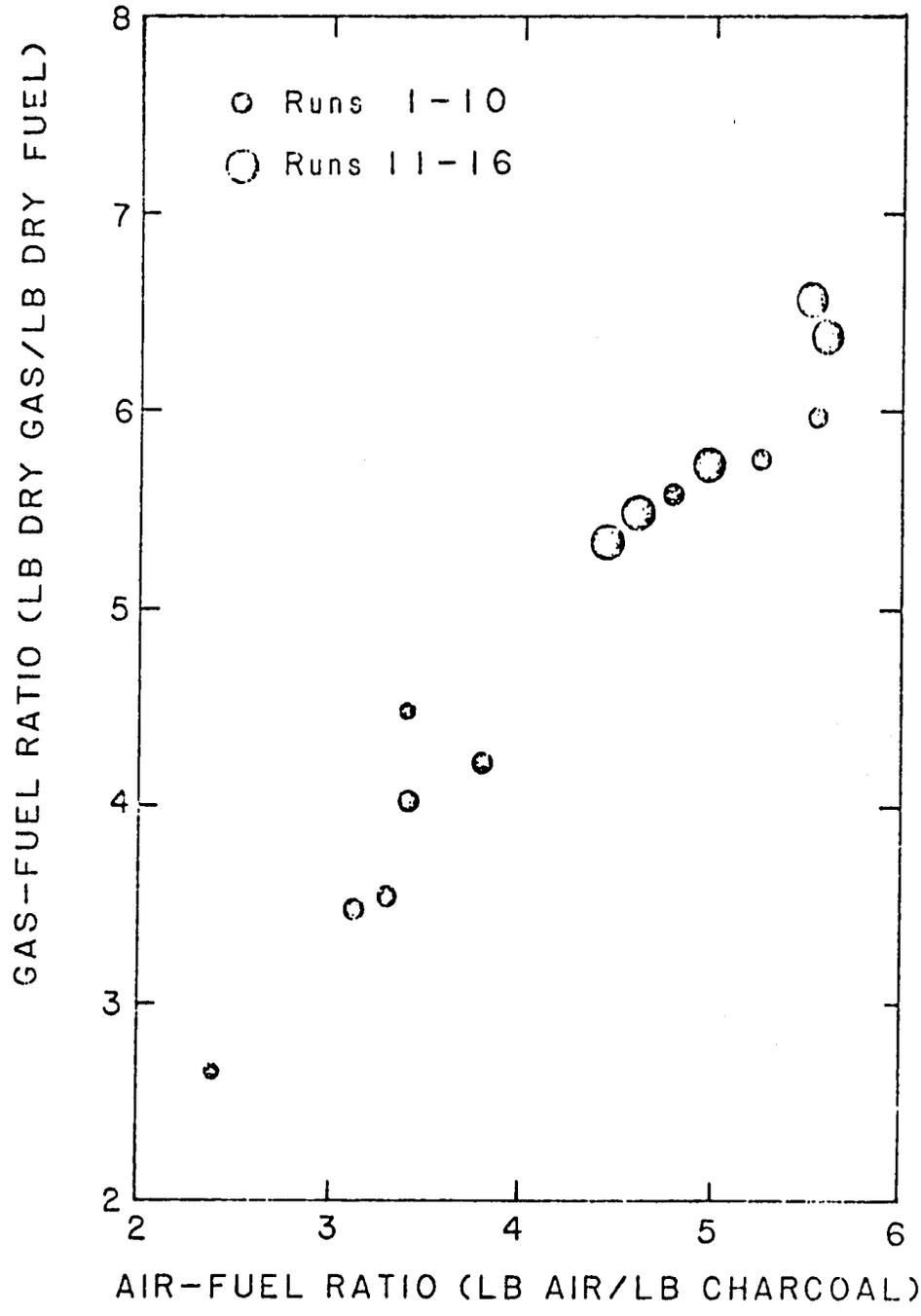


FIGURE 12 - GAS-FUEL RATIO Vs. AIR-FUEL RATIO

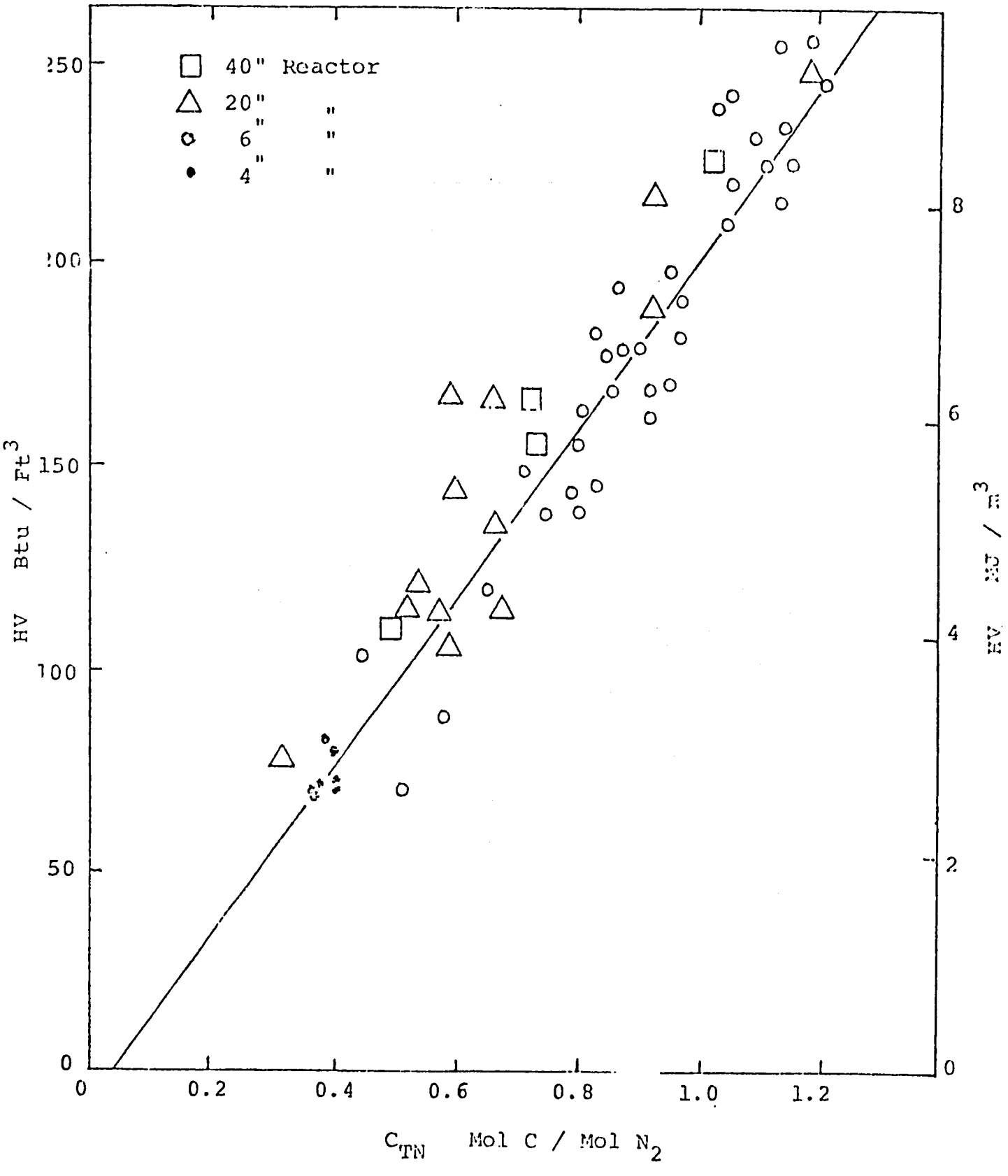

40" Reactor
20" "
6" "
4" "
250
200
150
100
50
0
HV Btu / Ft3
0
0.2
0.4
0.6
0.8
1.0
1.2
8
6
4
2
0
HV MJ / m3
CTN Mol C / Mol N2

Figure 2

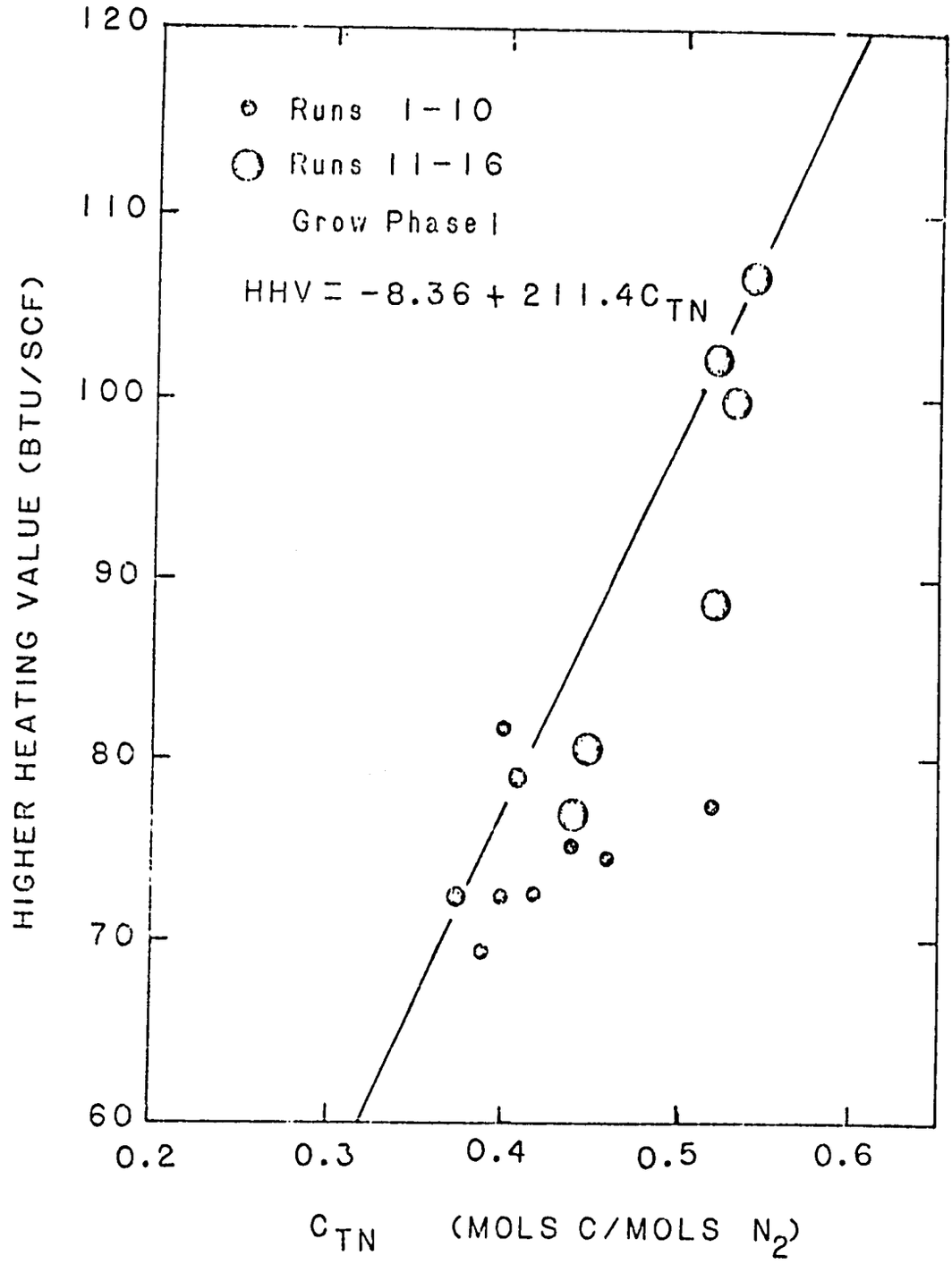


FIGURE 15 – HIGHER HEATING VALUE Vs. CARBON–NITROGEN RATIO

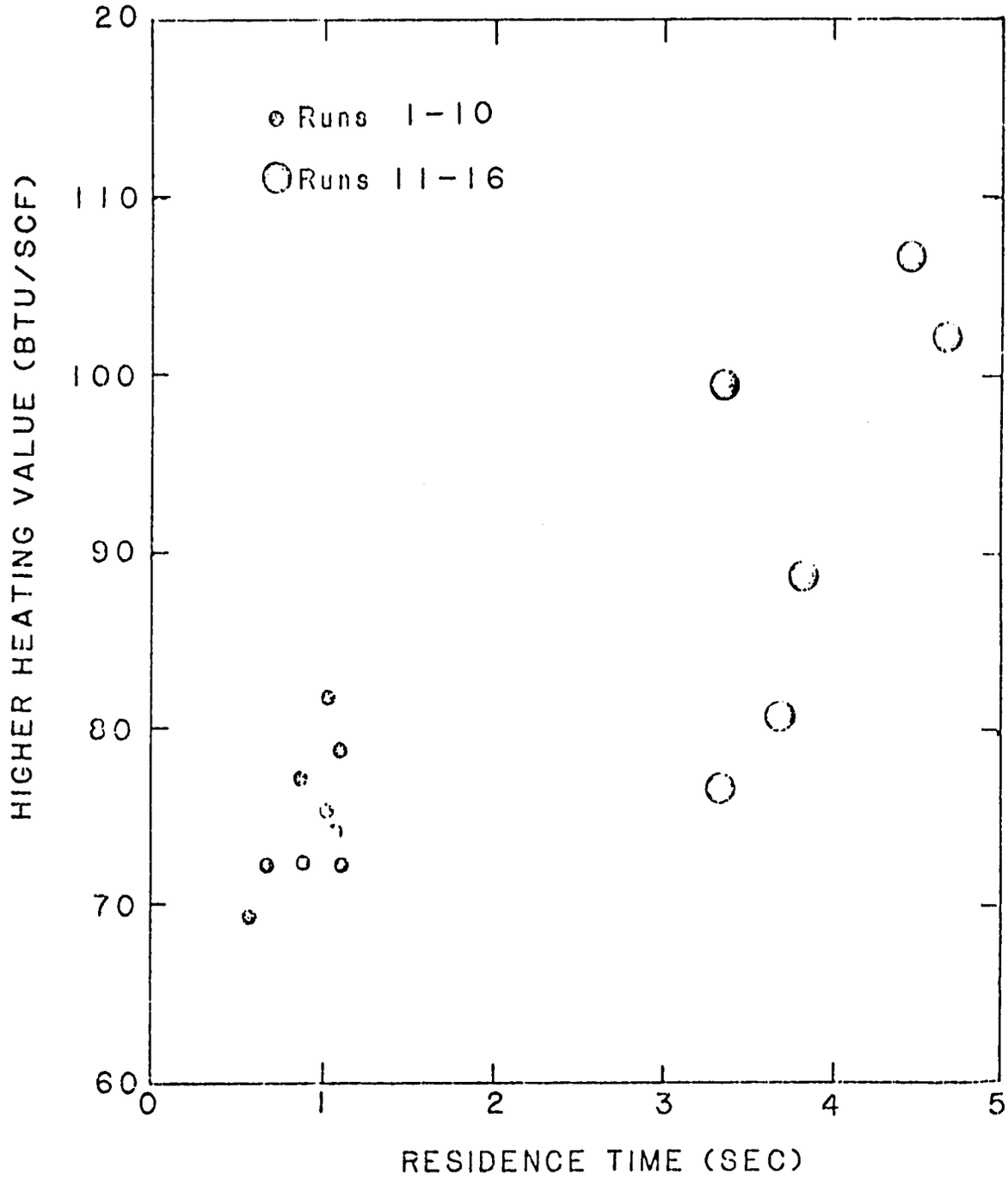


FIGURE 11 – HIGHER HEATING VALUE Vs. RESIDENCE TIME

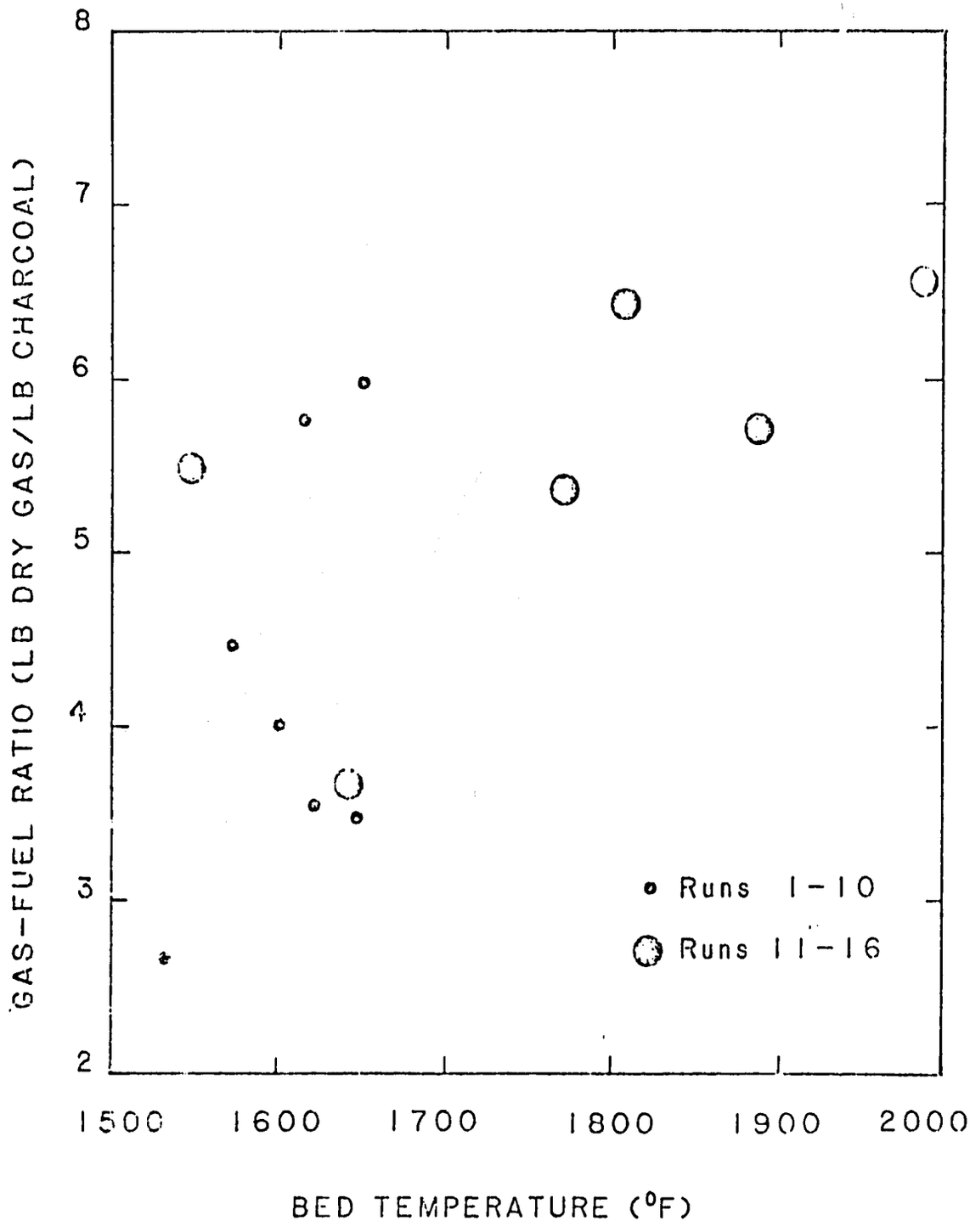


FIGURE 13 – GAS-FUEL RATIO Vs. BED TEMPERATURE

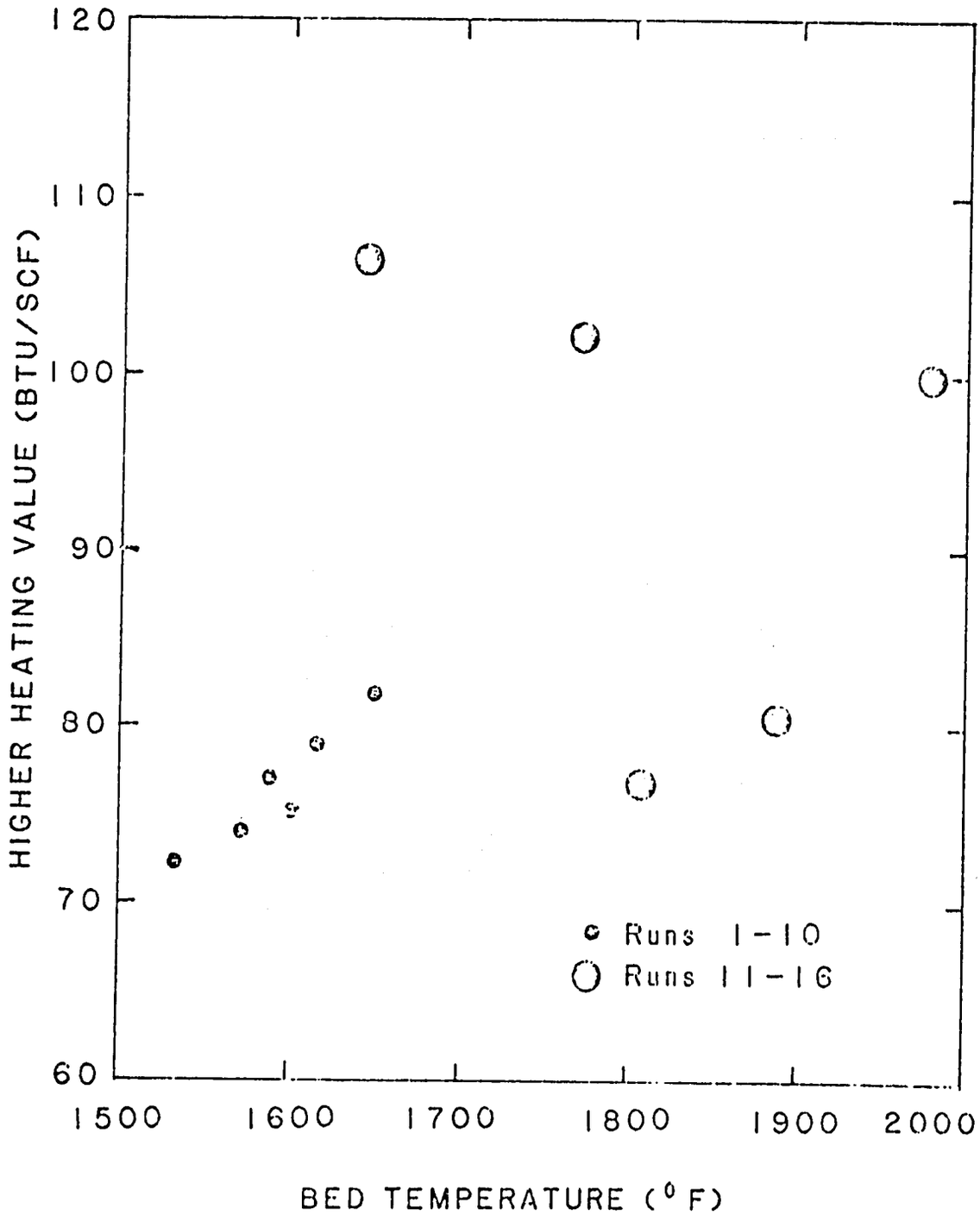


FIGURE 14 – HIGHER HEATING VALUE Vs. BED TEMPERATURE

CONCLUSIONS

1. SIMPLE DESIGN
2. MINIMUM CONSTRUCTION COSTS
3. HIGH SPECIFIC GASIFICATION RATES (54 - 75 $lb/ft^2Hr.$)
4. GASIFIES A VARIETY OF FEEDSTOCKS - EVEN THOSE WITH HIGH ASH CONTENT
5. CONSISTENT GAS PRODUCTION AND QUALITY (100Btu/SCF)
6. HIGH THERMAL EFFICIENCIES (96% CARBON CONVERSION)
7. NO OPERATIONAL SKILLS REQUIRED

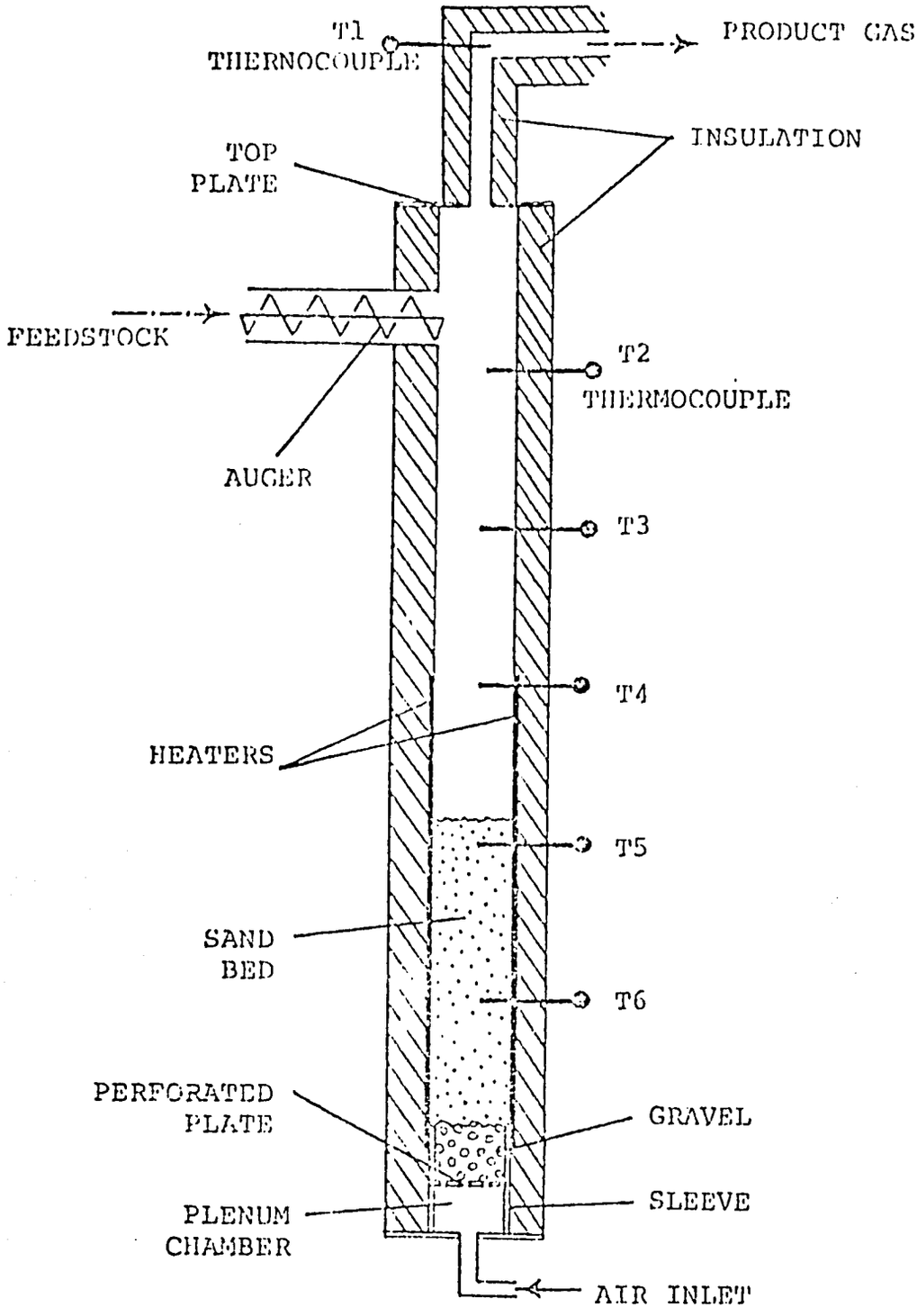


FIGURE 1. SECTION OF THE SIX-INCH REACTOR

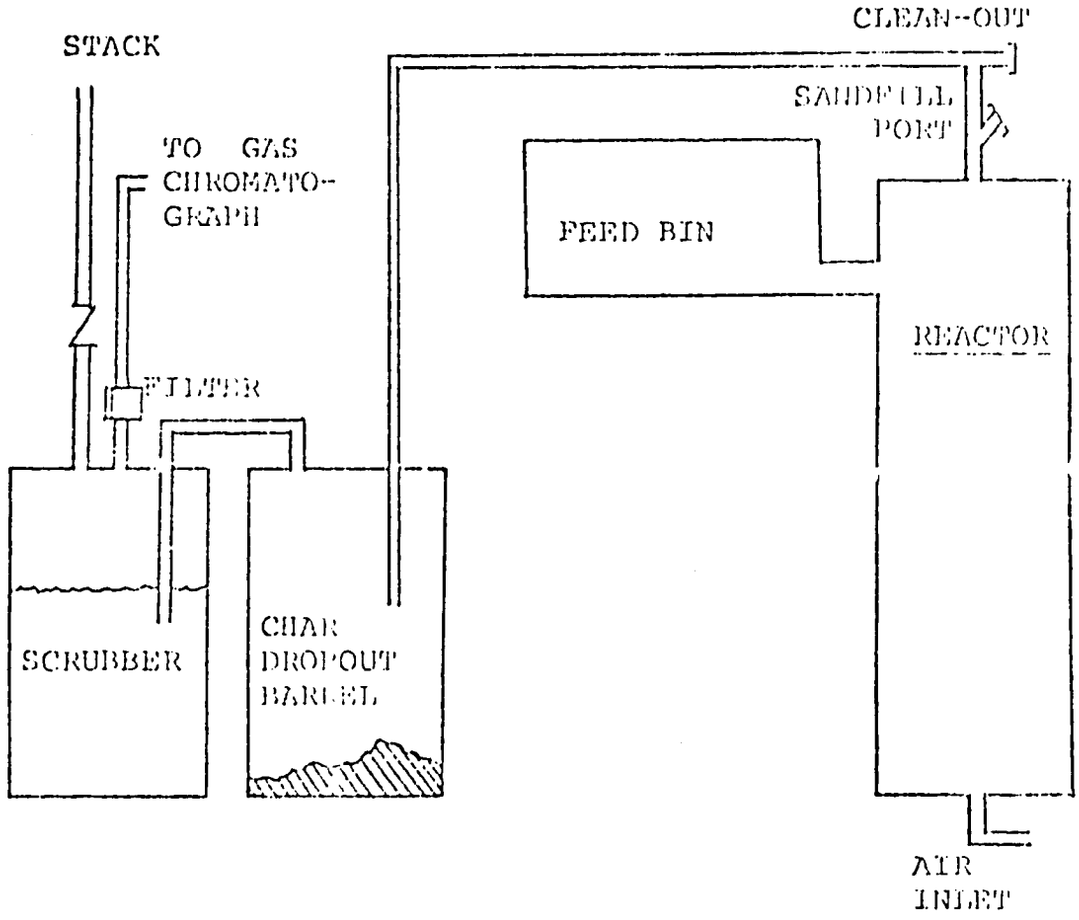


FIGURE 2. SIX-INCH REACTOR SYSTEM

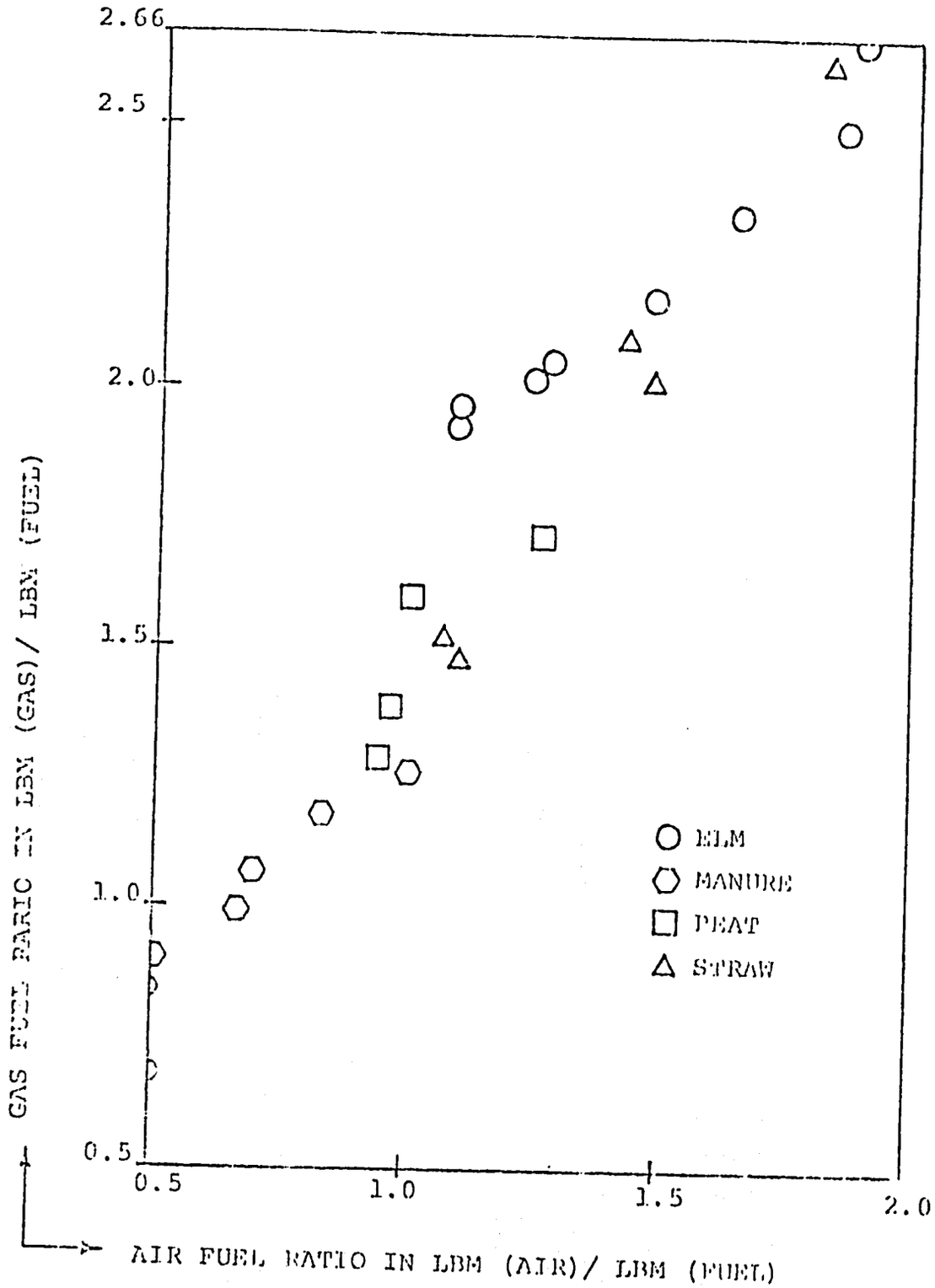


FIGURE 6. GAS-FUEL RATIO VS. AIR-FUEL RATIO
(ELM, MANURE, PEAT, STRAW)

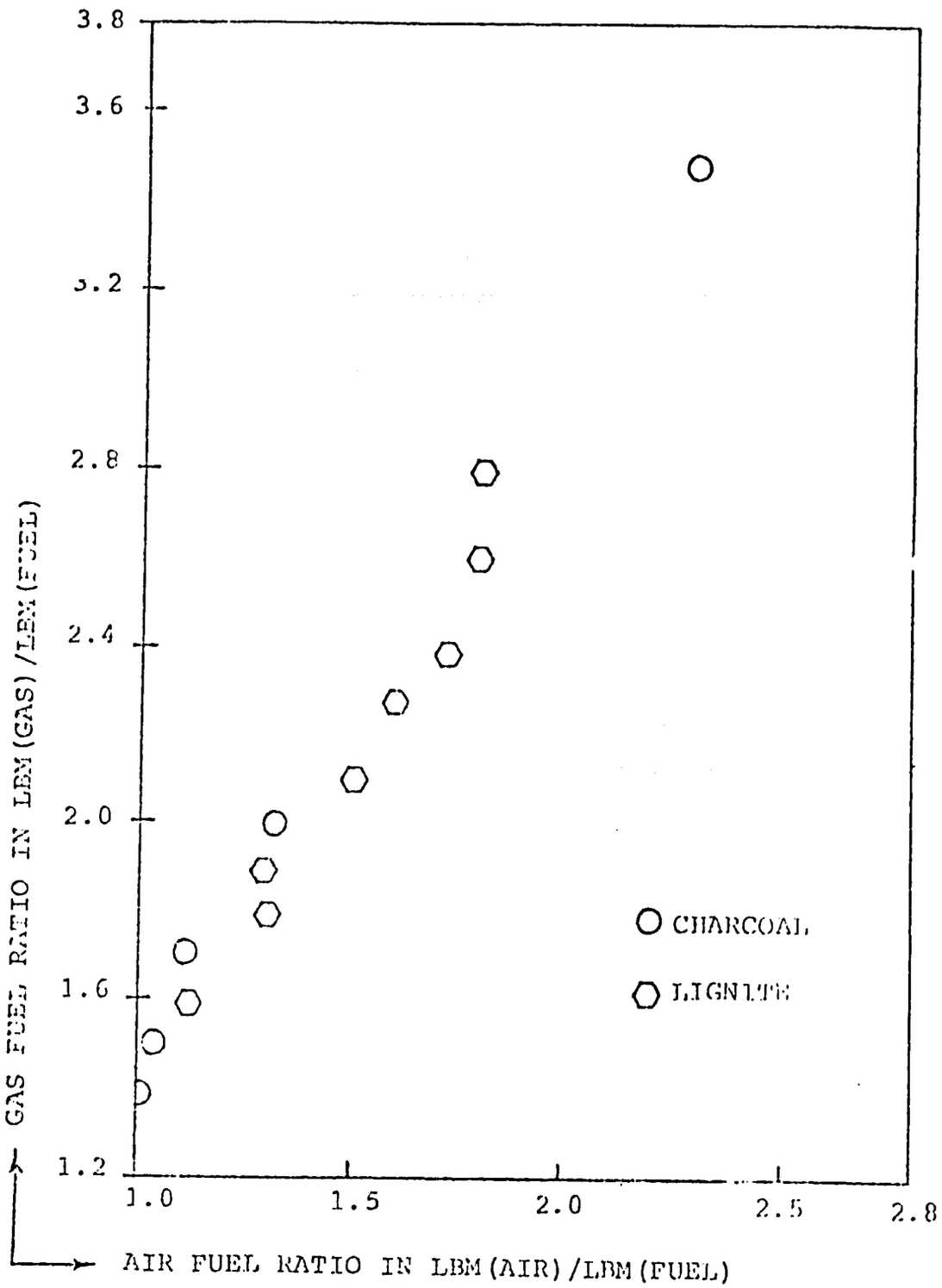


FIGURE 7 - GAS-FUEL RATIO VS. AIR-FUEL RATIO

(CHARCOAL, LIGNITE)

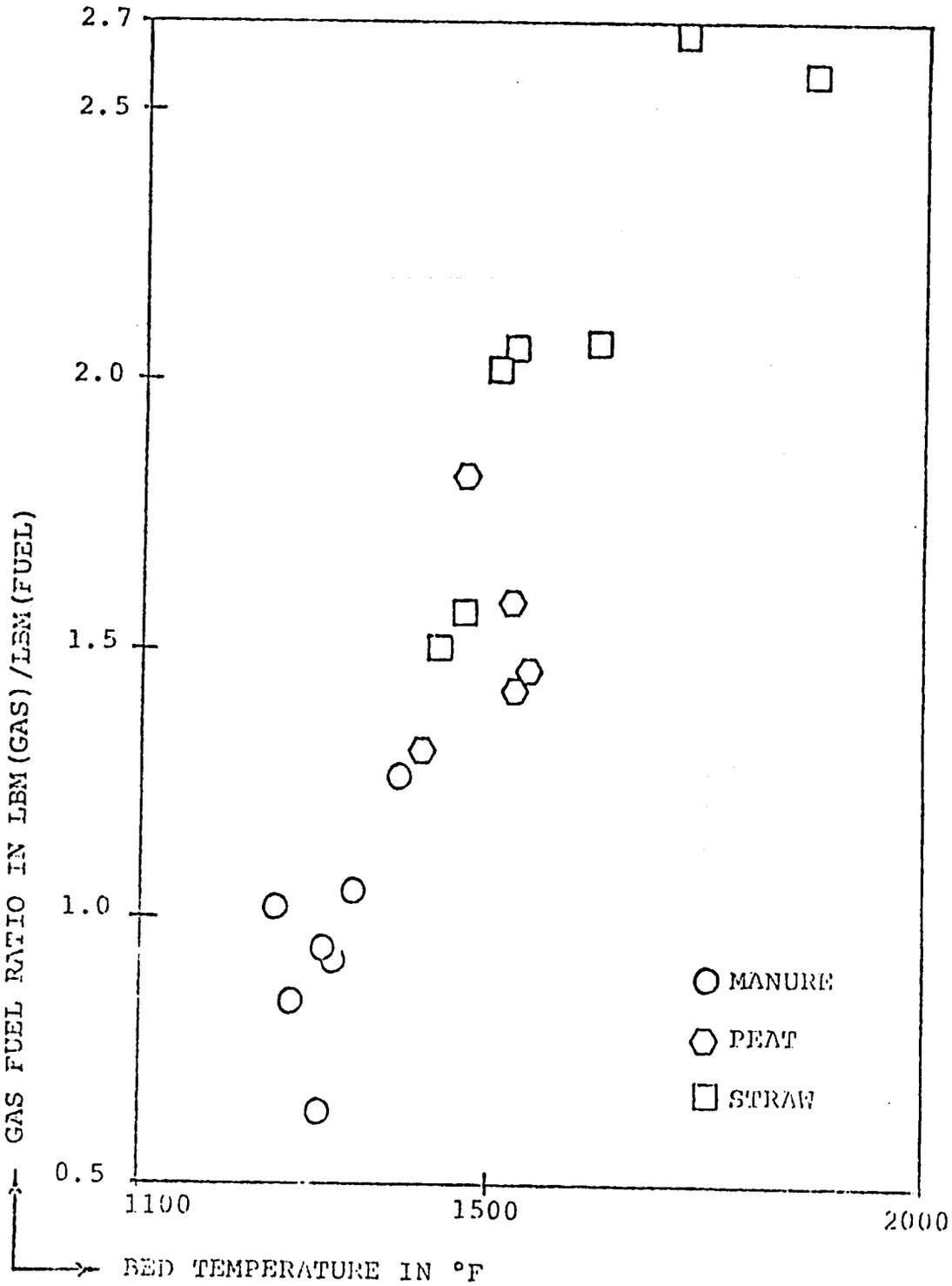


FIGURE 8 - GAS-FUEL RATIO VS. BED TEMPERATURE

(MANURE, PEAT, STRAW)

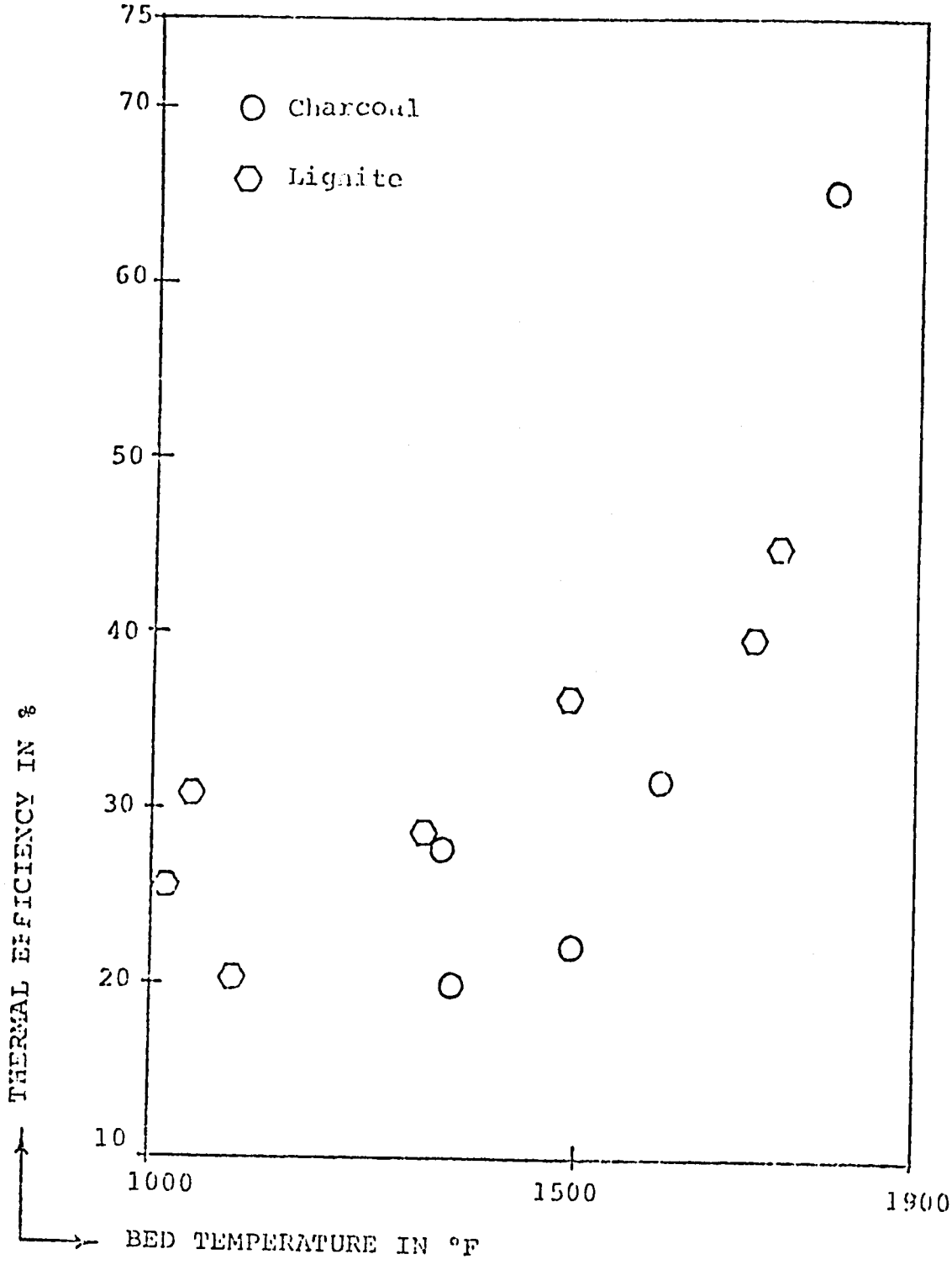


FIGURE 9 - THERMAL EFFICIENCY VS. BED TEMPERATURE

(CHARCOAL, LIGNITE)

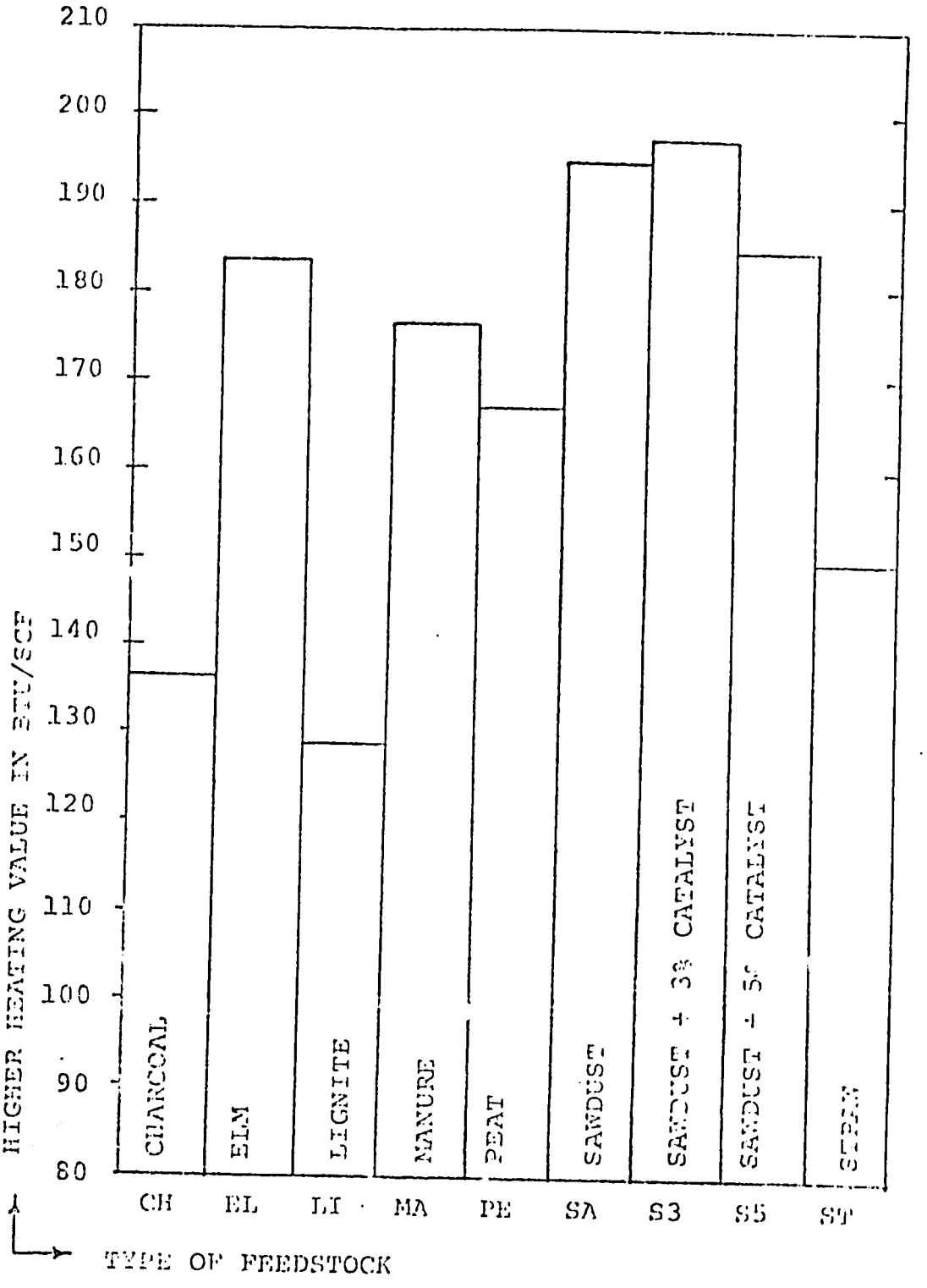
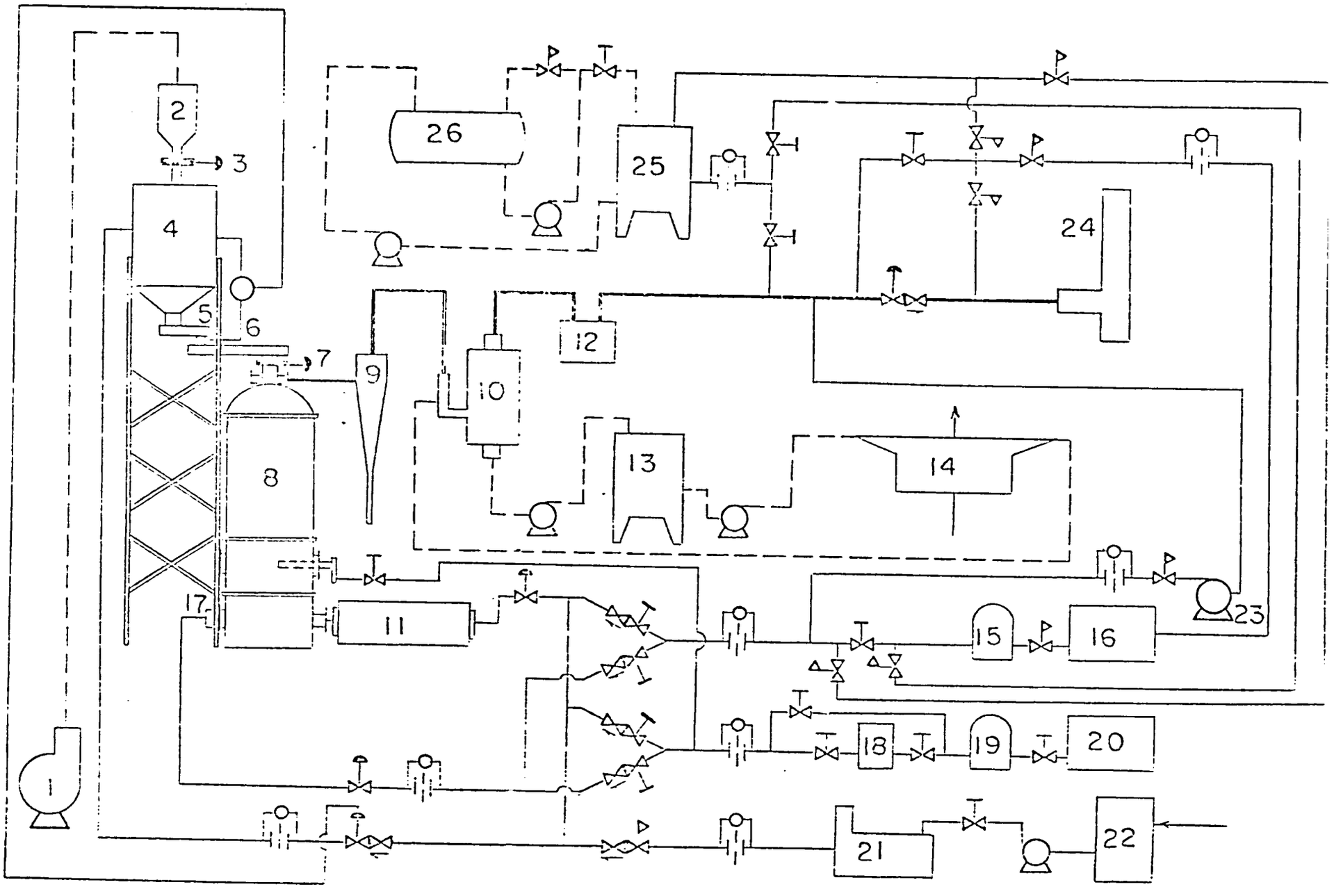


FIGURE 3. HIGHEST HEATING VALUE OBTAINED FOR EACH FEEDSTOCK


1
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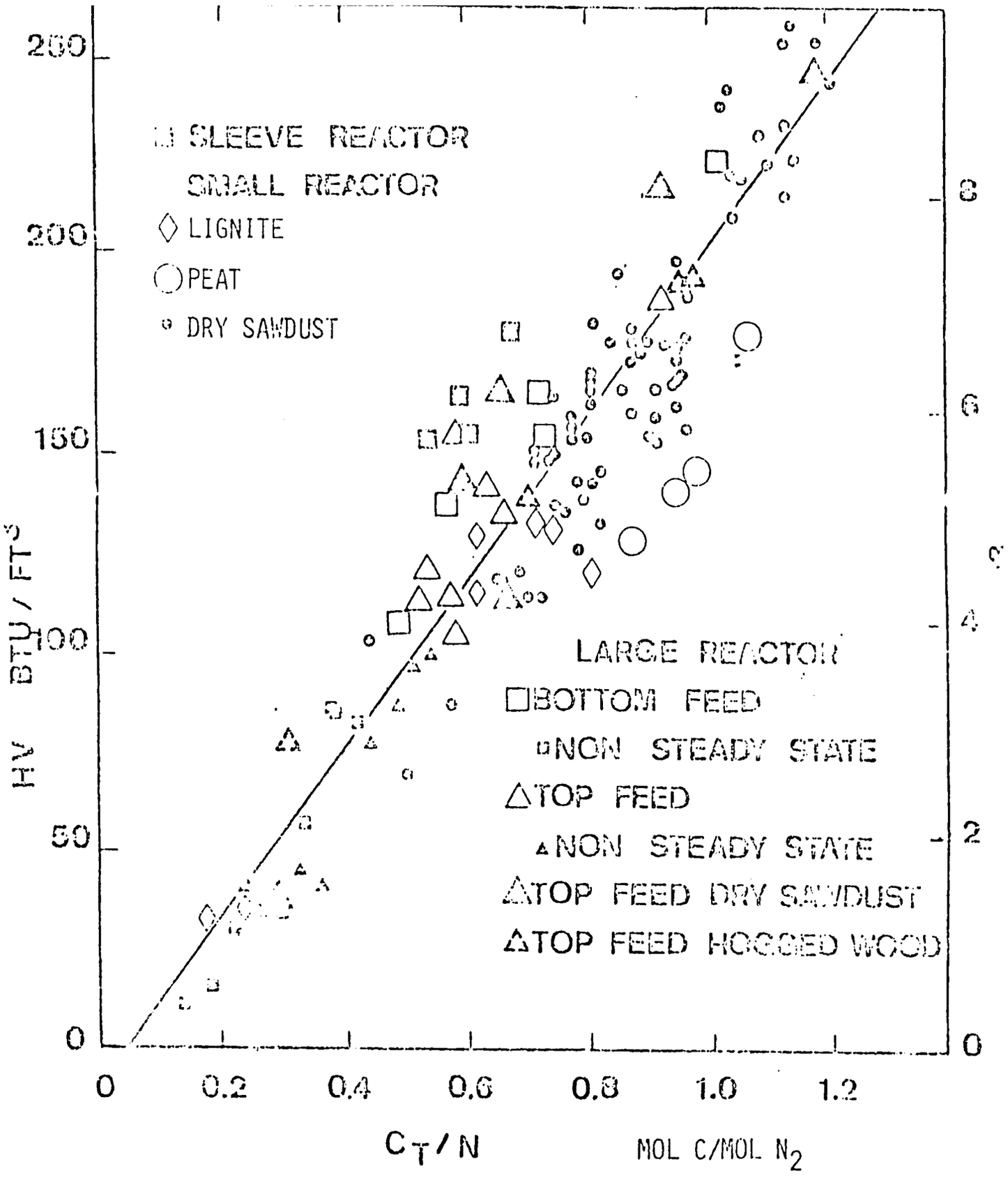


FIGURE 6 - HIGHER HEATING VALUE VERSUS TOTAL CARBON TO NITROGEN RATIO

DOE THERMOCHEMICAL EFFORT IN SMALL GASIFIER ENGINE SYSTEMS

THREE PROJECTS

1) DR. LAWRENCE SHAW
UNIVERSITY OF FLORIDA
AGRICULTURE ENGINEERING DEPARTMENT

RESEARCH: SUPERCHARGERS

OBJECTIVE: DEVELOP INNOVATIVE METHODS FOR IMPROVING SAFETY UTILITY, RELIABILITY AND CONVENIENCE OF OPERATION OF SMALL SCALE GASIFIERS BY RESTORING COMBUSTION ENGINE PERFORMANCE ON PRODUCER GAS TO PETROLEUM FUEL LEVELS BY SUPERCHARGING, USING POSITIVE DISPLACEMENT COMPRESSORS OR TURBO CHARGERS. FURTHER TO REDUCE OPERATOR MONITORING BY INCORPORATION OF MICROPROCESSERS OR OTHER AUTOMATIC CONTROLS

2.) MR. ROBERT HARGRAVE
ROCKY CREEK FARM GASOGENS
LACROSSE, FLORIDA

RESEARCH: FILTER MATERIAL (PRIMARY AND SECONDARY)

OBJECTIVE: TEST THE ADAPTABILITY OF DIFFERENT FILTER MATERIAL FOR GAS CLEAN-UP PURPOSE, MATERIAL WILL BE COMMON MATERIAL AVAILABLE IN LOCAL HARDWARE STORES.

3) MR. GEROGE SAVAGE
CALRECOVERY SYSTEM INC.
RICHMOND, GEORGIA

RESEARCH: DUAL FUELING

OBJECTIVE: INVESTIGATE ENGINE PERFORMANCE UNDER STEADY STATE AND VARIABLE LOAD USING PRODUCER GAS GENERATED FROM VARIABLE FEED STOCKS. PILOT FUEL ADDITION WILL BE AN IMPORTANT VARIABLE ALONG WITH OTHER PARAMETERS TO IMPROVE PERFOR CE AND OPERATIONS.

STATE-OF-THE-ART OF AGRICULTURAL RESIDUE GASIFIERS

J. GOSS

U.S. (Agency for International Development)

and the

Government of India

First Workshop On Alternative Energy
Resources and Development
Coal Conversion and Biomass Conversion

STATE OF THE ART OF AGRICULTURAL RESIDUE GASIFIERS IN THE U.S.

John R. Goss, Professor
Department of Agricultural Engineering
University of California
Davis, California, 95616, U.S.A.

Taj Palace Hotel
New Delhi, India

November 7-11, 1983

Previously Presented

at the

SECOND EXPERT CONSULTATION

ON

PRODUCER GAS DEVELOPMENT

IN ASIA AND THE PACIFIC REGION

Food and Agriculture Organization of the United Nations

In cooperation with

Lembaga Padi dan Beras Negara (LPN) - National Paddy & Rice Authority, Malaysia
and
Prince of Songkla University, Thailand

With the Title of:

STATUS OF BIOMASS GASIFICATION IN U.S.A.

6 - 11 August 1983
in Malaysia and Thailand

INTRODUCTION

Before the 1973-74 oil embargo, research of any kind or commercial utilization of gasification of wood, charcoal, coal, and coke was practically non-existant in the U.S. Teaching of the technology in engineering curricula had been dropped by the early 1950's. So it fell upon those who knew about the technology prior to this time, to initiate projects in the private and public sectors to revive this more-than-100 year old technology as one alternative to energy from petroleum products. Their efforts began in the mid 1970's and today occupy a very small nitche in the total research and industrial development in the U.S.

The author was one of those few who changed research directions in the mid 1970's to that of developing biomass gasification for the agricultural industry in the State of California. A state that produces about 10 percent of the total U.S. farmgate dollars from agriculture from the widest variety of products of any state in the Nation. This development research has been done at a Land-Grant University with minimal association with commercial or other Federally funded agencies. Thus, the assessment of biomass gasification is confined to the author's research setting.

AGRICULTURAL EXPERIMENT STATIONS, FORESTRY SCHOOLS AND OTHER COOPERATING INSTITUTIONS, U.S. DEPARTMENT OF AGRICULTURE RESEARCH AGENCIES

The Cooperative State Research Service of the U.S. Department of Agriculture has a computerized data bank of approximately 28,000 research projects. This data base is implemented with a computerized information retrieval system. One of the search options is with a list of key woods that are coded for each project. A search of this data base using the key words "Producer Gas" and/or "Gasification" coupled with manual editing of the identified projects resulted in 34 projects concerned with the key words. These projects are listed in Appendix A under four categories: Gasification/Gas Producer/Gas Producer-Engine Systems, Combined Systems, Fuels and System Analysis. Most of the project objectives for the first category are concerned with providing on-farm, alternate energy systems from air-blown, fixed-bed or fluidized bed gas producers using field crop residues or cord wood. None of the fixed-bed gas producers under development can be considered to be derived from the small-scale, downdraft gas producer that was extensively used in Europe through the World War II period. The fluidized bed gas producers under development or study are closely allied with the technology as it is known today. Three projects have commitments to engine operation with producer gas and hence are concerned with gas conditioning for engine operation. The majority of the projects are to study or develop systems for crop drying or farmstead heating for animal production.

Combined Systems. The five projects listed are alternate energy systems which are primarily based on the collection and use of solar energy and using mainly fixed-bed gasification as the "back-up" alternate energy system. The general objective of these projects seems to be to evaluate gasification or other thermochemical energy systems as a standby energy system when direct solar radiation is inadequate or non-existant because of long periods of heavy sky cover.

Fuels. Two of the projects listed under the fuels category are concerned with developing collection systems for field crop residues. One project is directed toward refueling downdraft gas producers while operating and two other projects are concerned with screening weed species and their gasification characteristics. Two projects have the objective of developing non-commercial wood species as a gasification fuel supply and two others are concerned with the dewatering of green wood and bark for better downdraft gas producer performance.

System Analysis. The four projects are concerned with model development and testing for biomass energy production and gasification as part of cotton production energy requirements and energy supplied by gasification as an alternate to traditional energy supply sources.

In summary, much of the past and future progress from these projects will be helpful for the development of producer gas technology in Asia and the South Pacific. However, because of farm size, available fuel types and level of rural development there does not appear to be gasification systems objectives in the 34 projects that are directly related to the needs of the global sector represented by the participants of this consultation.

AGRICULTURAL ENGINEERING DEPARTMENT
University of California, Davis

Introduction.

The study of the gasification of agricultural and wood residues was initiated in the Department by two co-principle investigators: Dr. Perry Stout of the Department of Land, Air and Water Resources and Dr. Brian Horsfield of this Department. They received funding from USDA and the Federal Energy Administration in early 1976 to conduct a "Technological and Economic Assessment of the Utilization of Rice Straw Residue from the California Sacramento Valley for On-Farm Power Generation".

Two phases of this work provided the impetus for a sustained emphasis by the Department of the gasification of crop and wood residues and the utilization of the producer gas generated by this process for firing steam boilers and air-heating burners and for fueling gasoline and diesel engines.

One of these phases was the design, construction and testing of a downdraft gas producer-air cooled gasoline engine driving a belted electric motor-generator. The other was a trip to France, England and Sweden by Horsfield to gather information on gasification activities in those countries. His most important contact was at the Swedish National Machinery Testing Institute, Uppsala, Sweden where he obtained a copy of the Institute's report on gengas (producer gas from wood) experiments conducted in the late 1950's and early 1960's. No modern work has been found to equal the design and performance information contained in the report. It is the basis for the downdraft gas producers designed, built and tested by the Department after the first design by Horsfield.

The gasification activities since the inception of this work are very briefly described hereafter. Concurrently with this work several important studies on crop and wood residues have been conducted but are not included in this paper.

Past Gasification Activities: 1976-1981

Experimental Gas Producer: This was a batch fuel feed, downdraft gas producer with fixed, slotted gate which fueled a 154 cubic inch, 4-cylinder, air-cooled gasoline engine for short periods. Satisfactory gas producer-engine operation was obtained with a wetted-packed bed gas conditioner while belt-driving a 7 horsepower, 3-phase, synchronous motor as a generator. Hot-raw gas was also supplied to a producer gas burner. Fuels gasified were walnut shells, alfalfa cubes, chipped tree prunings, and wood chips. This unit has been dismantled.

Laboratory Gas Producer: This is a batch fuel feed, downdraft gas producer with powered eccentric, step-plate grate (other types of grate designs were also tested for mulled walnut shells). Except for the fire box choke plate, design is very similar to that developed by the Swedish National Machinery Testing Institute. The fire box diameter is one foot. Gasification rates range from 20 to 90 pounds of dry fuel per hour (5). Extensive studies have been conducted with this gas producer on the gasification characteristics of 26 different crop and wood residues and the effect of fuel moisutre content on performance and producer gas quality (1). Clean-hot, producer gas generated from softwood chips by this unit satisfactorily fueled a producer gas burner for prune dehydration. This gas producer was built in 1976 and is maintained as an operational testing unit.

Pilot Plant Gas Producer: This was an automatic fuel feed/ash removal, downdraft gas producer with powered, stainless steel, internal ash-removal augers. The plant was semitrailer mounted and essentially a scale-up of the Laboratory Gas Producer except for the internal ash handling system. Fire box diameter was 4 feet and operated with 19-inch and 24-inch diameter choke plates. Maximum fuel rate was about 1100 pounds per hour of dry wood chips.

The plant was at three locations (2). First, at Sun-Diamond Growers of California, Staockton, California. Fuel was mulled walnut shells (wood chips were also used). Fuel and ash handling designs were only adequate for batch fuel loading operation. Second, at the State of California Printing Plant, Sacramento, California after redesign of fuel feed-ash removal systems. Fuel was wood chips for generating hot-raw gas to fire a 125 boiler horsepower steam boiler to heat the building. The plant was satisfactorily operated for about 170 hours on shifts ranging from 4 to 18 hours. Third, at the Primate Center, University of California, Davis where a steam boiler was fired to operate building the heating-cooling system for 531 hours, of which 339 were continuous operation. Limited test operations were conducted with a 2 million Btu per hour, air-heating, producer gas burner and a dual-fueled, naturally aspirated, pre-combustion chambered, 60 kW dieselelectric generator. This plant has been dismantled.

100 kW Portable Farm Power Plant: Another automatic fuel feed/ash removal, downdraft gas producer with powered eccentric, step-plate grate with gas conditioning system and dual-fueled, 100 kW, diesel-electric generating plant (6). The equipment was mounted on a tandem, three-axle trailer mounted. The gas producer was scale-up of the Laboratory Gas Producer having an advanced design for the combustion air plenum chamber. Fire box diameter was 32 inches with 14 and 16 inch choke plates.

Broken corn cob fuel was used to generate cool-clean producer gas for dual-fueling a 538 cubic inch, turbo-charged, inter-cooled, direct injection diesel engine with direct coupled, 100 kW, 3-phase multi-voltage, electric generator. Limited test results gave 60 kW of power furnished by gas producer. Gas cleaning system was inadequate for long-term operation. The gas producer-gas conditioning system has been removed from the trailer and stored for later use.

State-of-the-Art for Small Scale (to 50 kW) Gas Producer-Enginer Systems: A lengthy report based on a literature study dating from about 1900 and a world-wide questionnaire-survey of gasification activities (3). Topics covered are: History of gas producer-engine systems, chemistry of gasification, gas producers, fuel, conditioning of producer gas, internal combustion engines and small gas producer-engine system economics. A computer based, annotated file of some 350 references was developed as part of the study.

Current Activities.

An experimental loose rice hull gas producer-gas conditioning system has been designed, constructed and extensively tested for fueling single cyclinder engines in the range of 5 to 25 horsepower (4). This system will be designed and extensively tested with one cylinder engines for applications in the Developing countries.

Portable Irrigation Pumping Plant: A fluidized-bed gas producer fueling a natural gas engine-95 kW generator set, retro-fitted with turbocharger in being developed and tested. Fuels will be cotton and corn stalks, wheat and rice straw, alfalfa seed straw and screening from cleaning alfalfa seed. Design, construction and performance testing of the system in the laboratory will be done before placing on a ranch for a growing season to pump well water for irrigation.

Fluidized-Bed Gas Producer Performance: Determine the hot-raw gas, hot-clean gas, and cool-clean gas performance for almond shell screenings, cotton and corn stalks, rice and wheat straw, alfalfa seed straw and screenings from cleaning alfalfa seed.

GAS PRODUCERS MANUFACTURERS

Appendices B and C are listings of U.S. and non-U.S. Manufacturers of gas producer equipment. the author is aware of the following operational installations:

> Advanced Energy Application, Inc. fluidized bed gas producer fueled with cotton gin trash to provide cotton gin drying air at Tonopah, Arizona.
>
> Applied Engineering Co. updraft gas producers fueled with partially dry, whole log wood chips for steam boiler firing at Rome, Georgia (5-6 thousand pounds wet chips per hour) and Florida Power Company, Gainsville Florida (25 x 10^6 Btu/hr capacity)
>
> Combustion Power Co. fluidized bed gas producer fueled with wet, hogged, mill wood waste. Weyerhaeuser Company, Aberdeen, Washington (approximately 10 foot diameter reactor).

Energy Products of Idaho fluidized-bed gas producer fueled with wood waste at State of California Heating and Cooling Plant, Sacramento, California (30 x 10^6 Btu/hr capacity).

Independent Power of North America 100 kW, dual-fueled diesel engine generator set fueled with dry wood (KHD, West Germany gasifier-engine system)

Kleiber and Schulz, Inc. (Fritz Werner, West Germany, wood gas producer-gas engine generator set at Melville, New Jersy).

References

1. Goss, John R. An investigation of the down-draft gasification characteristics of agricultural and forestry residues: interim report. California Energy Commission, 1516 9th Street, Sacramento, CA 95814. Nov., 1979.

2. Goss, John R. and Richard C. Lang. Demonstration of a pilot plant gas producer using biomass residues. Vol. I and II. California Energy Commission, 1516 9th Street, Sacramento, CA 95814, July, 1980.

3. Kaupp, A., and J. R. Goss. State of the art for small scale (to 50 kW) gas producer-engine systems. Final report to USDA Forest Service, Contract No. 53-391R-0-141 editing for publication as a monograph.

4. Kaupp, Albricht. Air blown gasification of rice hulls: dependence of gas and solid properties on operating variables. Ph.D. Thesis, University of California, Davis, 1983.

5. Williams, R. O. and B. Horsfield. Generation of low-Btu fuel gas from agricultural residues. Experiments with a laboratory-scale gas producer. food, fertilizer and Agricultural Residues. pp. 465-487. Raymond C. Lochr, editor. Ann Arbor Science, Ann Arbor, Mich. 48106. 1977.

6. Williams, R. O., J. R. Goss, J. J. Mehlschau, B. Jenkins, and J. Ramming. Development of a pilot plant gasification system for the conversion of crop residues to thermal and electrical energy. ACS Symposium Series No. 76, Solid Wastes and Residues, J.L. Jones and S. B. Radding Editors American Chemical Society, Washington D.C. pp. 142-164. 1978.

3. **Organization**

Forest Resources & Conservation Dept.
University of Florida
Gainesville, Florida 32611

Project Leader

H. H. Lee

Project Title and (No.)

Advancement of Thermo-Chemical Gasification of Biomass to Methane. (FLA-FOR-02149-BG)

Scope

Develop Fundamental information required to produce methane from biomass by pyrolysis in inert (argon) and hydrogen environments.

4. **Organization**

USDA-ARS Southern Agricultural Energy Center
Georgia Coastal Plain Expt Sta
Tifton, Georgia 31794

Project Leader

W. L. Bryan

Project Title and (No.)

Farm-Scale Conversion of Biomass into Fuels and Energy. (7702-20355-001)

Scope

Design, install, and evaluate experimental equipment for farm-scale utilization of biomass for production of energy by direct combustion or for conversion into gaseous fueled via pyrolysis, partial combustion, gasification or anerobic digestion or for conversion into liquid fuels such as methanol ethanol.

5. **Organization**

Agri Engineering Dept.
Purdue University
Lafayette, Indiana 47907

Project Leader

J. R. Barrett

Project Title and (No.)

Utilization of Biomass for Energy. (IND056023) and (3302-20190-001)

APPENDIX A

Biomass Gasification Research Projects Reporting to the U.S. Department of Agriculture

I. GASIFICATION/GAS PRODUCER/GAS PRODUCER ENGINE SYSTEMS

1. **Organization**

Agri Engineering Dept.
University of California, Davis
Davis, California 95616

Project Leader

J. R. Goss

Project Title and (No.)

Utilization of Animal, Crop and Processing Residues. (CA-D*-AER-2971-H)

Scope

Laboratory and field studies of agricultural machinery and energy conversion processers (biochemical and thermo chemical) for management and/or energy recovery from animal, crop and food processing wastes. Thermo chemical component.

2. **Organization**

Agri Engineering Dept.
University of California, Davis
Davis, California 95616

Project Leader

J. R. Goss

Project Title and (No.)

Gas Producer Retrofitted Portable Natural Gas Engine Farm Irrigation Power Plant. (CA-D*-AER-4027-SG)

Scope

Design, develop and test a fluidized bed gas producer, natural gas engine-generator set to pump on-farm irrigation water using crop residues as the fuel source.

8. **Organization**

Chemical Engineering Dept.
Kansas State University
Manhattan, Kansas 66506

Project Leader

W. P. Walawander

Project Title and (No.)

Fluid Bed Gasification of Crop Residues for Gaseous and Liquid Fuel Production. (KAN-05-981)

Scope

Fluidized bed gasification of crop residues, gather gasifier design data, conduct long-term engine fueling tests using the producer gas and investigat methods for improving engine performance. Design and develop a gas clean-up system for tar removal. Conduct conceptual system design and economic feasability studies for large-scale liquid fuel production and small-scale on-farm applications.

9. **Organization**

Chemical Engineering Dept.
Kansas State University
Manhattan, Kansas 66506

Project Leader

W. P. Walawender

Project Title and (No.)

Energy Related Technological Development. (KAN00229)

Scope

Design and develop fluid-bed gasification processes for converting agricultural residues to fuels.

10. **Organization**

Chemical Engineering Dept.
Kansas State University
Manhattan, Kansas 66506

Project Leader

W. P. Walawender

Scope

Technology and design equipment and determine operational procedures for direct burning, gasification or pyrolysis of agricultural materials.

6. **Organization**

Agri Engineering Dept.
Purdue University
Lafayette, Indiana 47907

Project Leader

R. M. Peart

Project Title and (No.)

Equipment for Biomass Energy Conversion. (3090-20191-002A)

Scope

Investigate channel gasification of biomass, including corn cobs, corn stover and other agricultural crop residues into combustible producer gas and/or heat.

7. **Organization**

Agri Engineering Dept.
Kansas State University
Manhattan, Kansas 66506

Project Leader

S. J. Clark

Project Title and (No.)

Alternate Fuels for Agricultural Internal Combustion Engines.

Scope

Determine the most viable near and long term sources of fuel for agricultural diesel and spark ignition engines. Delineate and solve problems relating to the use of these fuels. Evaluate appropriate vegetable oils. Optimize spark ignition engine performance using alcohol and alcohol blends, biomass producer gas and hydrogen.

13. **Organization**

Agri Engineering Dept.
Clemson University
Clemson, South Carolina 29631

Project Leaders

F. A. Payne, J. G. Alphin, J. M. Bunn

Project Title and (No.)

Cord Wood Gasification/Combustion Demonstration for Curing Flue Cured Tobacco. (SC00521)

Scope

Design, construct, and demonstrate a 1 million Btu/hr cord wood gasifer-combustor and operate it on a flue-cured tobacco farm for one curing season.

14. **Organization**

Agri Engineering Dept.
Clemson University
Clemson, South Carolina 29631

Project Leader

F. A. Payne

Project Title and (No.)

Control Algorithm for Two-Stage Combustors. (SC01032)

Scope

Develop a microprocessor based control system for updraft gasification of selected agricultural fuels.

15. **Organization**

Agri Engineering Dept.
Texas A&M University
College Station, Texas 77843

Project Leader

W. A. Lepori

Project Title and (No.)

Fluidized-Bed Biomass Gasifier-Boiler System Evaluation and Design. (TEX06563)

Project Title and (No.)

Energy Related Technological Development. (KAN00946)

Scope

Development of a continuous low pressure, flash pryolysis pilot plant facility for the recovery of useful products from animal wastes and produce a synthesis gas (composed primarily of CO, H(2), CO(2) and CH(4)) from feedlot manure.

11. **Organization**

Agri Engineering Dept.
University of Kentucky
Lexington, Kentucky 40506

Project Leader

O. J. Loewer

Project Title and (No.)

Particulate Deposition when Passing Gasification-Combustion Gases through Grain. (KY04123)

Scope

Determine possible health hazard from passing biomass gasification-combustion gases directly through grain during drying.

12. **Organization**

Agri Engineering Dept.
Clemson University
Clemson, South Carolina 29631

Project Leader

F. A. Payne

Project Title and (No.)

Design of a Cord Wood Gasification & Gas Combustion System for Curing Tobacco. (SC00503)

Scope

Develop a cord wood updraft gasification combustion system to provide thermal energy for multiple farm applications but especially for curing flue-cured tobacco.

2. Organization

USDA-ARS Harvesting & Processing Research
Georgia Coastal Plain Expt. Sta.
Tifton, Georgia 31794

Project Leader

J. M. Troeger

Project Title and (No.)

Development of Design Criteria for Solar Crop Drying Including Backup Energy Systems. (7702-20195-007)

Scope

Development of basic design criteria for application of solar energy for crop drying. Development and integration of solar with backup systems. Development of equipment and procedures using combustion, gasification or extraction of liquid fuels from plant residue for energy management and conservation for crop drying systems.

3. Organization

Agri Engineering Dept.
Purdue University
Lafayette, Indiana 47907

Project Leader

G. H. Foster

Project Title and (No.)

Drying Grain Using Solar Energy and Biomass. (IND046036-B)

Scope

Develop and test a two-stage corn cob burner-gasifier for batch drying of shelled corn to about 20 percent moisture content. The effect of slow frying of the shelled corn to storage moisture content with solar heated air and mycostats will be studied.

4. Organization

Agri Engineering Dept.
University of Kentucky
Lexington, Kentucky 40506

Project Leader

B. F. Parker

Scope

A 0.6 meter diameter fluidized-bed gasifier coupled to a fire-tube boiler will be used to measure metal corrosion and behavior and boiler stack gas particulates.

16. Organization

Agri Engineering Dept.
Texas A&M Unitersity
College Station, Texas 77843

Project Leader

W. A. Lepori

Project Title and (No.)

Fluidized-Bed Biomass Gasifier-Boiler System Evaluation and Design. (TEX06123)

Scope

Establish gas cleanup requirements for various uses of gas produced from a fluidized bed biomass gasifier and evaluate promising cleanup techniques.

II. COMBINED SYSTEMS

Organization

USDA-ARS Southern Agricultural Energy Center
Georgia Coastal Plain Expt. Sta.
Tifton, Georgia 31794

Project Leader

J. L. Butler

Project Title and (No.)

Development of Systems for Utilizing solar and Biomass Energy to make farms Energy Self-Sufficient. (7702-20195-001)

Scope

Systems will be developed to efficiently collect, store and utilize solar energy, crop residues and selected biomass crop for crop drying and other applications such as heating and cooling.

Project Title and (No.)

Utilization of Animal, Crop and Processing Residues. (CA-D*-AER-2971-H)

Scope

Laboratory and field studies of agricultural machinery and energy conversion processes (biochemical and thermochemical) for management and/or energy recovery from arrived crop and food processing wastes. Residue fuels component.

2. Organization

Agri Engineering Dept.
University of Florida
Gainesville, Florida 32611

Project Leader

L. N. Shaw

Project Title and (No.)

Fuel Chipping and Continuous Feeding Systems for Downdraft Gasifiers. (FLA-AGE-02194)

Scope

Evaluate methods of cutting and slicing wood to prepare downdraft gasifer fuel from waste wood from farm woodlots. Develop mechanical assemblies to continuously feed downdraft gasifiers while in operation.

3. Organization

Agric Research & Education Cntr
Bradenton, Florida 33508

Project Leader

J. P. Gilreath

Project Title and (No.)

Native "Weed" Species for Biomass Production. (FLA-BRA-01263-BG)

Scope

Screen "weed" species to determine their cultural requirements, productivity and suitability for biomass production. Five weed species have been evaluated for biomass production, these were castor bean, dogfennel, sida, pigweed, and saltbush.

4. Organization

Agri Engineering Dept.
University of Kentucky
Lexington, Kentucky 40506

Project Leader

B. F. Parker

Scope

A high temperature grain drying system using solar collectors and rock-bed storage and a crop residue gasification combustion process will be studied. Computer simulation will be used to evaluate energy efficiency and effectiveness of the grain harvesting, delivery, drying and storage system.

5. Organization

Agri Engineering Dept.
University of Kentucky
Lexington, Kentucky 40506

Project Leader

I. J. Ross

Project Title and (No.)

Integrated Multiple-Use Solar System with Biomass Gasification Combustion Backup.

Scope

A high temperature grain drying system using solar collectors and rock-bed storage and a crop residue gasification combustion process will be studied. Computer simulation will be used to evaluate energy efficiency and effectiveness of the grain harvesting, delivery, drying and storage system.

III. FUELS

Organization

Agri Engineering Dept.
University of California, Davis
Davis, California 95616

Project Leader

D. J. Hills

Project Title and (No.)

Saw Palmetto Potential for Biomass Production. (FLA-ONA-02165-BG)

Scope

Determine the potential for biomass production of the native woody shrub, saw palmetto.

Organization

Forestry Dept.
University of Illinois
Urbana, Illinois 61801

Project Leader

P. Chow

Project Title and (No.)

The Utilization of Two-Year Short-Rotation Deciduous Biomass for Energy, Particle Board and Chemicals. (ILLU-55-0304)

Scope

Develop gasification and combustion to use woody biomass grown under intensive silvicultural techniques to substitute for fossil fuels. Evaluate the feasability of converting high-yield plantation-grown wood to paper and particleboard. Seven species will be innvestigated: Autumn olive, black alder, black locust, E cottonwood, royal paulownia, silver maple, and sycamore.

8. **Organization**

Forest Products Dept.
College of Forestry
St. Paul, Minnesota 55108

Project Leader

J. G. Haygreen

Project Title and (No.)

Systems for the Drying and Processing of Fuel-Wood Chips. (MIN-43-067)

Scope

Development of evaporative drying and compression drying for reducing the moisture content of wood and bark chips for fuel in combustion, gasification or pyrolysis processes will be developed.

4. **Organization**

Forest Resources & Conservation
University of Florida
Gainesville, Florida 32611

Project Leader

K. Eoff

Project Title and (No.)

Thermochemical Gasification of Biomass — Screening. (FLA-FOR-02147-BG)

Scope

Determine the air-blown downdraft gasification characteristics of land and marine plants and waste biomass being evaluated for biomass energy production.

5. **Organization**

Forest Resources & Conservation
University of Florida
Gainesville, Florida 32611

Project Leader

J. Huffman

Project Title and (No.)

Moisture Reduction System to Prepare Woody Biomass for Thermal Gasification.

Scope

Improve thermal gasification of woody biomass by developing energy efficient de-watering methods. Accumulate data on several target biomass species (laurel oak (Quercus larifolia), slash pine (Pinus elliottii) and sweetgum (Liquidambar styraciflua)) that relate to their harvesting, drying, storing, and processing to maximize handling efficiencies; design and test several on-site pre and post harvest treatment systems to reduce moisture in woody biomass; explore methods for off-site processing and drying that will lead to energy efficient designs for moisture reduction.

6. **Organization**

Agricultural Research Center
Ona, Florida 33865

Project Leader

W. Pitman

Project Title and (No.)

Preliminary Research in Agricultural Economics. (FIA-FRE-00001)

Scope

Conduct preliminary investigations into the nature and extent of research required to solve a given agriculturally oriented economic problem. A producer gas powered irrigation system has been evaluated and develop a research project on alternative energy systems.

3. Organization

Agri Engineering Dept.
Purdue University
Lafayette, Indianna 47907

Project Leader

R. M. Peart

Project Title and (No.)

Develop simulation models using appropriate field and laboratory data for integrating energy crop production for crop research including energy crop production, grain drying and biomass gasification.

Organization

Agri Engineering Dept.
Texas A&M University
College Station, Texas 77843

Project Leader

C. B. Parnell

Project Title and (No.)

Engineering Systems and Energy Needs for Cotton Production. (TEX03341)

Scope

Systems engineering study of utilization alternatives of cotton gin trash including use of gin trash as a source of biomass energy, compost, cattle feed and particle board.

9. Organization

Agri Engineering Dept.
North Dakota State University
Fargo, North Dakota 58105

Project Leader

J. A. Lindley

Project Title and (No.)

Biomass Utilization as an Energy Source

Scope

Evaluate systems for: collecting residue from field crops, for densification of biomass, and for the direct combustion and gasification of biomass.

IV. SYSTEM ANALYSIS

1. Organization

Agri Engineering Dept.
University of Florida
Gainesville, Florida 32611

Project Leader

D. Kirmse

Project Title and (No.)

Process Engineering Analyses for Biomass Gasification. (FLA-AGE-02156-BG)

Scope

Select and obtain computer software for process synthesis and analysis in gasification technology. Access physical and chemical property data base for thermo-chemical and biological conversion steps; Established methodology for conceptural design development, unit operation selection, process condition selection, material and energy balance calculation, equipment sizing, and capital and operating cost estimation.

2. Organization

Agri Economics Dept.
University of Florida
Gainseville, Florida 32611

Project Leader

L. Polopolus

E.Z. Manufacturing Co.
R.D. #1, New Holland, PA 17557
(717) 354-4348, Bill Richey, Ex. V.P. Sales, Ed Zimmerman, Bob charleton

Forest Fuels Manufacturing, Inc.
Water Street, P.O. Box 547, Marlborough, NH 03455
(603) 876-3331/3353, Martin Stevens, Sales, J. Calhoun, T. Simkin

Foster Wheeler Synfuels Corp.
110 South Orange Ave., Livingston, NJ 07039
(201) 533-2826, Roger Gaire, Biomass Conversions

Gilbert Associates
P.O. Box 1498, Reading, PA 19603
(215) 775-2600, Robert Stevens, Marketing, Sherm Goodman, Glen Davidson, ext. 7777

Guaranty Fuels, Inc.
P.O. Box 1087, Independence, KS 67301
(316) 331-0027, Butch Holum

Halcyon Associates, Inc.
The Halcyon, Maple St., P.O. 145, East Andover, NH 93231
(603) 735-5356, William G. Finnie, President
Updraft

Kemp Reduction Corp.
2410 Anacapa St., Santa Barbara, CA 93105
(805) 966-7556, Klaus Kemp

Lurgi Corp.
1 Davis Drive, Belmont, CA 49002
(415) 594-2000, George Quiter or Truman Lee

Marenco, Inc.
13961 Jarvi Sra Box 815, Anchorage, AK 99502
(907) 344-4279, Joe Marks

Natural Resource Gasification, Inc.
701 Madison N.E., Albuquerque, NM 87110
(505) 345-4591, Tom Taylor

Riley Stoker Corp.
3706 Mt. Diablo Blvd., Suite 211, Lafayette, CA 94549
(415) 284-2610, Bill Pierce

Sverdrup Technology
600 William Northern Blvd., P.O. Box 884, Tullahoma, TN 37388
(615) 455-1800, Glen Norfleet or Fred Nelms

APPENDIX B

U.S. Biomass Gasification Manufacturers
(Compiled by S. Dzodhi, California Energy Commission, June 1983)

Advanced Energy Applications Inc.
1386 Halt Ave, Los Altos, CA 94022
(415) 964-5429, Fred Moreno, President
Fluidized Bed

American Fyr Feeder Engineers
1265 Rand Rd., P.O. Box 285, Des Plaines, IL 60016
(312) 298-0044, Victor Gauger, Jr., Sales Mngr.

Applied Engineering Co. (APCO)
P.O. Box 1327
1525 Charleston Highway, Orangeburg, SC 29115
(803) 534-2424 Ralph Hanberry, Dev'mt Engineer
Updraft Wood Chip

Bio-Solar Research & Development Corp.
1600 Valley River Dr., Suite 220, Eugene, OR 97401
(503) 686-0765, Rudolf W. Gunnerman

Bio Therm Energy Co.
7690 El Camino Real, Suite 105, Carlsbad, CA 92008
(619) 436-3011, Jim Anderson

"Buck" Rogers Co., Inc.
150 Industrial Parkway, Industrial Airport, KS 66031
(913) 829-2825, Bill Ayres, V.P. Marketing
Downdraft

C.H.H. Technology, Inc.
Route 1, Warsaw, VA 22572
(804) 333-4847, Herbert J. Mulqueen, Jr., President

Combustion Power Co.
1346 Willow Road, Menlo Park, CA 94025
(415) 324-4744, Mike O'Hagen

Energy Conservation Co. (ECON)
P.O. Box 828, Alexander City, AL 35010
(205) 329-0835, Ben Russell
Downdraft for U.S. Cars and Pickups

Energy Products of Idaho (EPI)
4006 Industrial Ave., South, Coeur d' Alene, ID 83814
(208) 765-1611, Michael W. Oswald, V.P. Sales, Mike Murphy, Engineer
Fluidized Bed

APPENDIX C

Non-U.S. Biomass Gasification Manufacturers

Non-U.S. Manufacturers

Lasmb Cargate Industries, Ltd.
P.O. Box 440, 1135 Queens Avenue, New Westminister, B.C. V3L 4Y7
(604) 521-8821
Cable LAMCAR
Telex 0435-1165
(Well cell burners)

Omnifuel Gasification Systems Ltd.
3284 Yonge Street, Suite 501, Toronto, Canada M4N 3M7
(416) 485-0701, Robin F. Guard, Keith Bircher

Duvant Moteurs Diesel
B. P. 236, 59308 Valenciennes, France
Contact: Dr. A. Dennetiere
Downdraft

Pillard
13 Rue Raymond - Teissere
13008 Marseille, France

Fluidyne
62 Henderson Valley Road, Auckland 8, New Zealand
Contact: Jack R. Humphries, Director
Downdraft

H. E. Gardner & Sons LTD
Orari Street, P.O. Box 877, Dunedin, New Zealand
Downdraft

Gasifier and Equipment Manufacturing Corp (GEMCOR)
Rudgen Building I and II
Shaw Blvd., Pasig, Metro Menila, Philippines
693-62-66. Luis C. Baja, Manager
Downdraft (Charcoal)

GASPRO
P.O. Box 43328, Industria, Transvaal 2042, South Africa
Contact: Ronnie Crause, Sales Director
Downdraft

Gotland Gengas
Gyle Ala, S-620 23 Romakloster, Sweden
(0598) 55080 Kjill Alfvengren
Downdraft

Universal Energy International (Angelo Manufacturing Co.)
400 Old Orchard Court, Danville, CA 94526
(415) 820-3924, Dr. Bruce H. Winter

Vermont Wood Energy Corp.
P.O. Box 280, Stowe, VT 05672
(802) 253-9372/7220, J. Phillip Rich, President, Peter Bauer, Project Engineer

Wellman Thermal Systems Corp.
1 Progress Road, Shelbyville, IN 46176
(317) 392-5461, W.G. Colleen, III, Manager of Business Development

Wonder Burner International
2893 Sunrise Blvd., Suite 102, Rancho Cordova, CA 95670
(916) 638-8186, Takumi Noma, President

Wood Power Energy Corp.
Miles W. Fry & Son, Inc., Rural Delivery No. 3, Ephrata, PA 17522
(717) 354-4130, Morton Fry, (215) 267-4944, David Cunningham, Engineer

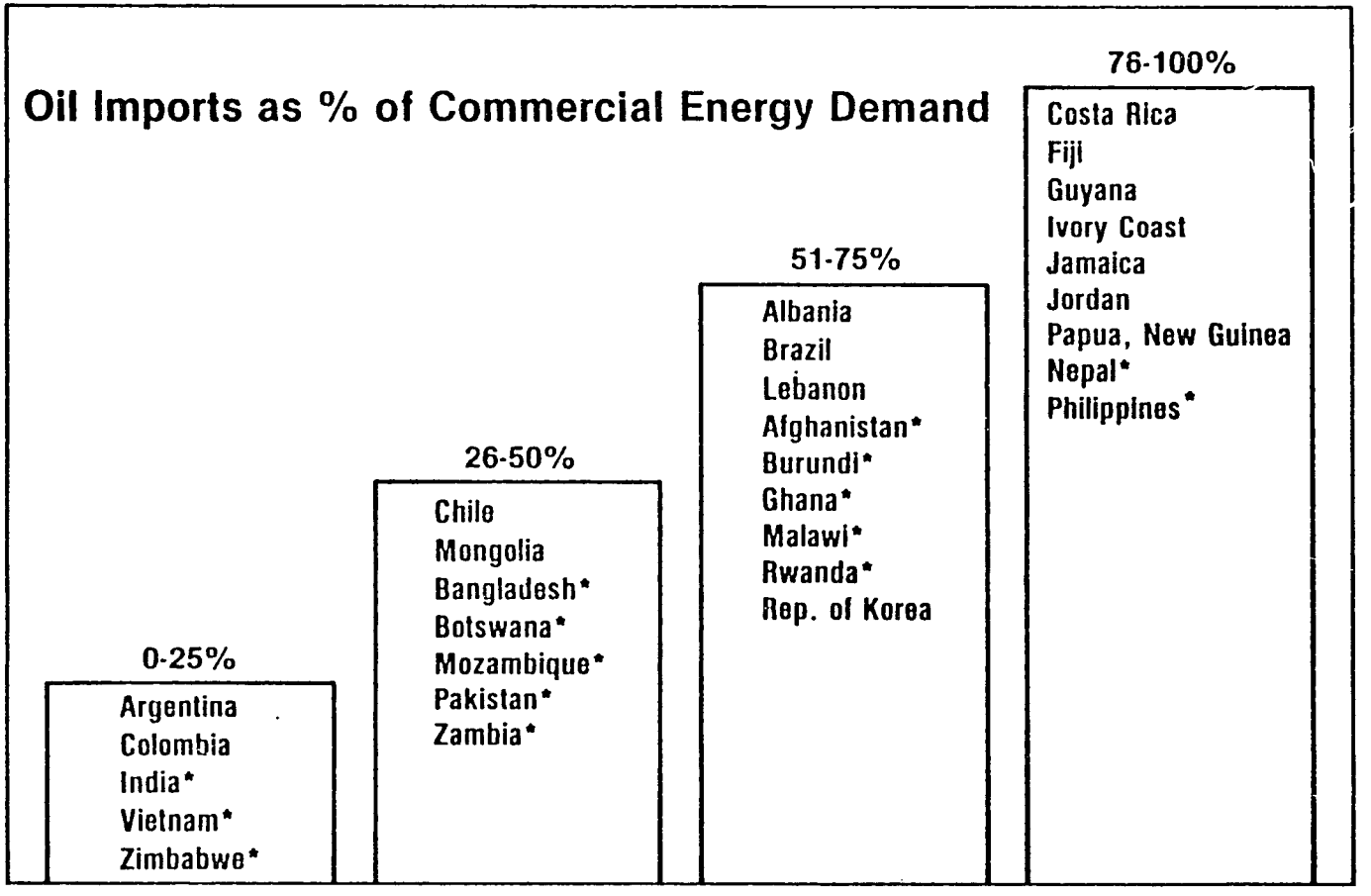
IMPLEMENTATION OF WOOD/BIOMASS ENERGY PROJECTS IN DEVELOPING COUNTRIES

ABU TALIB

Implementation of Wood/Biomass Energy Projects in Developing Countries

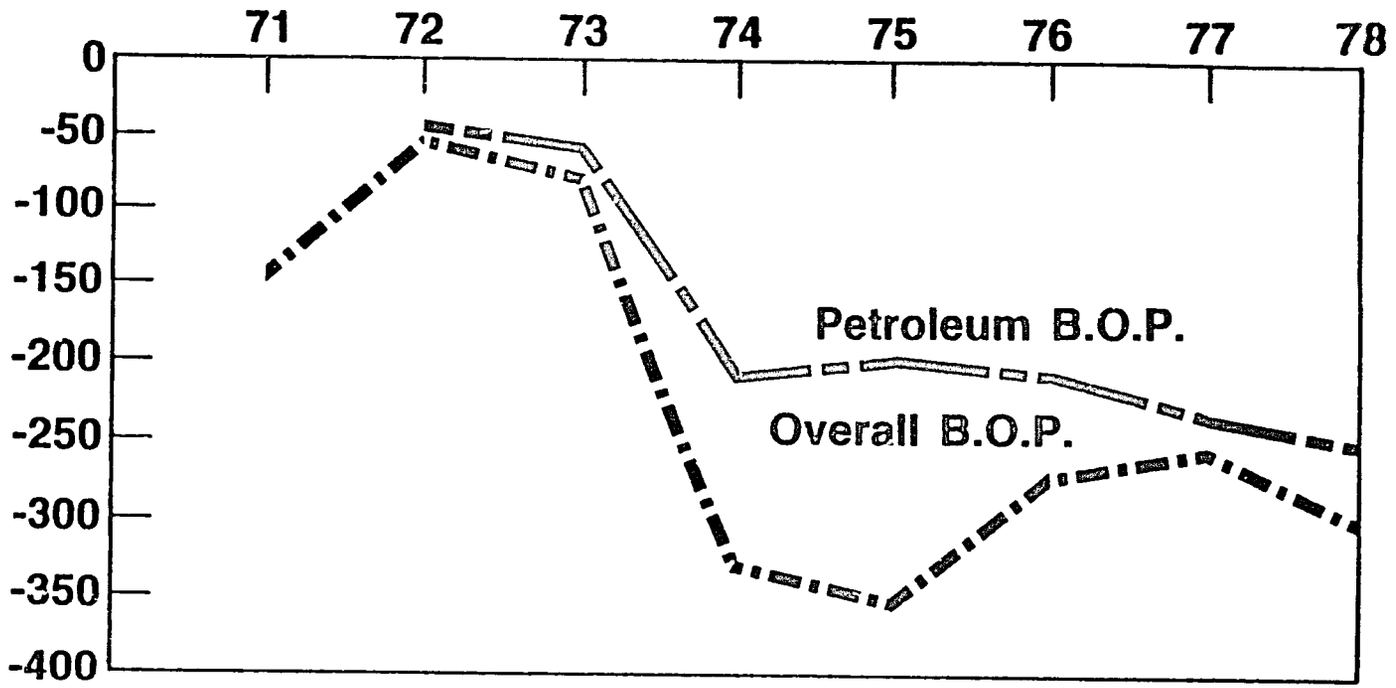
Abu Talib

The MITRE Corporation
1820 Dolley Madison Boulevard
McLean, Virginia 22102



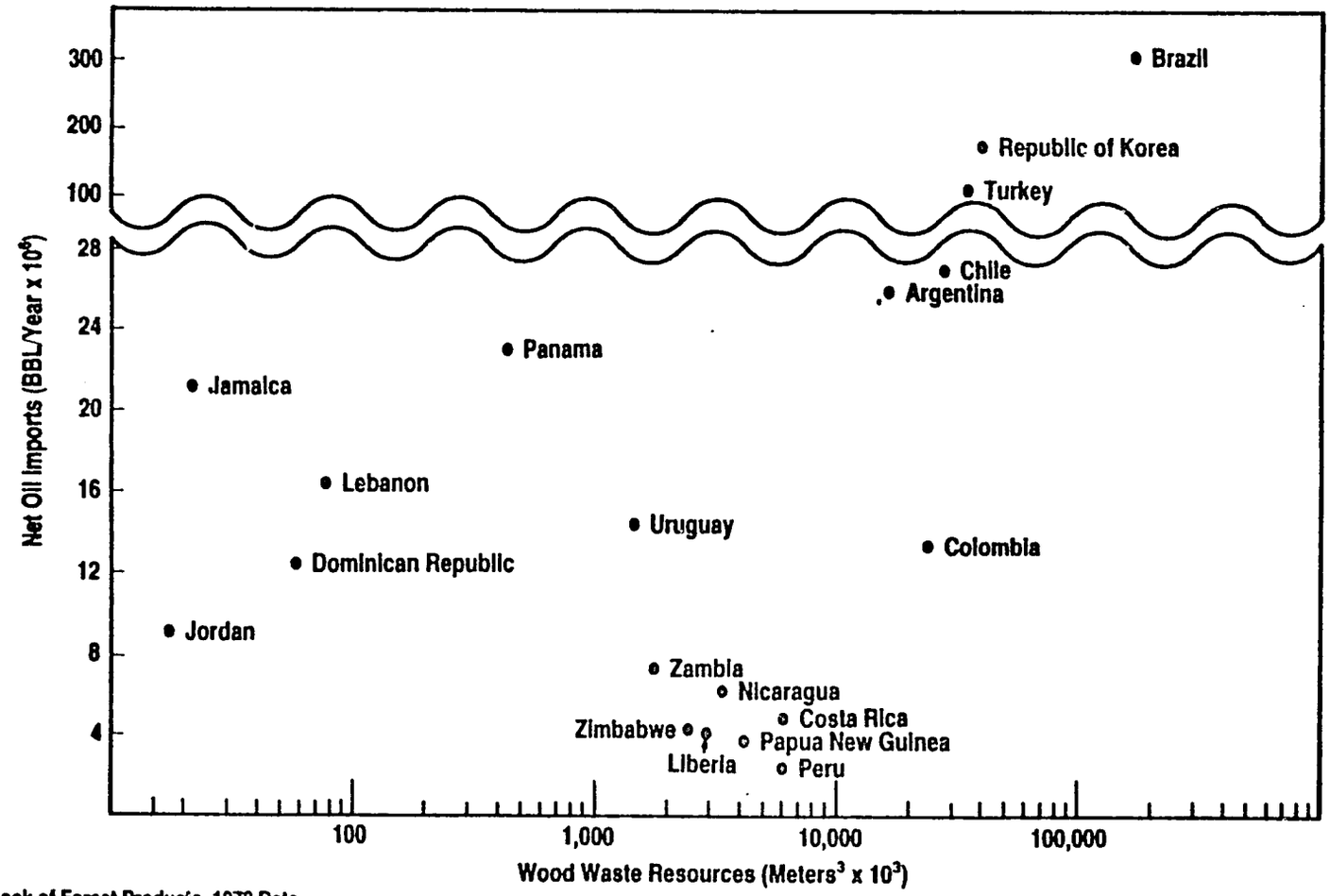
*Countries with Actual or Potential Deforestation Problems
Source: World Bank, 1980.

NET OIL IMPORTS OF SELECTED DEVELOPING COUNTRIES



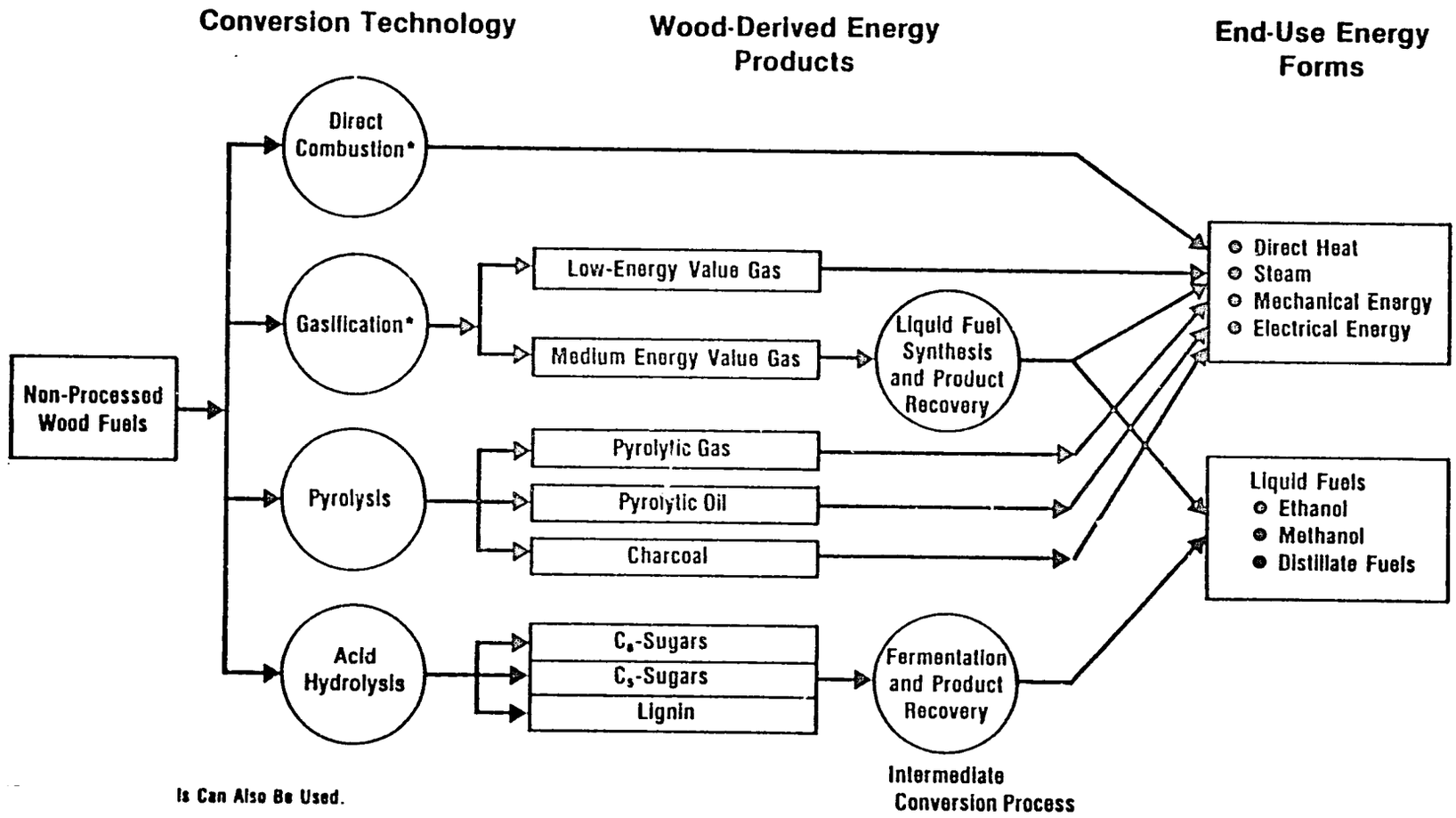
Source: The MITRE Corporation, Energy and Development–
A Preliminary Analysis for Less Developed Countries,
MTR-79W00216, 1979

MEAN BALANCE OF PAYMENTS FOR NON-OIL
EXPORTING DEVELOPING COUNTRIES



Source: Yearbook of Forest Products, 1978 Data

ENERGY POTENTIAL FROM WOOD RESIDUES



USE SCENARIO FOR WOOD AS A SOURCE OF INDUSTRIAL ENERGY

Petroleum-Derived Fuels	Direct Substitute	Indirect Substitute
• Gasoline	○ Ethanol ○ Methanol ○ Low-Energy Value Gas	• Methanol
• Diesel	○ Low-Energy Value Gas ○ F.T. Liquids	
• Distillate Oil	○ Low-Energy Value Gas ○ Medium-Energy Value Gas ○ F.T. Liquids	• Solid Fuel
• Residual Fuel Oil	○ Pyrolytic Oil ○ Char-Oil Slurry ○ Low-Energy Value Gas ○ Medium-Energy Value Gas	• Solid Fuel
• LPG	○ Low-Energy Value Gas ○ Medium-Energy Value Gas ○ F.T. Liquids	

POTENTIAL WOOD-DERIVED FUEL SUBSTITUTES FOR PETROLEUM FUELS

Application / Project	Electricity and Power Generation	Irrigation System	Food Products Industries	Forest Products Industries	Other Industries
• Wood-Fired Power and Cogeneration Plants	• Rural Electrification	—	○ Grain Drying ○ Fish Processing ○ Milk Processing ○ Meat Packing ○ Bottling Plants and Canneries ○ Others	○ Electric Power for Sawmills ○ Lumber Drying ○ Plywood and Veneer Production ○ Pulp and Paper	• Distilleries and Breweries • Textile
• Wood Gasifiers Air-Blown	• Rural Electrification	• Pumping Water	Retrofit to Existing Oil-Fired Equipment in the Above Food Products Industries	○ Electric Power for Sawmills ○ Retrofit to Existing Oil-Fired Equipment	○ Brick Kilns ○ Calcination
• Wood Gasifiers Oxygen-Blown	—		—	—	○ Liquid Fuel Production ○ Refractory Manufacturing • Lime and Cement Kilns

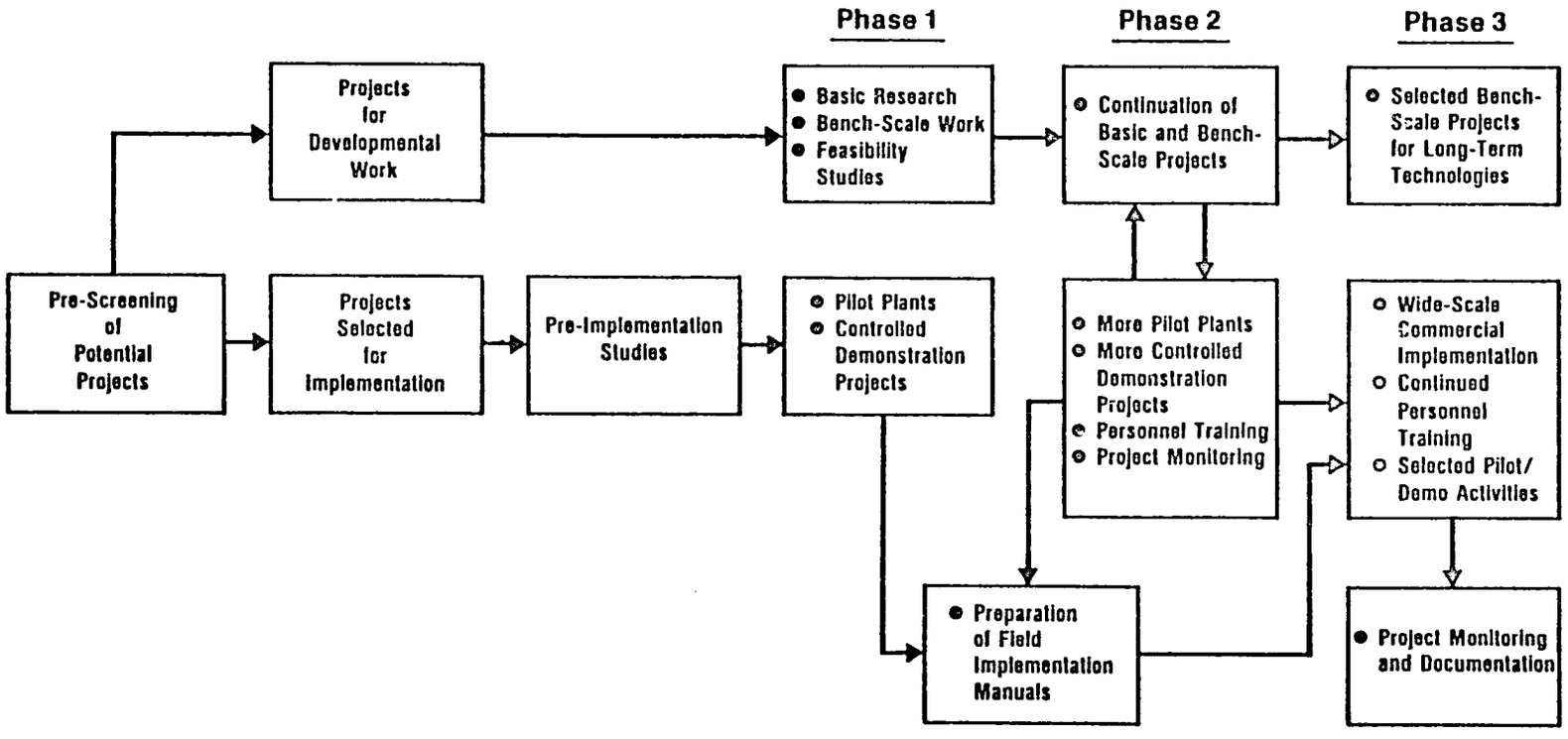
POTENTIAL WOOD ENERGY PROJECTS
IN DEVELOPING COUNTRIES

Application / Project	Electricity and Power Generation	Irrigation System	Food Products Industries	Forest Products Industries	Other Industries
● Integrated Charcoal Production (State-of-the-Art)	○ Utility Power Generation by Char/Oil Slurry	○ Water Pumping Using Small Charcoal Gasifiers	—	—	● Pig Iron Manufacturing ● Pig Iron and Other Metallurgical Operations ○ Activated Carbon Manufacturing
● Advanced Charcoal Production Systems	○ Utility Power Generation ● On-Site Power Generation	—	● Retrofit of Existing Oil-Fired Equipment	● Retrofit of Existing Oil-Fired Equipment	
● Wood-to-Ethanol Plants	—	—	—	—	● Liquid Transportation Fuels ● Chemical Industry

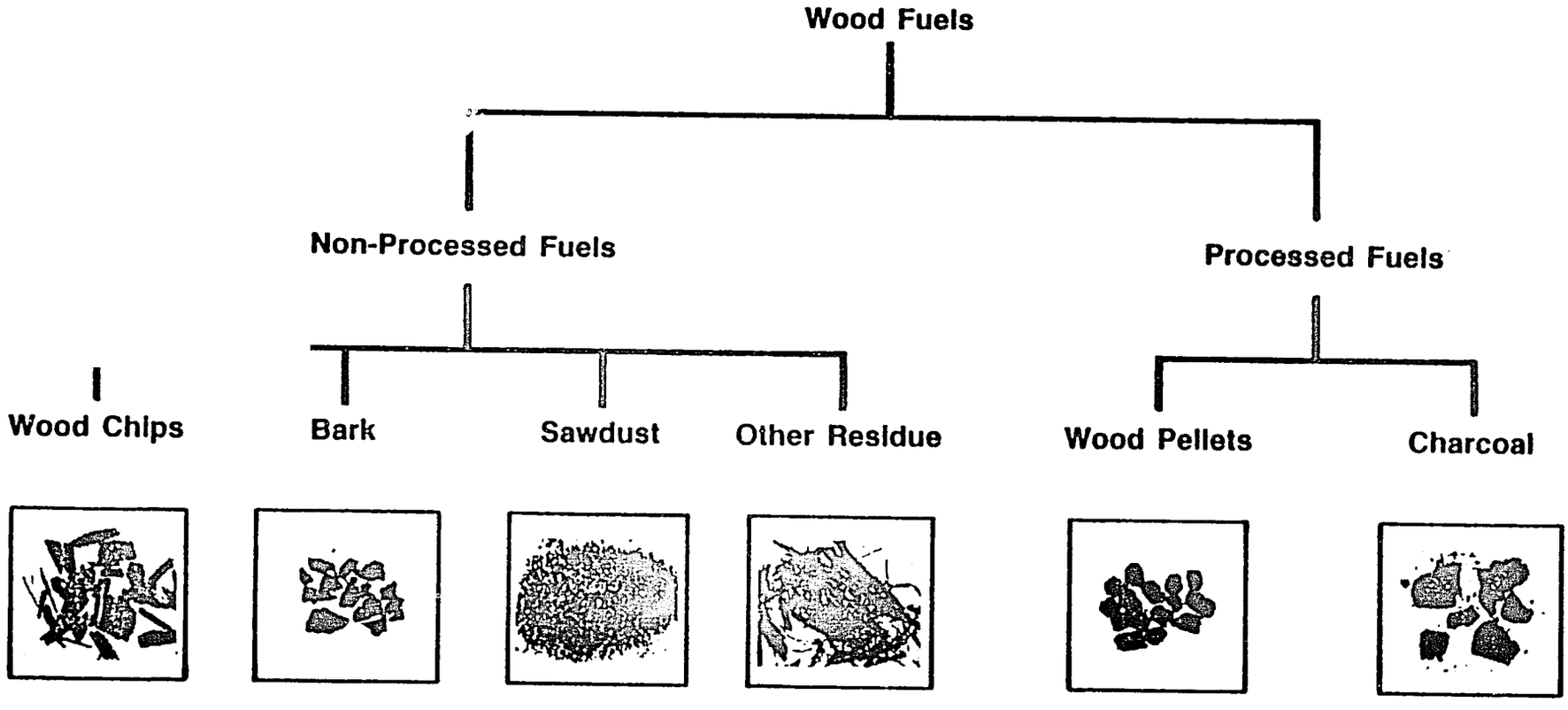
POTENTIAL WOOD ENERGY PROJECTS IN DEVELOPING COUNTRIES (CONCLUDED)

- **Resource Factors**
  - Type and Approximate Quantities of Wood Resource Available
  - Existing Uses and/or Disposition Methods
  - Potential Deforestation Problems
  - Location of Resource with Respect to Prospective Energy User
- **Country Energy Consumption Factors**
  - Type and Approximate Quantities of Petroleum-Derived Fuel Consumption
  - Identification of Petroleum-Derived Fuel(s) and Consuming Sector for Potential Wood Fuel Substitution
- **Technology Factors**
  - State-of-the-Art of the Technology
  - Operating Experience in Developing Countries
  - Potential for Local Fabrication
  - Compatibility with the Existing Technologies
  - Environmental Impacts
- **Socioeconomic/Institutional**
  - Commensurate to Existing Government Policies
  - Ability to Enhance Employment Opportunities
  - Compatibility with the Existing Resource Allocation and Distribution System

SUGGESTED IMPLEMENTATION FACTORS FOR WOOD/BIOMASS GASIFIERS



PHASED IMPLEMENTATION STRATEGY



TYPES OF WOOD FUELS SUITABLE FOR
INDUSTRIAL APPLICATIONS

Properties \ Fuel Type	Wood Chips*	Wood Pellets	Charcoal L.V.M.	Charcoal H.V.M.	Illinois #6 Coal
Energy Density BTU/Lb. (as Received)	4200	8290	12070	10,785	11480
Bulk Density Lb./Cu.Ft.	20	40	20		50
Volatile Matter % (M.F.)	79.4	81.2	2.6	28.4	46
Fixed Carbon % (M.F.)	20.1	18.2	90.0	56.6	44.5
Moisture Content % (W.B.)	50-55	5-10	5.2	1.5	12.1
Sulfur Content % (M.F.)	—	—	0.1	0.1	4.9
Ash Content % (M.F.)	0.5	0.6	7.4	15.0	9.8

*Typical Soft Wood
L.V.M. = Low Volatile Matter
H.V.M. = High Volatile Matter

CHARACTERISTICS OF SELECTED WOOD FUELS

Country	Population* (Million)	Oil Imports** (1000 bbl)	Potential Deforestation	Stage of Wood Energy Technology Implementation
Papua, New Guinea	3.0	4,360	No	Pre-Implementation
Indonesia	146.0	19,020	Yes	Phase 1
Philippines	49	68,770	Yes	Phase 3
Brazil	119	376,148	No	Already Implemented

*1980 Statistical Data
**1979 Data
***Net Oil Exporting Country
Source: World Development Report, 1982, World Bank

EXAMPLES OF WOOD ENERGY TECHNOLOGY IMPLEMENTATION
IN DEVELOPING COUNTRIES

Project Type

- Wood Gasifier Retrofit to Existing Oil-Fired Boiler

Location

- S.P. Brewery, LAE, Papua New Guinea

Existing Steam Plant System

- System Description
  - Three 250 HP No. 6 Oil-Fired CB Boilers
  - Feedwater Treatment and Steam Distribution Systems
  - Fuel Storage Tank, Feed, and Air Atomized
  - No. 6 Oil Burner System
- Operating Schedule
  - On Stream Time–5,544 Hr/Yr
  - Units in Operation–Two
  - Peak Demand–480 HP (16,500 Lbs of Steam per Hour)
  - Annual Oil Consumption–8,400 Bbl/Yr

Proposed Wood-Fired System

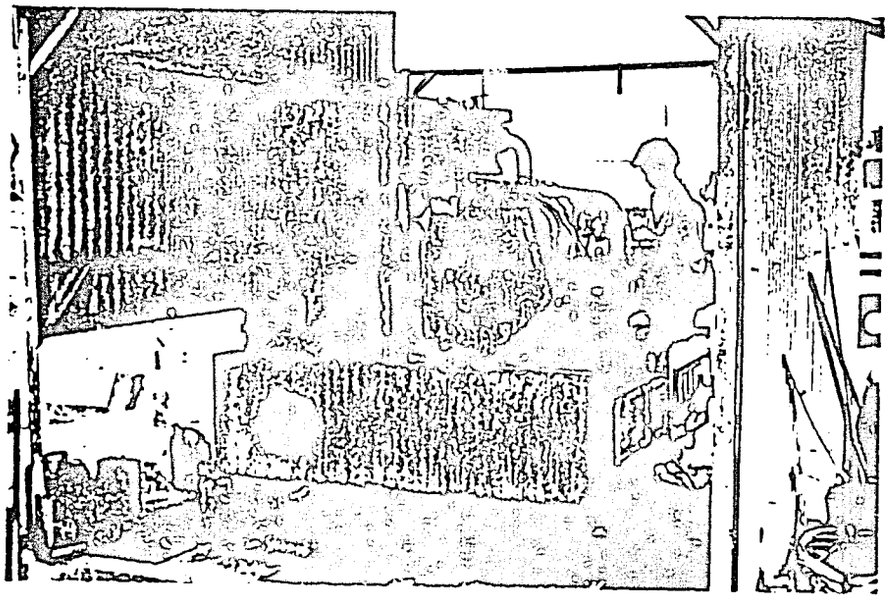
- System Description
  - Two Wood Gasifiers to Retrofit to Two Existing Oil-Fired Boilers
  - Third Oil-Fired Boiler Will Serve as Back-Up System
  - Complete Wood Fuel Unloading, Storage and Feed System
- Type of Fuel
  - Mill Residue from a Nearby Sawmill
  - Annual Fuel Consumption–4,200 Tons/Yr

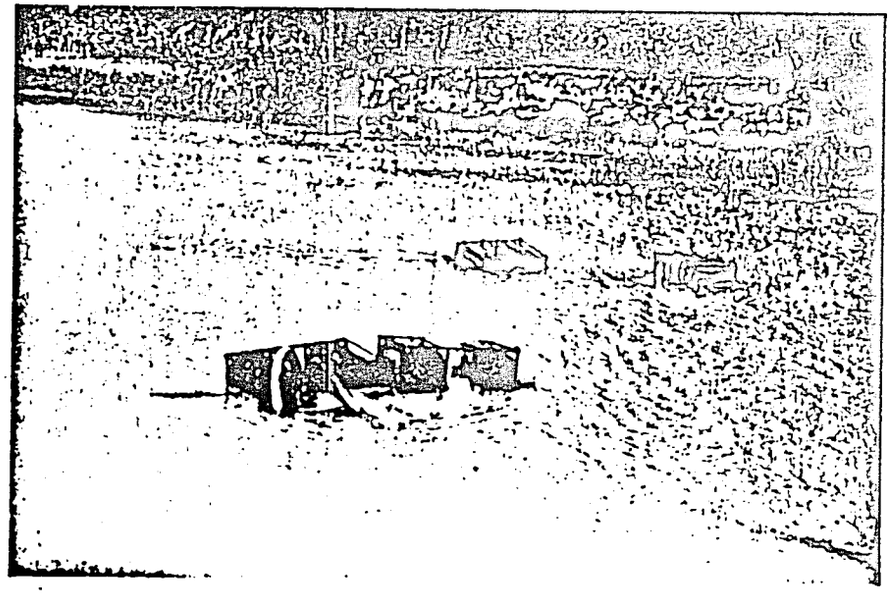
Comparative Economic Indicators

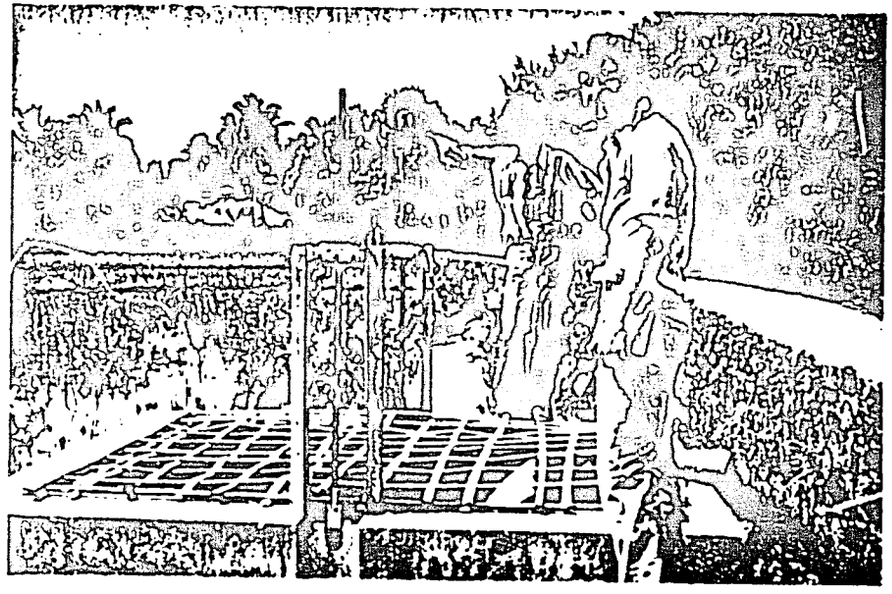
- Existing System
  - Capital Cost*–$45,000
  - Fuel Cost–$421,000/Yr
  - O&M Cost–$50,000/Yr
- Proposed Wood-Based System
  - Capital Cost $517,000
  - Fuel Cost–$82,000/Yr
  - O&M Cost–$72,000/Yr
  - Discounted Payback–24 Months

*Only Working Capital

SELECTED DEMONSTRATION PROJECT FOR PAPUA NEW GUINEA







SMALL WOOD GASIFIER PUMPING IRRIGATION WATER IN PICON, INDONESIA

	Project No. 1	Project No. 2
Type	Small Rural Direct Wood-Fired Power Plant	Wood-Fired Cogeneration Plant
Suggested Location	Near a Rural Community in Sumatra or Kalimantan	Existing Saw and/or Plywood Mill in Sumatra, Kalimantan or Other Wood-Rich Islands
Fuel Type	Wood Chips, Logging Residue	Saw Mill Residue
Size	500 KW Electric Power (1980 Lb/Hr Bone Dry Wood)	1500 KW Electric Power and 4400 Lb/Hr Low Pressure Saturated Steam
Major Equipment	Wood Chipper*, Fuel Storage Bin, Boiler, Turbin-Generator, and Auxiliary Equipment	
Equipment Price F.O.B. New York	$660,000	$1,400,000

*A Hog May Be Required for Waste Wood Fuel

SELECTED DEMONSTRATION PROJECTS FOR INDONESIA

Project Type

- Dendro Thermal Power Plants (Dedicated Tree Farms to Supply Fuel to Wood-Fired Power Plants)

Selected Locations

- Approximately 72 Sites Situated in the Islands of Luzon, Panay, Negros, Cebu, Bohol, Samar, and Others

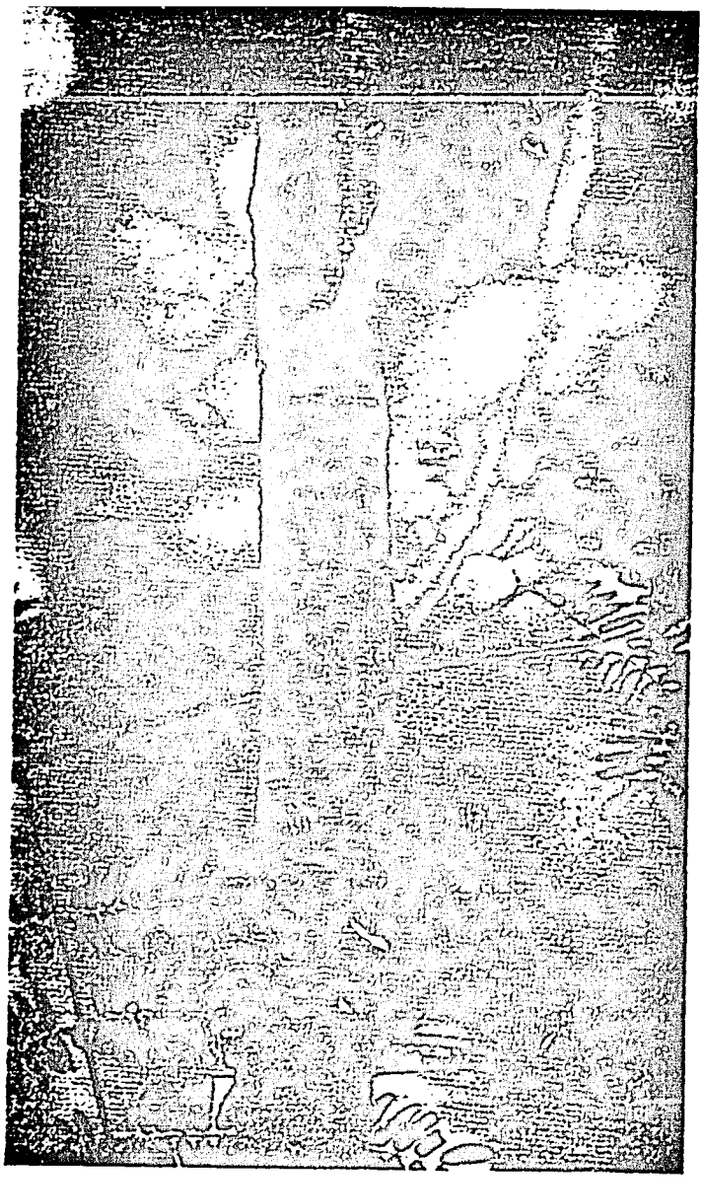
Description of a Dendro Thermal Power Plant

- Size: 3-MW Direct Wood-Fired Steam Electric Power Plant
- Major Equipment: Boiler, Turbine-Generator, Condenser, Switch Gears, Substation Equipment, and Auxiliary Equipment
- Operating Conditions
  - Boiler: 300-600 PSI
  - Turbine: Exhaust–3-3.5 Inch Hg
    RPM–7,000-10,000
  - Generator: RPM–1,800
    Volts–440
- Fuel Type
  - Wood Fuel Logs (3 x 12 Inch) to Chips (2 Inch Minus)
- Fuel Source–1,000 Hectares of Dedicated Fast-Growing Tree (Ipil-Ipil) Farm
- Fuel Requirement–Approximately 40,000 Wet Tons/Yr

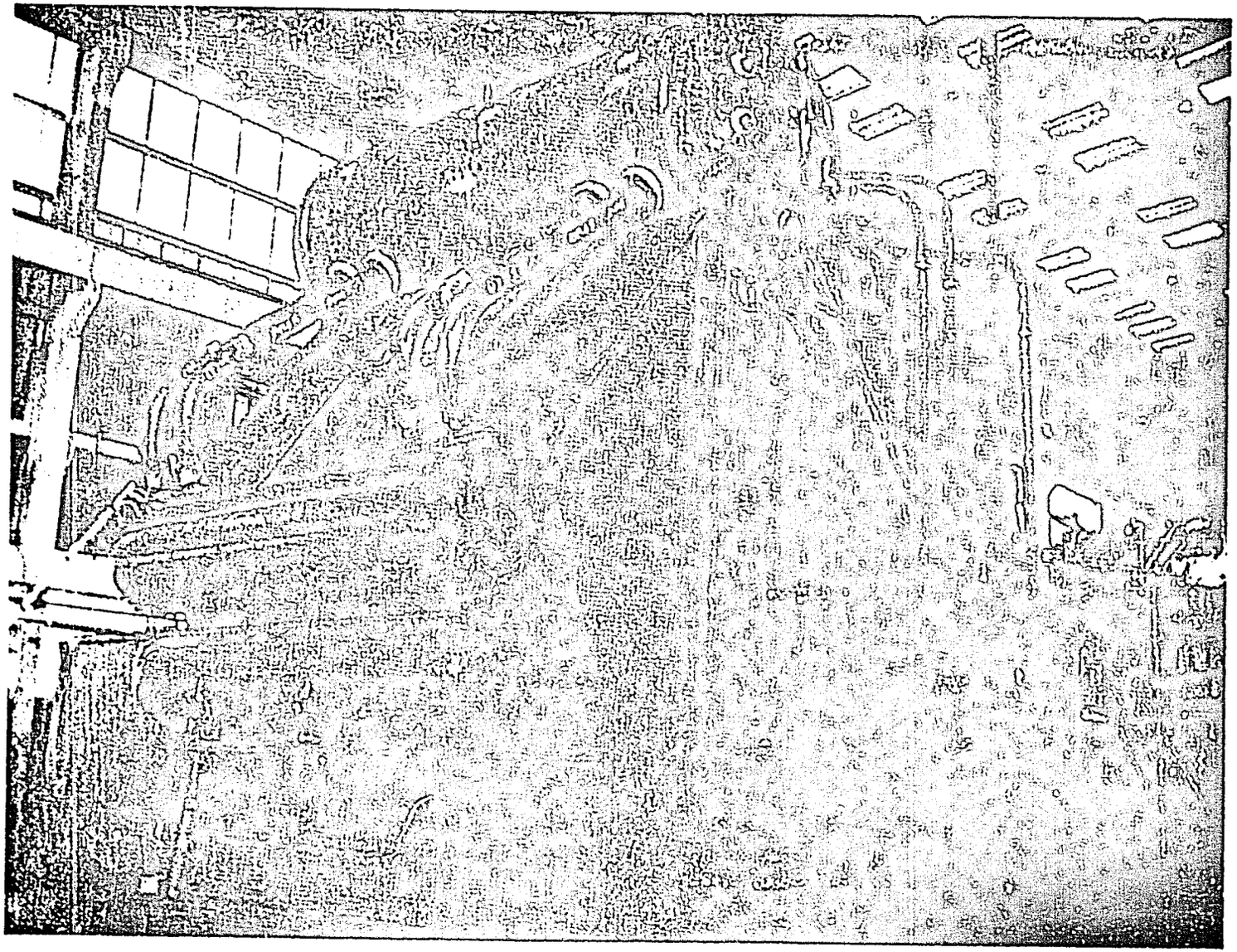
Comparative Economic Indicators

- Capital Cost
  - Equipment–$1,100/KW
  - Civil Works–$275/KW
- Fuel Cost–$7-8 per Green Ton
- Transport Cost–$82,500/Yr
- Labor Cost–$82,500/Yr
- Net Power–3,000 KW
- Operating Hours–5,500 Hr/Hr
- Net Annual KWH–16,500,000
- Total Estimated Generating Cost–49 Mills/KWH
- Oil-Based Electricity Generating Cost–60-90 Mills/KWH

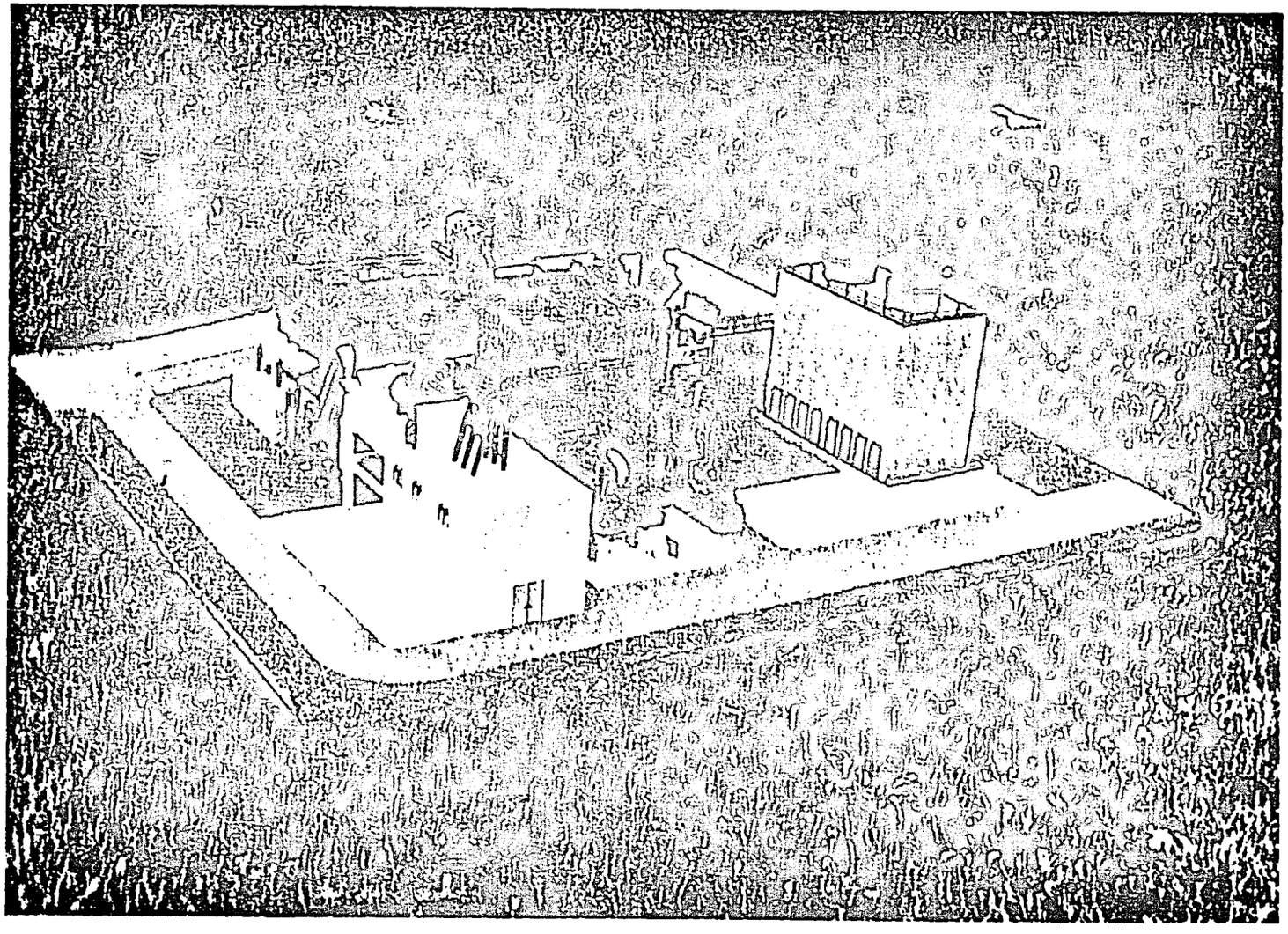
PHILIPPINE DENDRO THERMAL PROGRAM HIGHLIGHTS



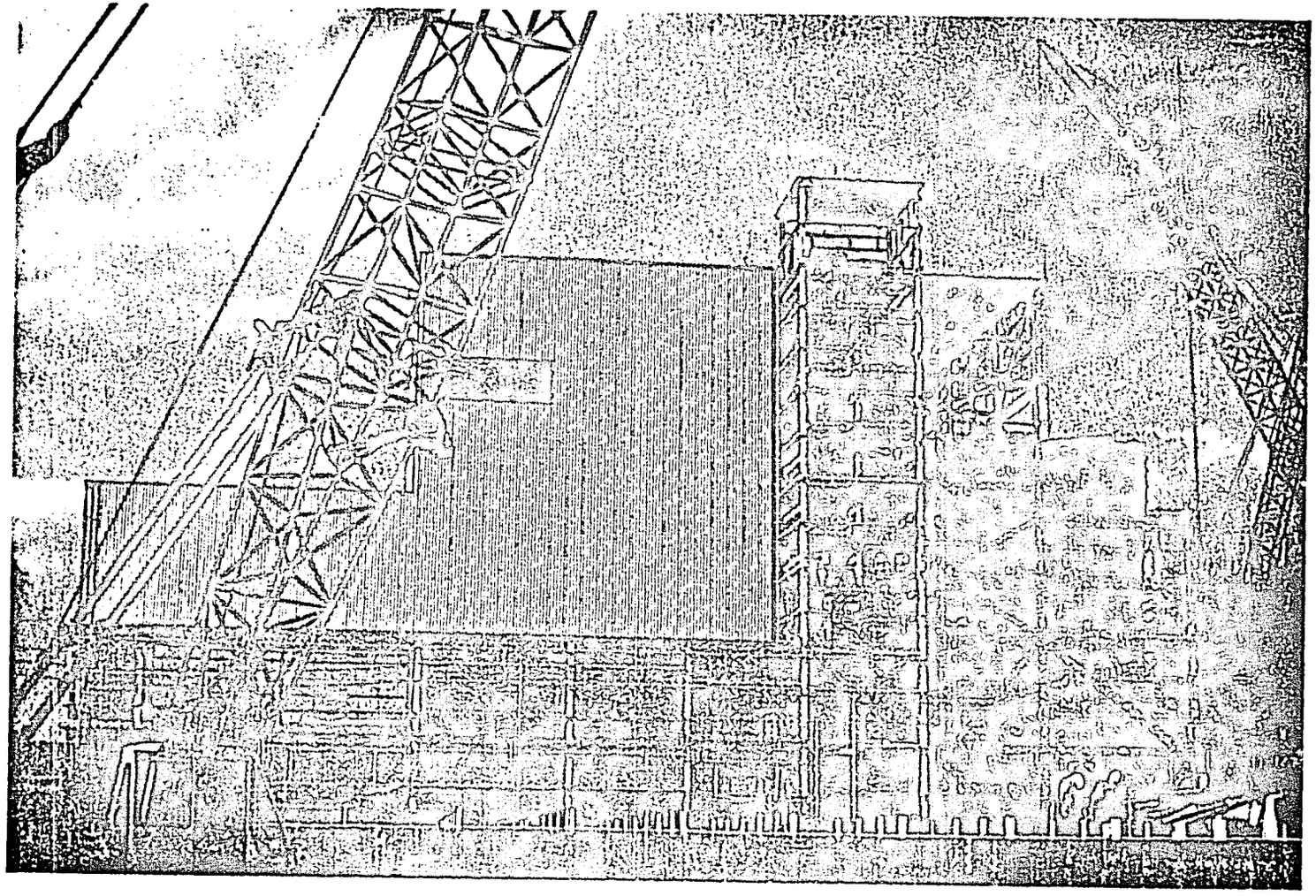
ONE-YEAR OLD IPIL-IPIL TRUNK



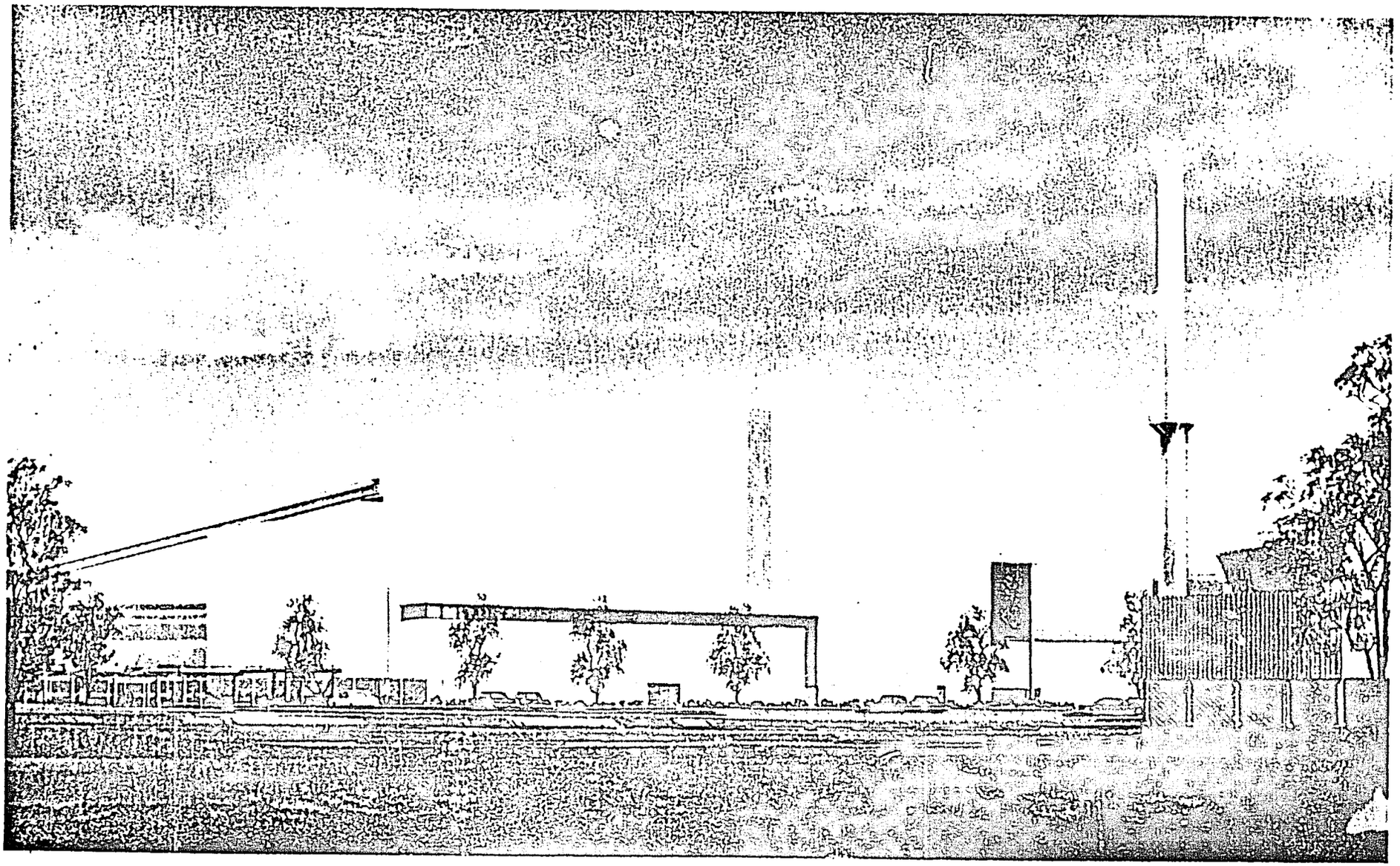
WOOD-FIRED BOILER FOR DENDRO THERMAL PLANT
IN SOLSONA, ILOCOS NORTE, PHILIPPINES



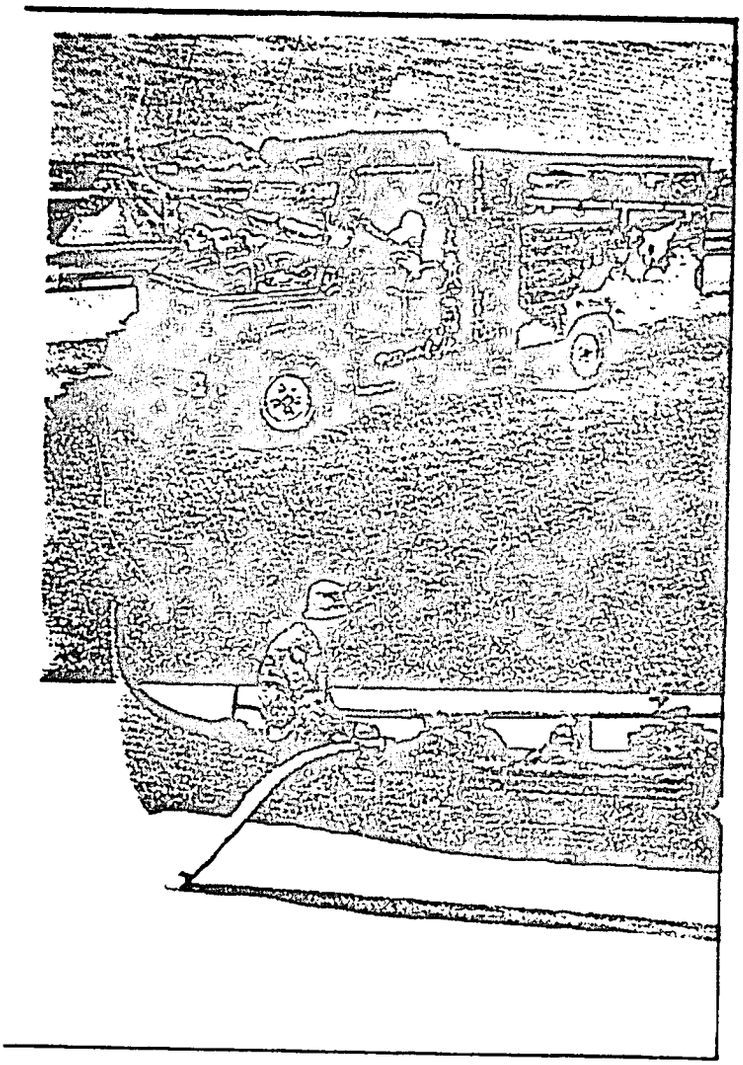
A 3 MWe DENDRO THERMAL POWER PLANT MODEL TO BE IMPLEMENTED IN PHILIPPINES



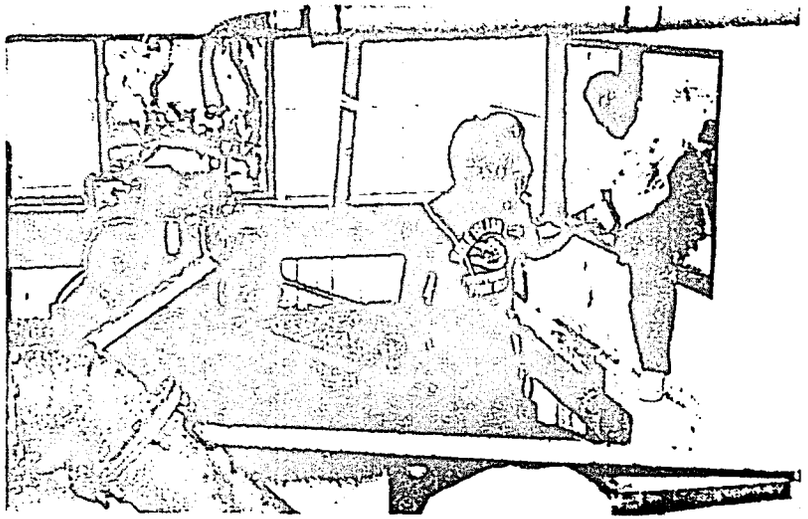
A 50 MWe WOOD-FIRED BOILER POWER PLANT UNDER CONSTRUCTION IN THE UNITED STATES

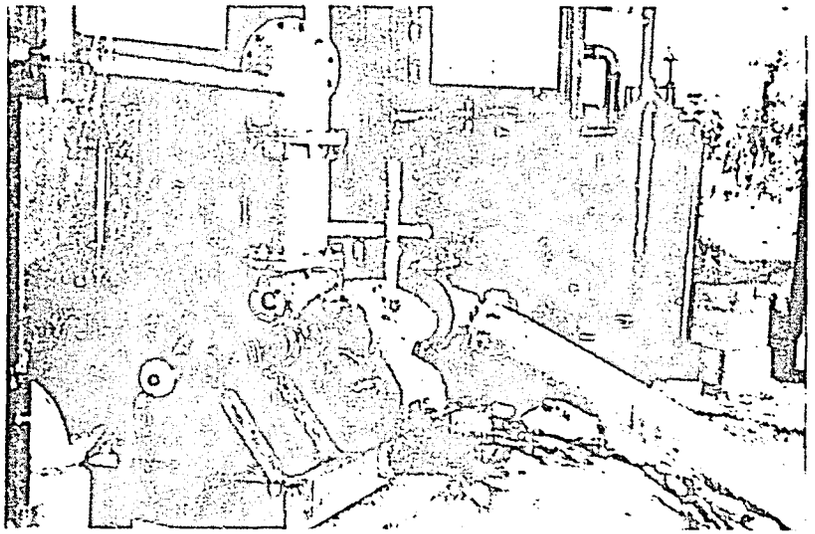


A 50 MWe WOOD-FIRED POWER PLANT MODEL
UNDER CONSTRUCTION IN THE UNITED STATES



MOBILE APPLICATIONS FOR CHARCOAL GASIFIER IN PHILIPPINES





Charcoal-Based Gasifier-Engine System Running Irrigation Pump in Philippines

Project Type

- Charcoal Production from Native Forest and Energy Tree Farms

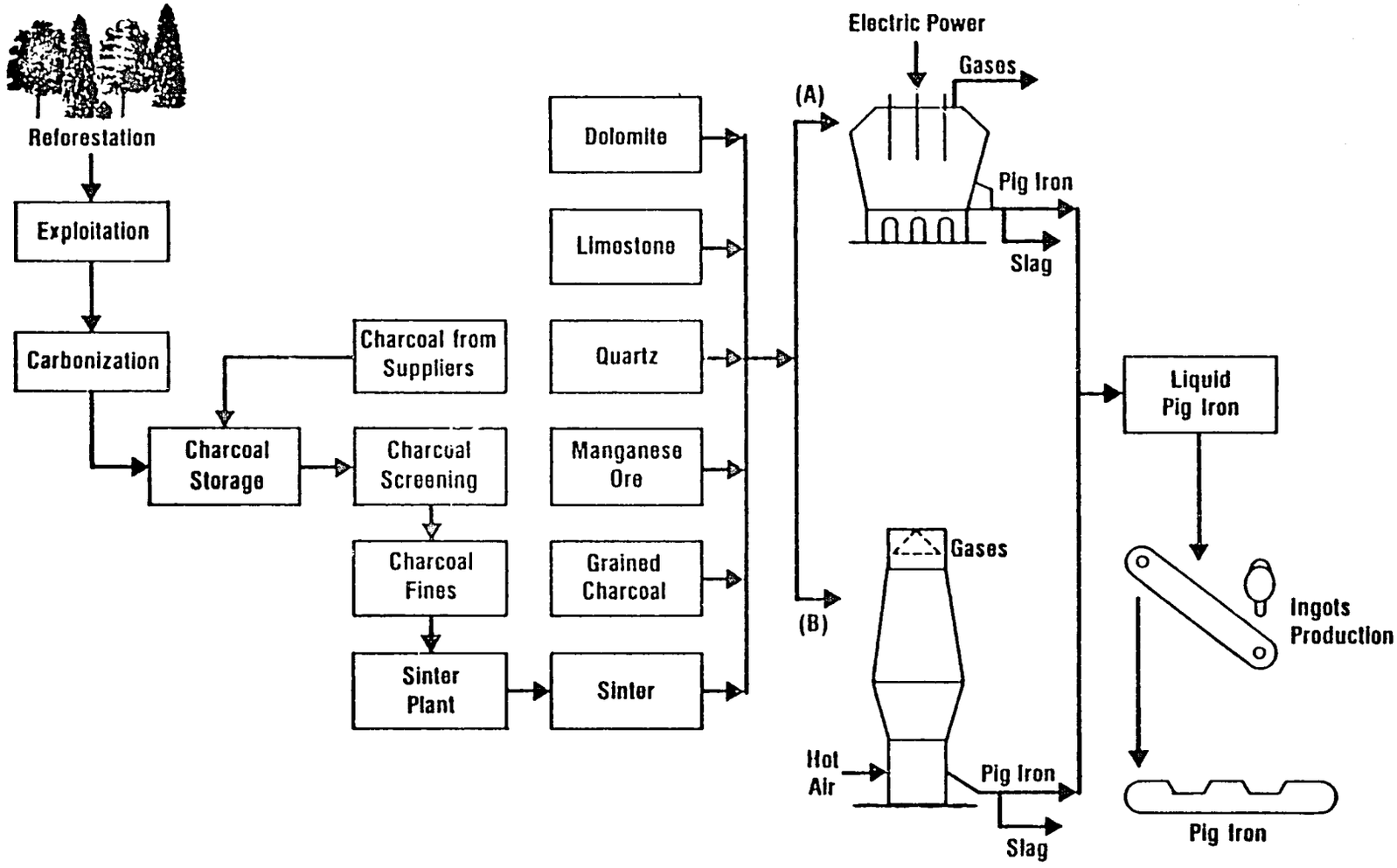
Location

- State of Minas Gerais

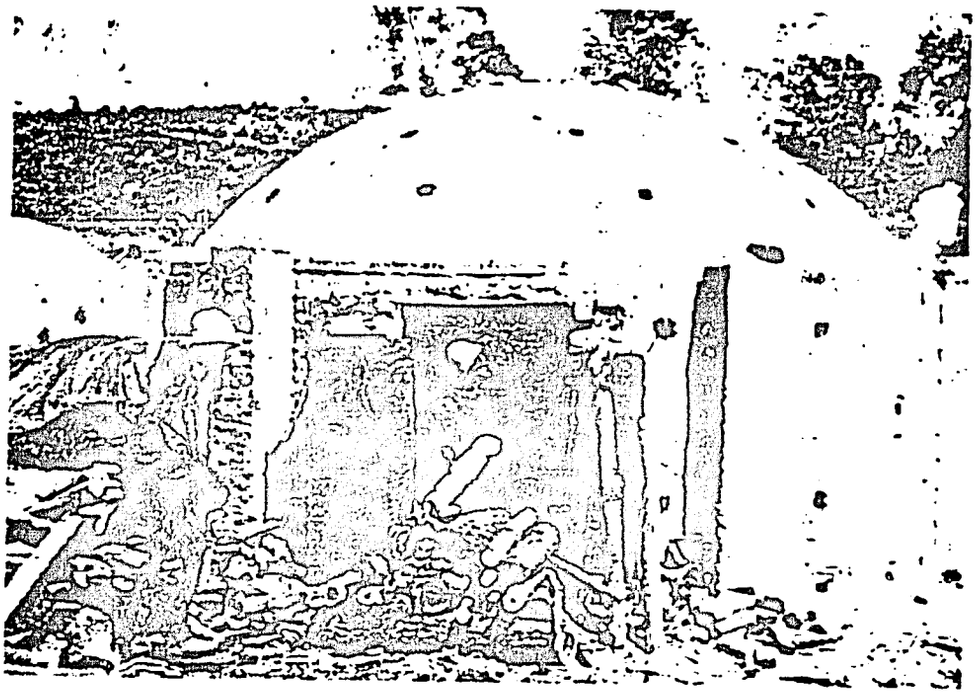
Charcoal Consumption

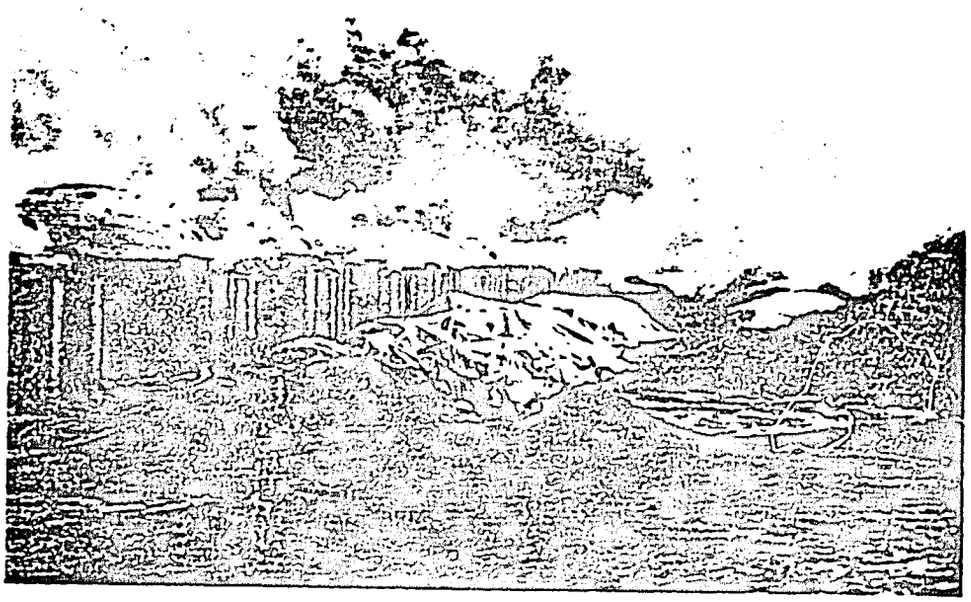
- For Pig Iron Production: 4,228,000 Tons (1981)
- Charcoal Sources: 72 Percent from Native Forest
  28 Percent from Tree Farms
- Production Method: Labor Intensive Brick Beehive Kilns

BRAZILIAN INTEGRATER CHARCOAL
PRODUCTION PROGRAM HIGHLIGHTS

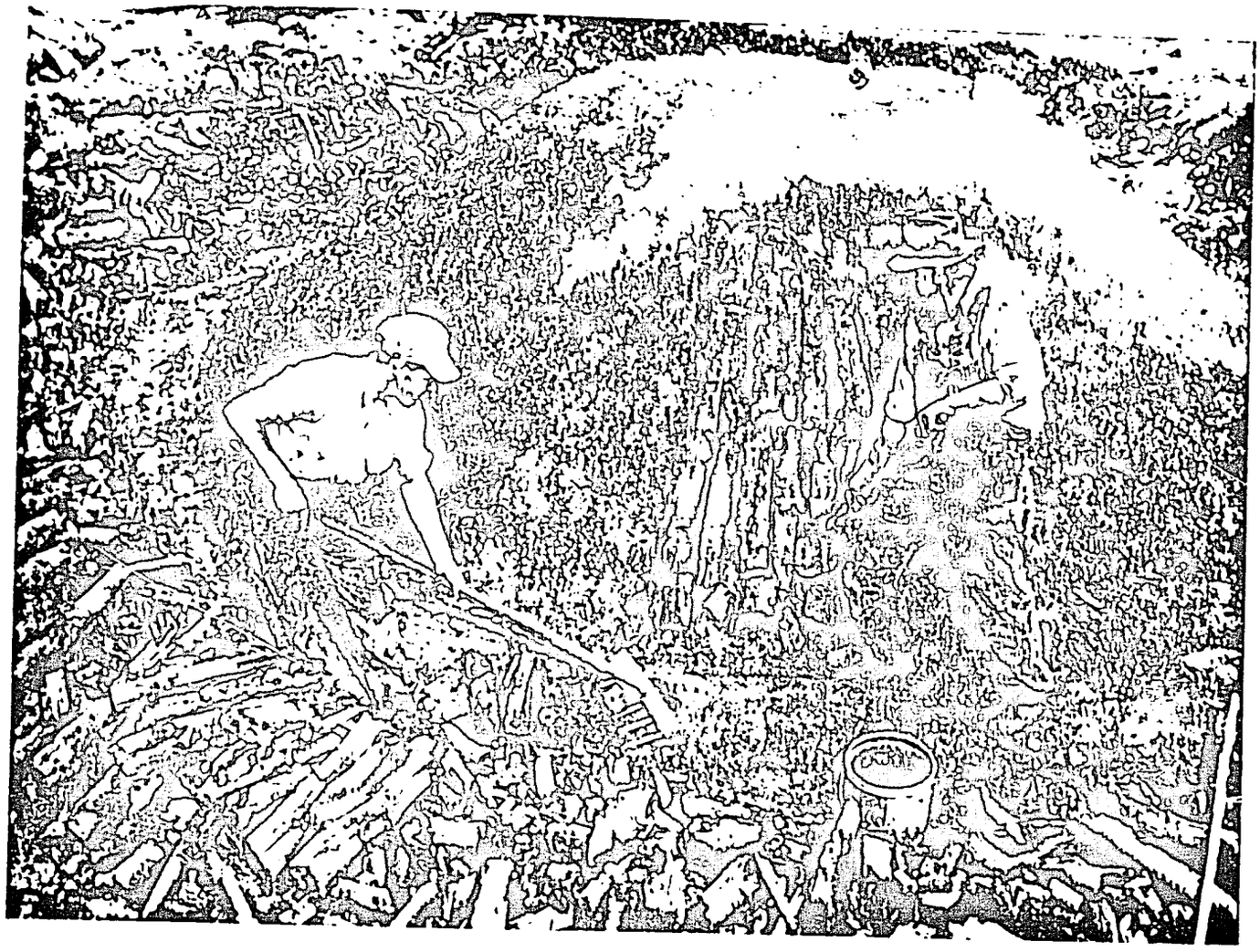


CHARCOAL-BASED PIG IRON PRODUCTION OPERATION IN BRAZIL

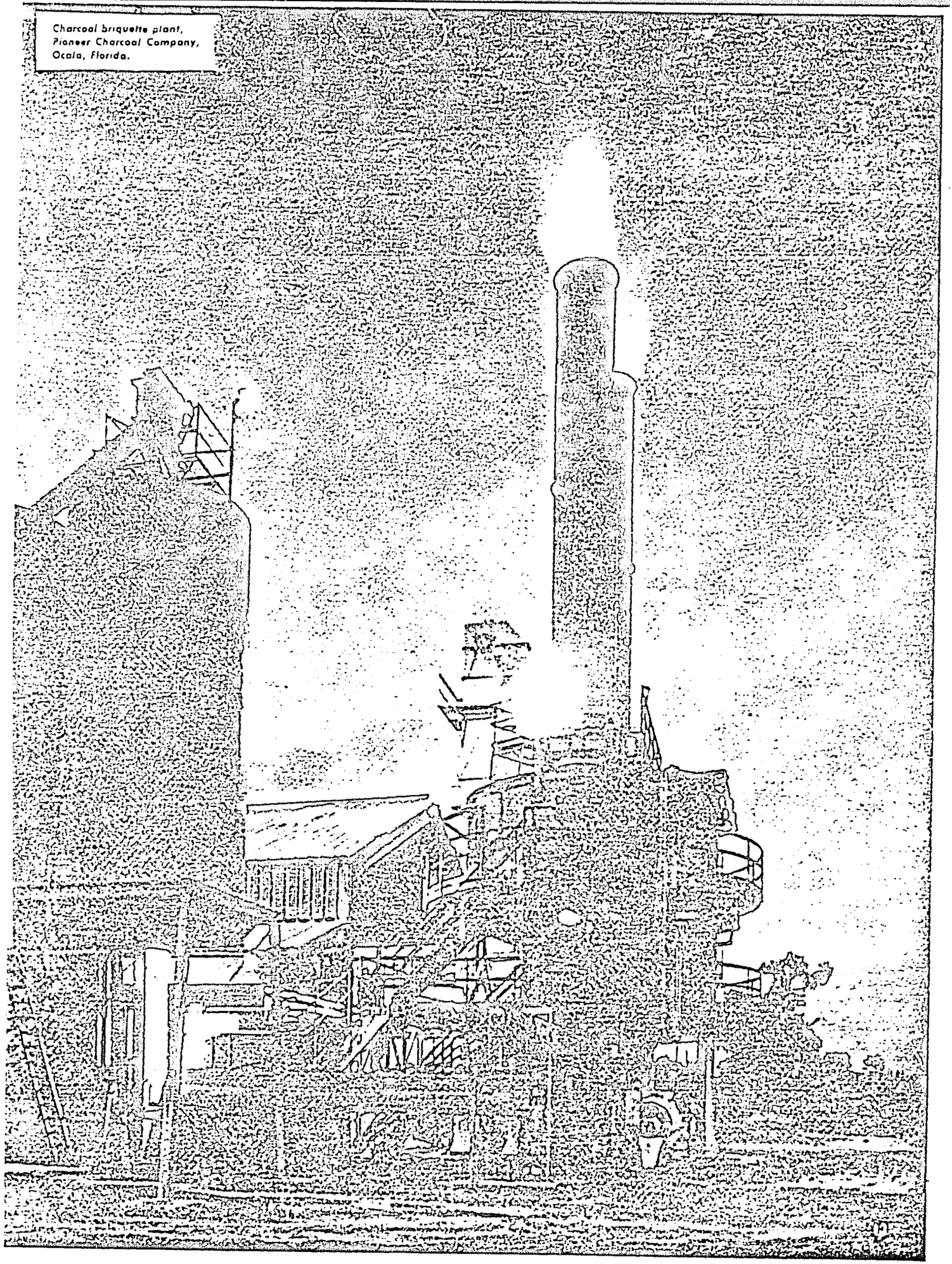




BATTERY OF CHARCOAL KILNS OPERATING IN
BRAZIL WITH MANUAL LOADING

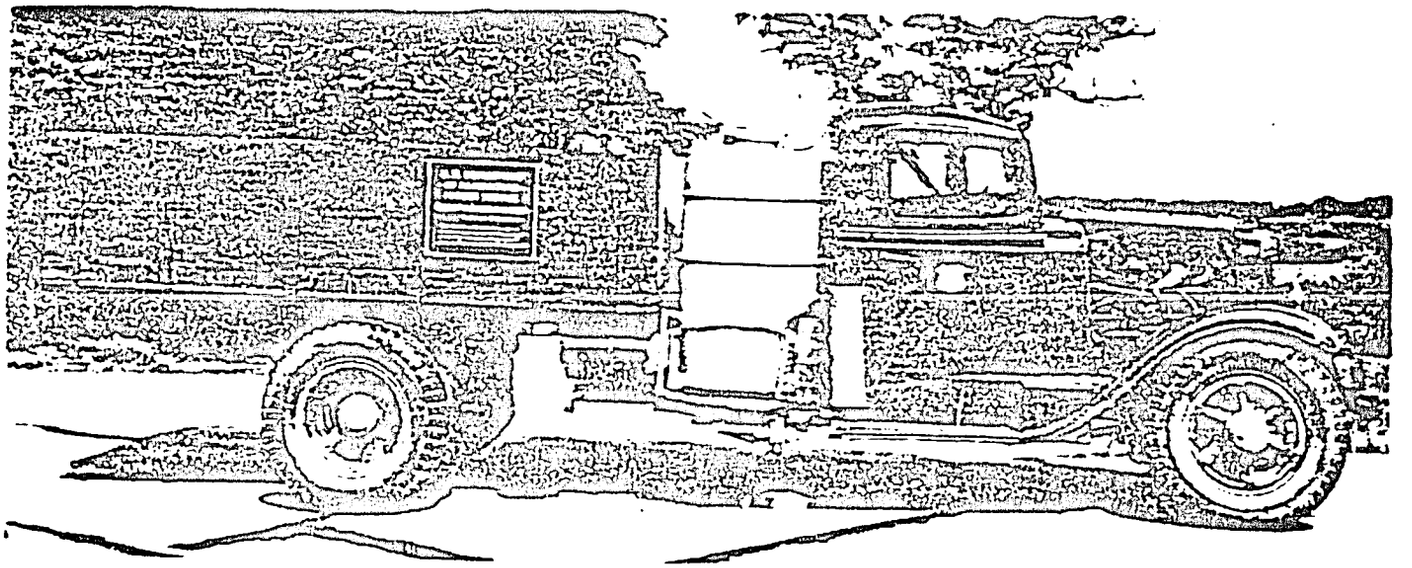


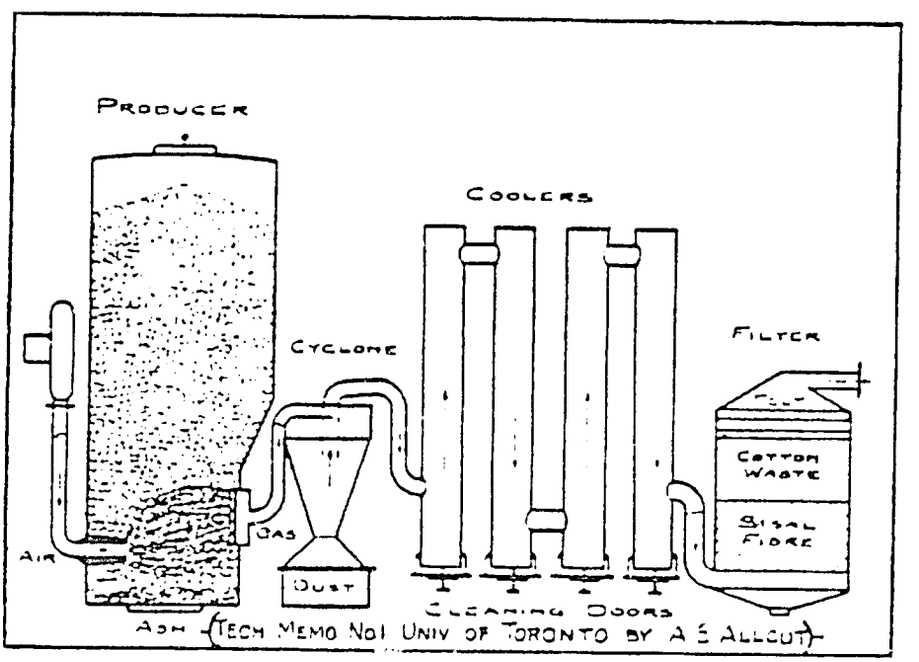
CHARCOAL PRODUCTION IN EARTH KILNS



Charcoal briquette plant, Pioneer Charcoal Company, Ocala, Florida.

MECHANIZED CHARCOAL PRODUCTION
IN THE UNITED STATES




PRODUCER
COOLERS
CYCLONE
FILTER
COTTON WASTE
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GAS
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DUST
CLEANING DOORS
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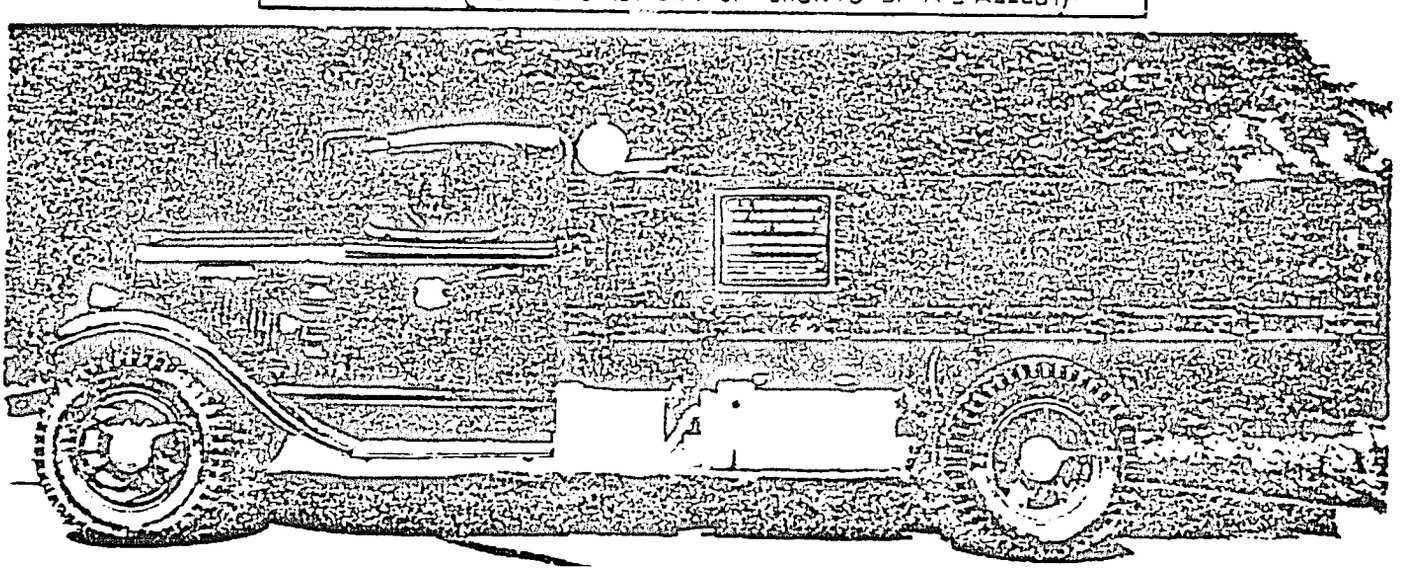


BRIEF REVIEW OF WOOD/BIOMASS DEVELOPMENT WORK BY PYRENCO, INC.

F. BIERLE

PYRENCO'S EXPERIENCE IN BIOMASS GASIFICATION

Frederick P. Beierle
President
Pyrenco, Inc

The Pyrenco gasification system utilizes a fixed bed, downdraft gasifier which incorporates a catalytic process to produce engine quality low BTU synthesis gas. Since 1980, Pyrenco has demonstrated the safety and durability of its gasifiers in various applications. This precommercial experience includes nursery heating, crop drying, vehicle fuel conversions, dual fuel diesel power generation, and spark ignition power generation. A 3 MW commercial power plant using Pyrenco technology is scheduled for groundbreaking in October 1983.

Introduction

Research that eventually led to the Pyrenco gasification system was motivated by the problems associated with field burning of agricultural and forest wastes and based on the premise that a suitable catalyst could be found to enhance the performance of "gasogen" technology. Ten years of sporadic work resulted in the 1978 discovery by Dr. Donald E. Chittick of a catalytic reaction which eliminated the production of tar in the output gas stream of a gasifier.

Pyrenco, Inc. was incorporated in 1979 to commercialize the gasification processes discovered by Dr. Chittick. Early testing concentrated on producing gas continuously, and at atmospheric pressures. Interest has always centered on engine quality gas and by the end of 1979 gasifiers ha been built and tested on engines ranging from a 4 HP Briggs and Stratton to a 1979 GMC V-8.

U.S. Forest Service Wind River Nursery

In the Spring of 1980, a 650,000 BTU per hour gasification unit was built and installed at the Wind River Forest Service Nursery in the Cascade

Mountains of Washington State. Fuel produced in the Pyrenco Gasifier at Wind River was used to heat three greenhouses where forest seedlings were being grown. Testing with the Wind River Gasifier continued throughout the Spring and early Summer of 1980 and included operating a 45 Kilowatt generator coupled to a Waukesha engine fueled with the synthetic gas.

Wyckoff Farms

In September 1980, Pyrenco, Inc. designed and had B&B Equipment Company build a 3.5 million BTU per hour gasifier. This unit was successfully tested at the Wyckoff Farms, Inc. hop dryer in Grandview, Washington. At the end of the drying season this gasifier was moved to the Pyrenco Pilot Plant for further testing with a diesel engine generator.

Caterpillar Engine Testing

In July 1980, Pyrenco signed an agreement with Halton Tractor, a Caterpillar dealer in Portland, Oregon to initiate testing on larger engine-generator sets. Testing began with a scale up in generator size of almost 4 times (45 KWH to 175 KWH) using a diesel Caterpillar Model 3406T. A suitable control panel was designed and built by Lloyd Controls of Seattle, Washington. By May 1981, Pyrenco had installed the engine generator and related equipment and signed a contract with the Benton County Public Utility District (PUD) to sell the power. On June 8, 1981, Pyrenco went "on line" for the first time.

Testing in June 1981 was around the clock. The 3406T engine generator was run on a fuel mixture of diesel and synthetic gas from the Pyrenco gasifier. Controlled tests showed that as little as 5% diesel could be run with power output at 70% of rated capacity of the generator. This Syn Gas/diesel mode was operated for more than 500 hours continuously during the Summer of 1981. In February 1982, a spark ignition Caterpillar Model G-398 natural gas engine was installed, and B&B Equipment and Pyrenco, Inc. designed and built a special carburetor to handle low BTU gas. This engine was proved to be exceptionally well suited to Synthesis Gas fueling.

Future Fuels Challenge Rally

In October 1981, Pyrenco, Inc. competed in the Future Fuels Challenge Rally from Los Angeles to New York City. The Pyrenco entry was a 1981 Chevrolet pickup with a gasifier mounted on the bed. This vehicle was driven 3,500 miles from coast to coast using wood pellets converted to synthetic gas as its only fuel. The Pyrenco entry was the only one of six gasifier fueled vehicles to be certified by the Sports Car Club of America (SCCA) as completing the rally. In fact, it was the only gasifier entry to make it past Denver, Colorado and still meet all of the stringent requirements of the rally.

BPA Biomass Power Generation Project

In September 1982, Pyrenco, Inc. received notice from Bonneville Power Administration (BPA), U.S. Department of Energy, Portland, Oregon that the company's biomass power generation proposal had been selected by BPA for funding. Pyrenco's 400 KW test facility will be operated in a semi-commercial mode in order to gather detailed engineering, environmental and economic data on gasification for power generation. This is the only such project receiving BPA funding. It will demonstrate that low BTU gas from a variety of renewable resources (i.e., forest, agricultural and food process waste) is suitable for fulltime power production using commercially available reciprocating engine-generator technology. BPA has also asked Pyrenco to include testing on municipal solid waste (MSW) as a part of this project. On April 8, 1983, Pyrenco signed a two year, $700,000 Cooperative Agreement with BPA for the Project.

The Mio, Michigan 3 MW Power Plant

Pyrenco, Inc. is completing contracts to design and construct its first commercial biomass power generation facility using Pyrenco gasification technology. This project is the result of over one year of effort by the Company to fund a commercial demonstration of its system. This plant is expected to begin operation in 1984.

The Mio Project consists of the construction and installation of three megawatts of biomass power generation in an industrial park south of Mio, Michigan, which is being developed by the Oscoda County Economic Development Corporation. The facility will process biomass (i.e., solid wood, sawdust, woodchips and bark) into fuel pellets which will be fed into a gasifier where Pyrenco's catalysed, continuous pyrolytic process will convert them into a low BTU gas and activated carbon. The gas will be drawn off, cooled, filtered and burned as fuel in six Caterpillar G399 engine generators rated at 580 kilowatts each, generating electrical power for sale to Consumers Power Company (CPC).

The Plant is projected to be capable of operating at least 85% of the time. CPC has entered into a Purchase Agreement with Pyrenco to purchase electricity generated by the Project when it becomes fully operational and a Test Energy Purchase Agreement for the purchase of electricity generated during the startup and testing period. Excess wood pellets produced at the plant will be sold for home, institutional and commercial heating.

The gasification process will generate activated carbon (charcoal) and waste heat as by-products. Carbon will be removed from the gasifier, cooled and ground into powder to be sold for use in liquid filtration systems. Waste heat from the plant cooling water system will be utilized in a hot-water heating system to heat other buildings in the industrial park when such other buildings are constructed.

The principal buildings on Pyrenco's 5-acre Project site are the main plant, which houses the gasifiers, engine generators, plant equipment, offices and control room, and the covered storage building, which will be capable of holding a 30-day supply of biomass. The truck scale, truck dumper, miscellaneous process equipment and main transformer are located in the yard areas of the site.

In the process of obtaining financing for the Mio Plant, the Pyrenco technology was evaluated by Gibbs & Hill, Inc. on behalf of Insurance Company of North America (INA). This evaluation resulted in the availability of "System Performance" insurance on Pyrenco's system through INA.

INDIAN BIOMASS CONVERSION EXPERIENCE

R. C. MAHESHWARI

Located in Appendix C

DEVELOPMENT OF SMALL (3-5 kW) PRODUCER GAS PLANT RUNNING ON LOCALLY AVAILABLE WASTE

A. K. RAJVANSHI

NOTE: THIS PAPER AVAILABLE FROM THE AUTHOR

STATUS OF HOT GAS CLEANUP DURING PFBC AND PFBG

R. RANGAN

NOTE: THIS PAPER AVAILABLE FROM THE AUTHOR

STATUS OF GAS PREPARATION AND GAS CLEANUP TECHNOLOGY IN THE U.S.

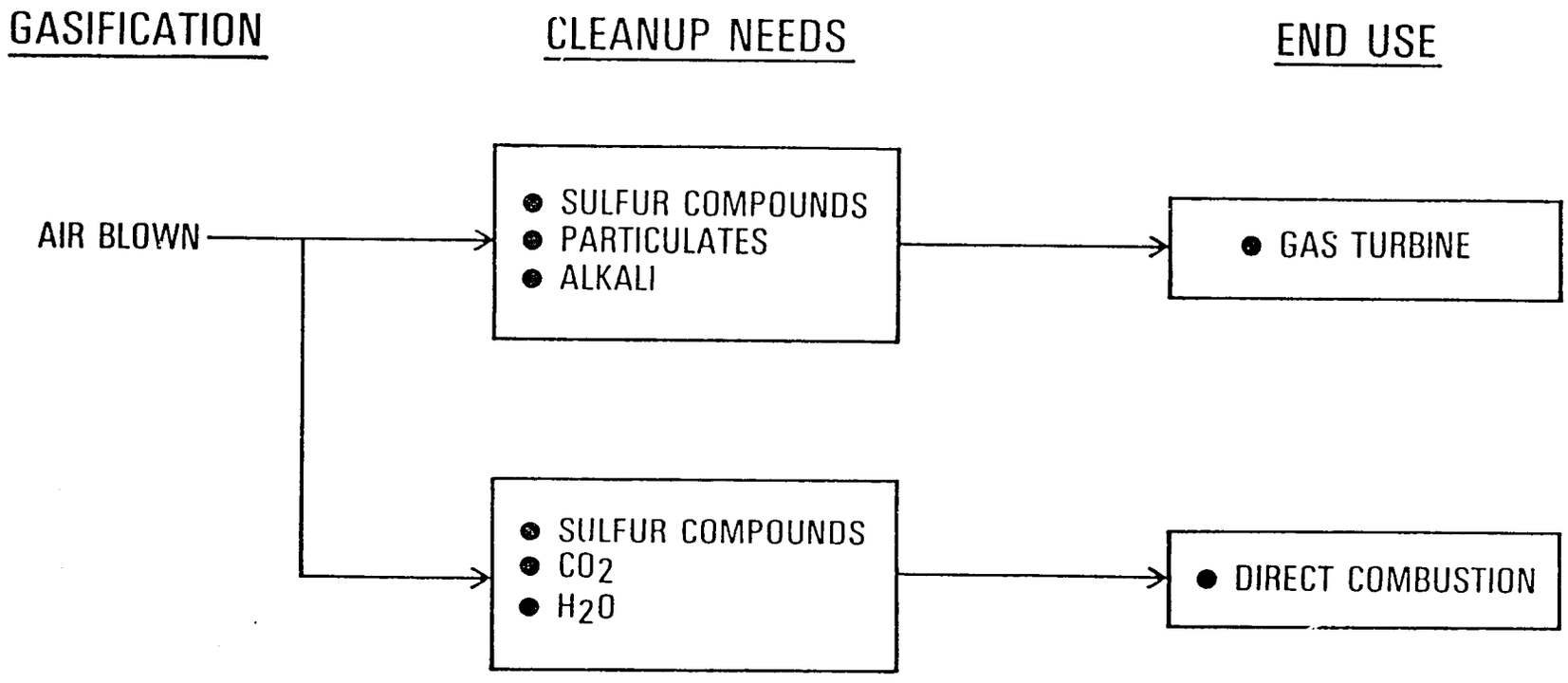
M. GHATE

GAS SEPARATION AND CLEAN UP METHODS

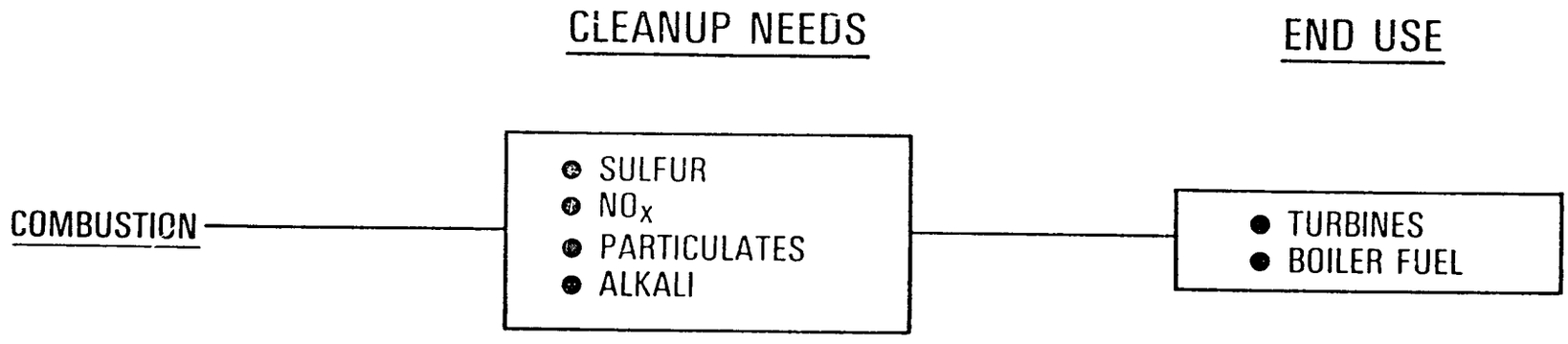
Morgantown Energy Technology Center

FOSSIL FUEL CONVERSION ROUTES

- GASIFICATION
- COMBUSTION


GASIFICATION
CLEANUP NEEDS
END USE
AIR BLOWN
SULFUR COMPOUNDS
PARTICULATES
ALKALI
GAS TURBINE
SULFUR COMPOUNDS
CO_2
H_2O
DIRECT COMBUSTION

GASIFICATION	CLEANUP NEEDS	END USE
OXYGEN BLOWN	• CO • CO_2 • H_2O • SULFUR COMPOUNDS	• HYDROGEN FOR HYDRO-TREATMENT
	• CO • CO_2 • H_2O • SULFUR COMPOUNDS	• HYDROGEN FOR AMMONIA MANUFACTURE
	• CO • CO_2 • H_2O • SULFUR	• SYNGAS FOR METHANOL • FISCHER-TROPSCH • METHANE • HYDROGEN FOR FUEL CELLS


CLEANUP NEEDS
END USE
COMBUSTION
SULFUR
NO_X
PARTICULATES
ALKALI
TURBINES
BOILER FUEL

DRIVING FORCES

- ENVIRONMENTAL
- MATERIALS
- PROCESS NEEDS
- ECONOMICS

CONTAMINANTS

- GASIFICATION
  - — SULFUR COMPOUNDS (H_2S, COS, CS_2, ETC.)
  - — PARTICULATES
  - — ALKALI
  - — ACID GASES (CO_2)

- COMBUSTION
  - — OXIDES OF SULFUR
  - — OXIDES OF NITROGEN
  - — PARTICULATES
  - — ALKALI

SYSTEM NEEDS

- END USE

COMBUSTION ROUTE NEEDS

- NO_X REDUCTION
- SO_X REDUCTION
- PARTICULATES
- ALKALI

PROCESS OPTIONS

- COLD GAS CLEAN UP
- HOT GAS CLEAN UP

COLD GAS CLEAN UP

- PHYSICAL ABSORPTION
- CHEMICAL ABSORPTION
- ADSORPTION

PHYSICAL ABSORPTION

- ORGANIC SOLVENTS
- NO CHEMICAL REACTIONS
- REGENERATION OF SOLVENT BY HEAT/PRESSURE
- HIGH DEGREE OF SELECTIVITY TO CO_2, H_2S
- CAN REMOVE COS, CS_2, HYDROCARBONS
- LOW CORROSION RATES
- HIGH OPERATING COSTS
- COMMERCIAL (RECTISOL, SELEXOL)

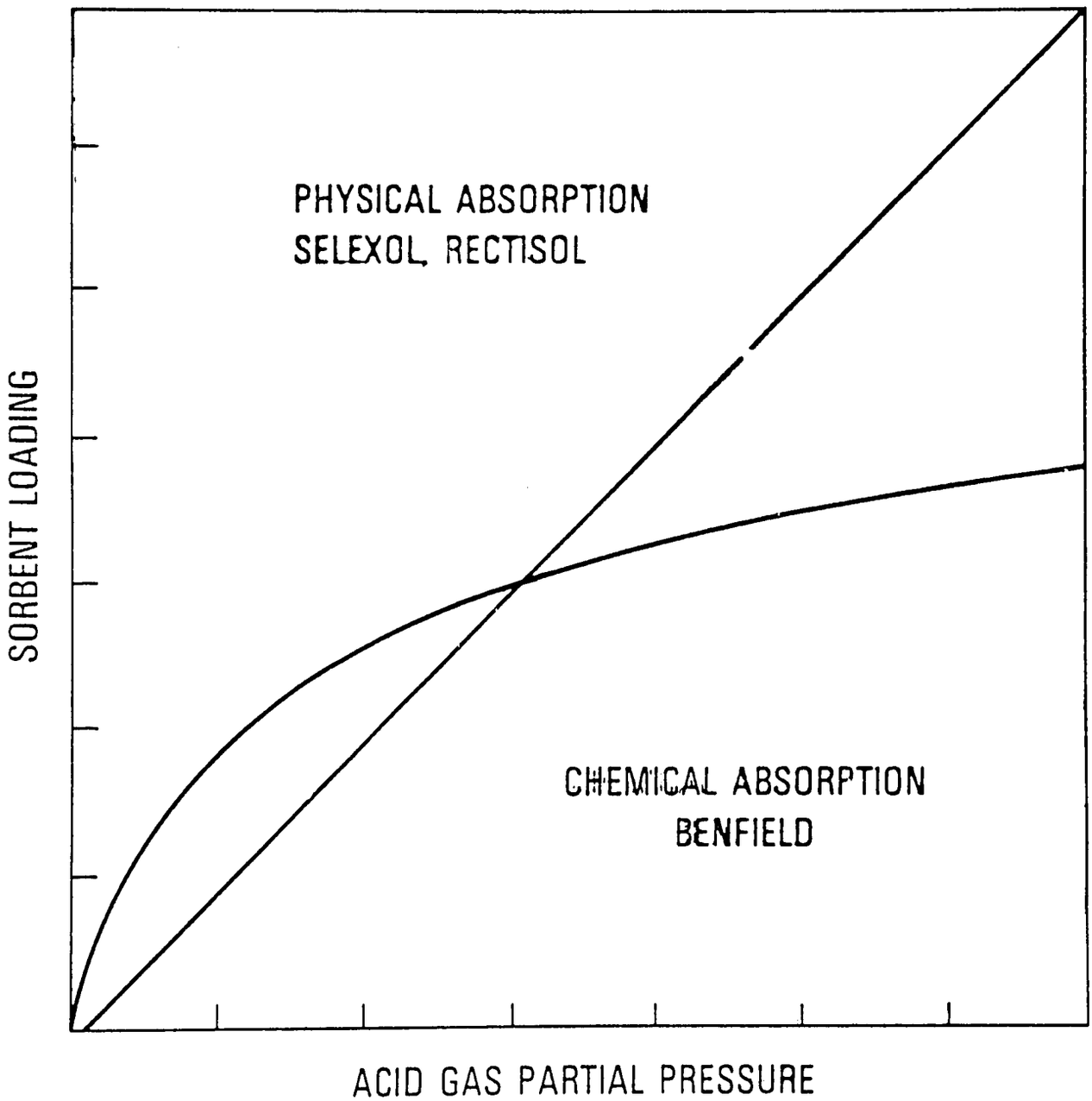
CHEMICAL ABSORPTION

- AQUEOUS SOLVENT
- CHEMICAL REACTION
- LOW AFFINITY FOR HYDROCARBONS
- HIGH CORROSION RATES
- COMMERCIAL (HOT-POT PROCESS)

ACID GAS REMOVAL PROCESSES

PROCESS	INPUT H_2S	OUTPUT H_2S	SORBENT	OPERATING TEMPERATURE	OPERATING PRESSURE	PRODUCT	REMARKS
RECTISOL	1%	0.1 PPM	METHANOL	-100° -0°F (ABSORBER) +150°F (STRIPPER)	300-2000 PSIG (ABSORBER) ATMOSPHERIC (STRIPPER)	H_2S	1) REQUIRES EXTERNAL REFRIGERATION 2) NEEDS CLAUS
SELEXOL	ANY	1 PPM	DIMETHYL ETHER OF POLYETHYLENE GLYCOL	20-1000 PSIG	500-1000 PSIG (ABSORBER) 0-5 PSIG (STRIPPER)	H_2S	1) NEEDS CLAUS
STRETFORD	300 PPM TO 95%	1 PPM	ANTHRAQUINONE-DISULFONIC ACID SODIUM METAVANADATA CITRIC ACID SODIUM CARBONATE	80-120°F	0-1000 PSIG	ELEMENTAL SULFUR	1) DOES NOT REMOVE COS OR CS_2 2) NEEDS SPECIAL DISPOSAL OF CYANATES, THIOSALTS, AND VANADIUM SALTS
ACTIVATED CARBON	ANY BUT BEST FOR <30 PPM	0.2 PPM	ACTIVATED CARBON	150°F	NO PRESSURE LIMIT	ELEMENTAL SULFUR	1) FREQUENT REGENERATION 2) SULFUR DISCARDED WITH BED WHEN REPLACED
CLAUS	>20%	15,000 PPM (SO_2)		2000°-3000°F (BURNER) 200°F (CATALYTIC STAGE)	ATMOSPHERIC	ELEMENTAL SULFUR	1) 94-98% OF REMOVED SULFUR CONVERTED TO ELEMENTAL SULFUR 2) NEEDS A TAIL GAS CLEANUP PROCESS
ZINC OXIDE	50 PPM	0.02 PPM	ZINC OXIDE	660-840°F	0-750 PSIG	ZINC SULFIDE	1) SULFUR DISCARDED WITH BED 2) ZINC RECOVERY EXTREMELY COSTLY

COMPARISON OF PHYSICAL ABSORPTION VS CHEMICAL ABSORPTION SYSTEMS



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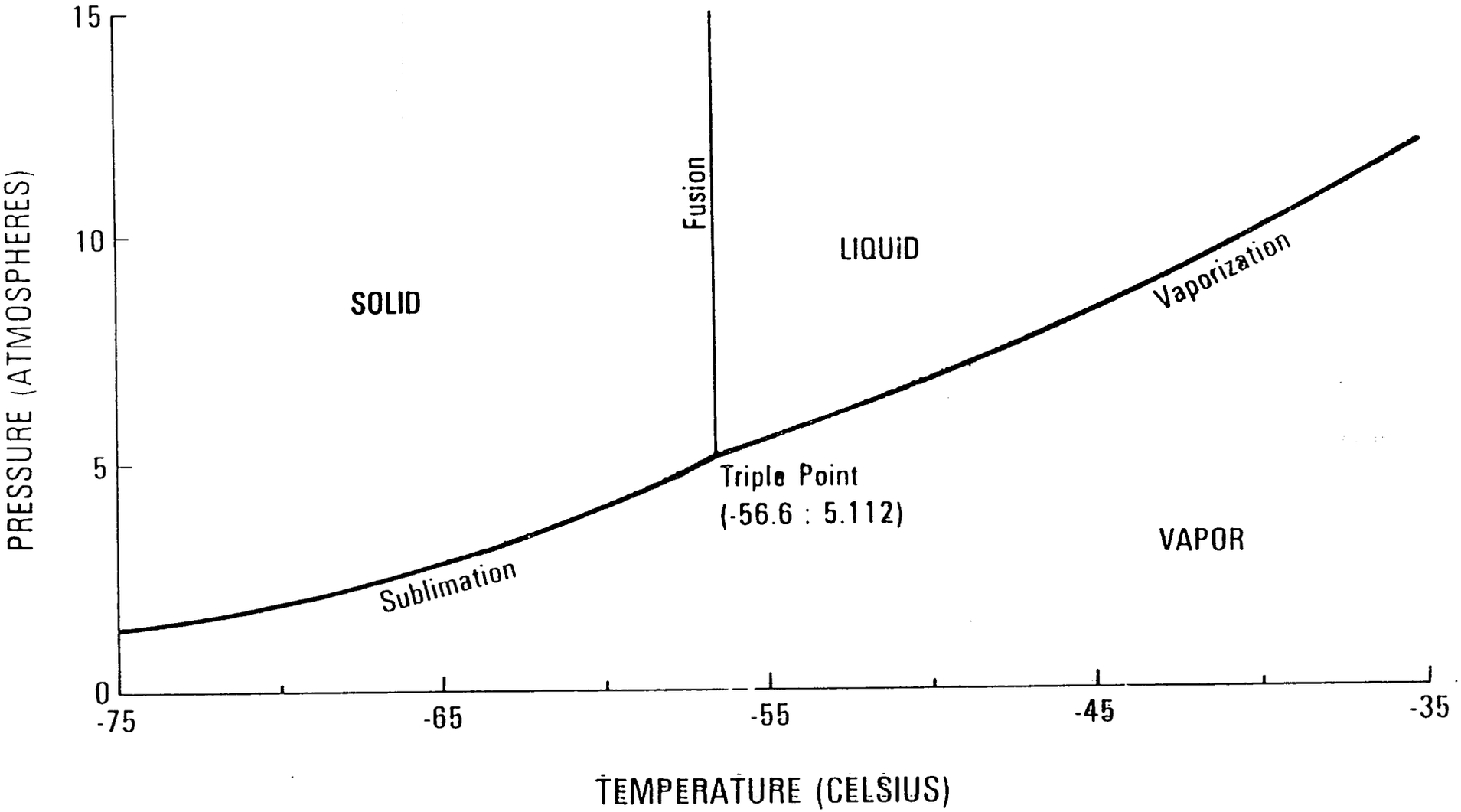
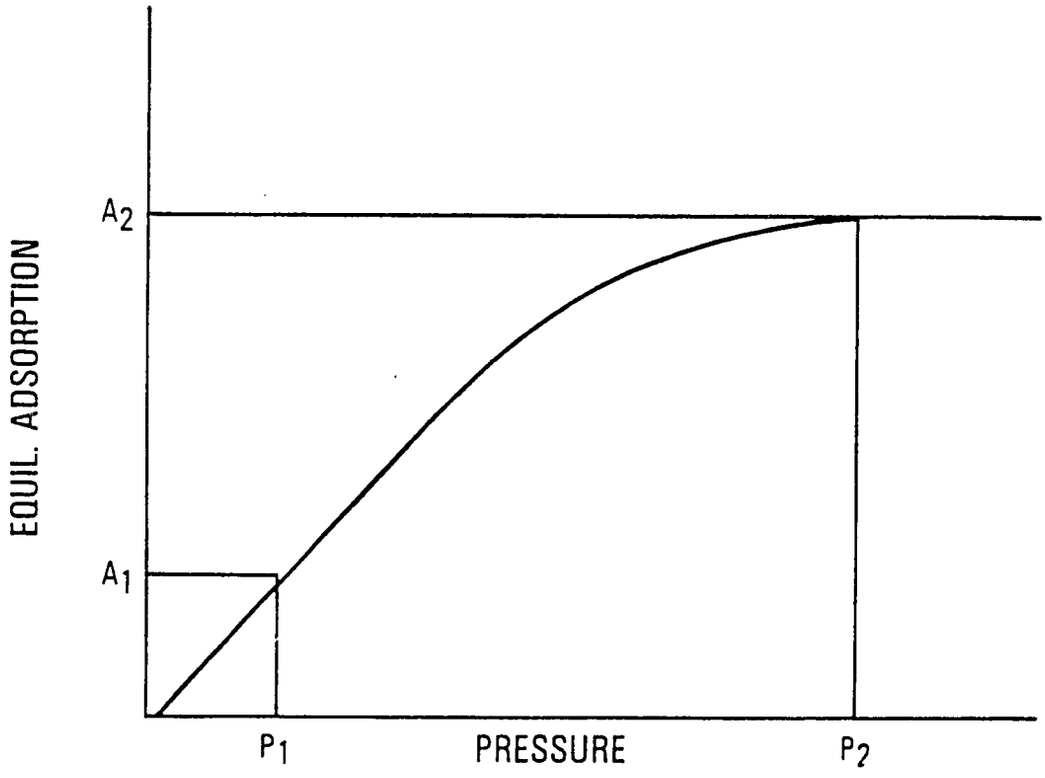
CARBON DIOXIDE PHASE DIAGRAM



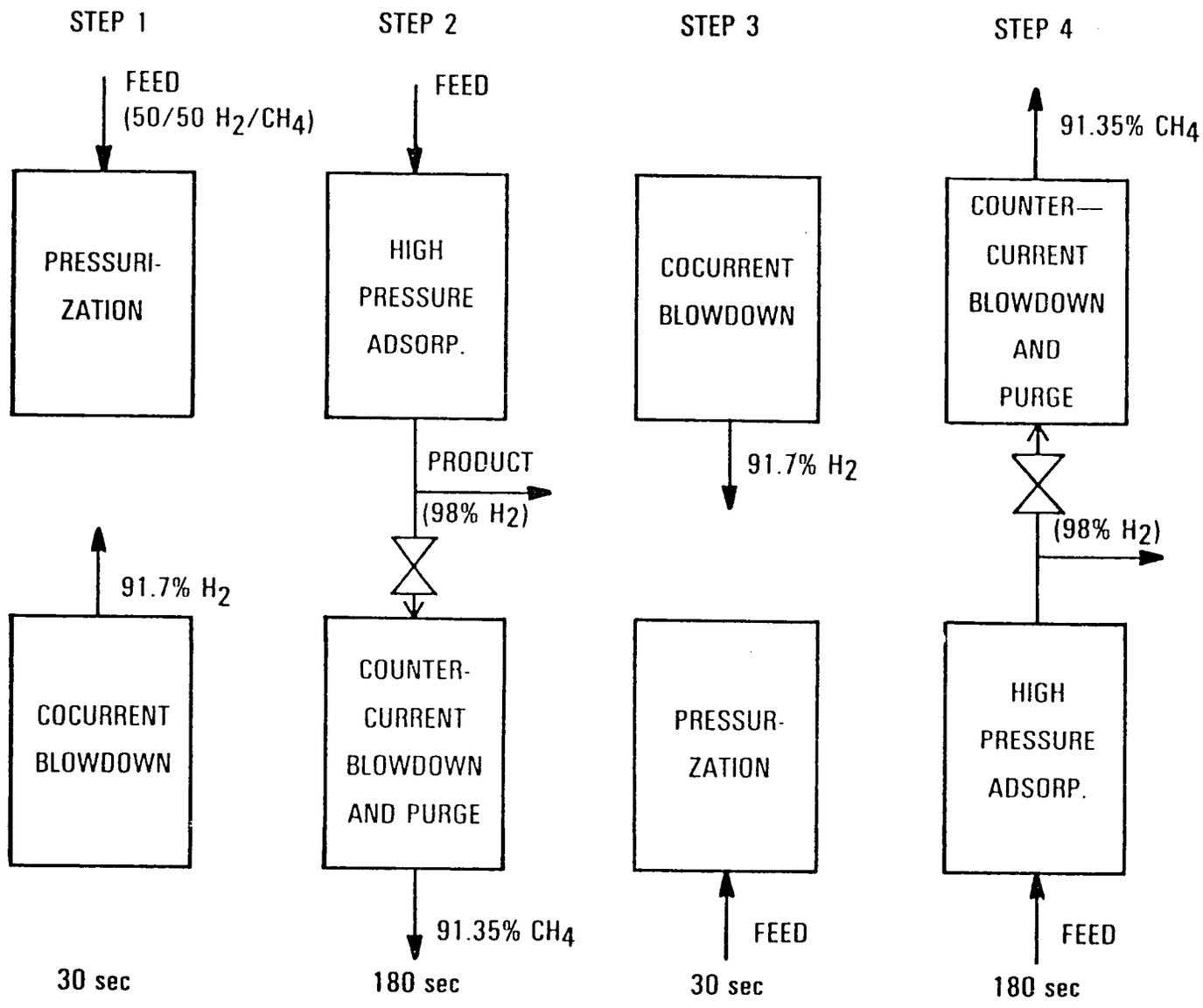
ADSORPTION

- GAS/SOLID CONTACTING
- HIGHLY SELECTIVE
- COMMERCIAL IN 50'S
- MAKING COMEBACK

PRESSURE SWING ADSORPTION



- DRIVING FORCE (A_2 - A_1)
- TWO BEDS (REACTORS) NEEDED
- ADSORPTION AT P_2
- DESORPTION AT P_1


STEP 1
STEP 2
STEP 3
STEP 4
FEED
(50/50 H_2/CH_4)
PRESSURI-
ZATION
FEED
HIGH
PRESSURE
ADSORP.
COCURRENT
BLOWDOWN
91.35% CH_4
COUNTER—
CURRENT
BLOWDOWN
AND
PURGE
PRODUCT
(98% H_2)
91.7% H_2
91.7% H_2
(98% H_2)
COCURRENT
BLOWDOWN
COUNTER-
CURRENT
BLOWDOWN
AND PURGE
PRESSUR-
ZATION
HIGH
PRESSURE
ADSORP.
91.35% CH_4
FEED
FEED
30 sec
180 sec
30 sec
180 sec

ADVANTAGES

- HIGH THROUGHPUTS
- LOW ENERGY REQUIREMENT
- LOW CAPITAL COST
- COMMERCIAL

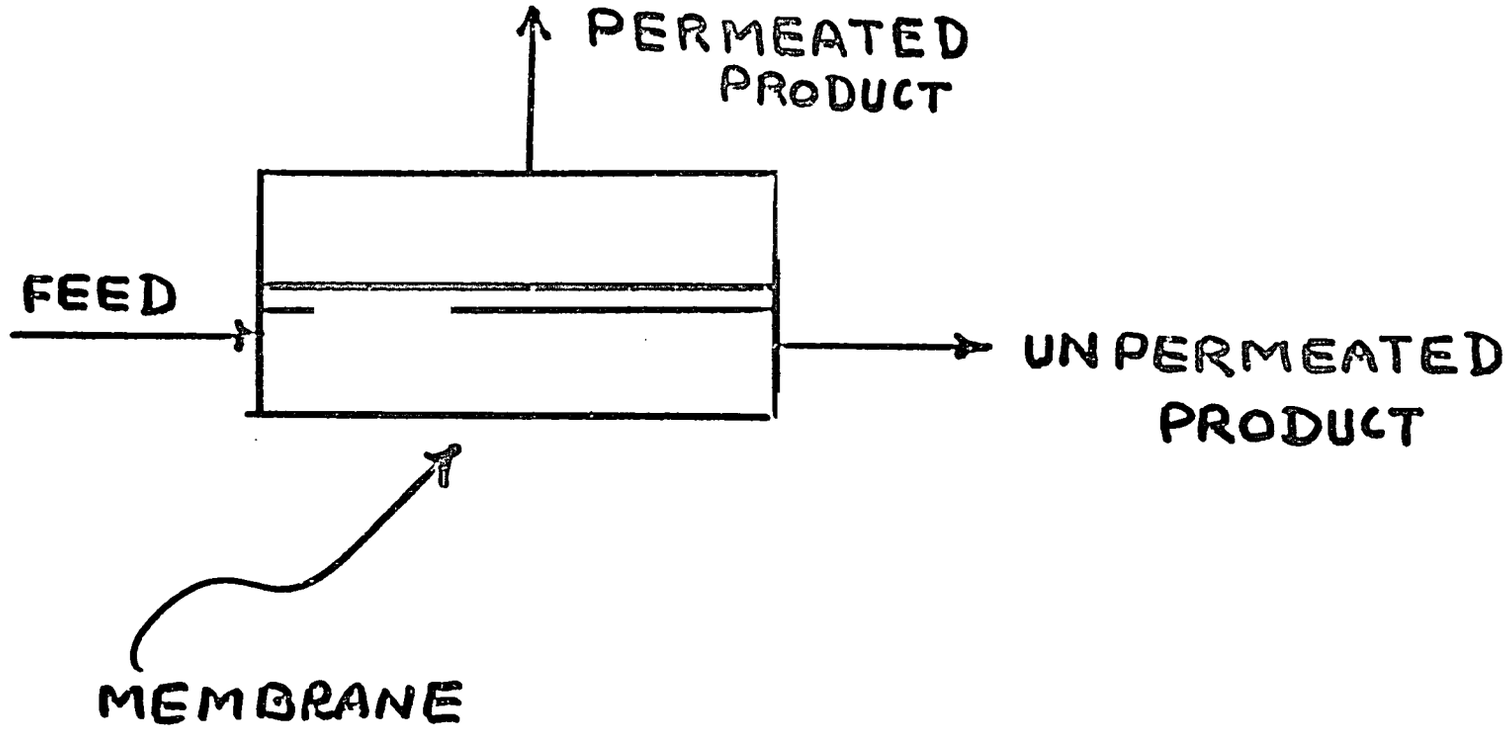
FUTURE APPLICATIONS

- PURIFICATION OF FUEL GASES
- SEPARATION OF GASIFICATION PRODUCTS

UNCONVENTIONAL

- MEMBRANES
- COMPLEXING AGENTS
- LIQUID CO_2, (CNG PROCESS)

MEMBRANE SEPARATION



MEMBRANES

- POLYMERIC
- FACILITATED TRANSPORT
- ASYMMETRIC
- SYMMETRIC

MEMBRANE NEEDS (CRITERIA)

- HIGH SELECTIVITY
- HIGH FLUX
- IMPROVED LIFE

THE MARKETS FOR MEMBRANES

MARKET	1980	1983	1988	1993	AVERAGE ANNUAL GROWTH RATE 1983-'93
	MILLIONS OF DOLLARS				
SEPARATION MEMBRANES					
Potable water via desalination	24	33	57	97	11.4%
Ultrapure water and chemicals	10	15	33	72	17
Effluent treatment/concentration	33	47	112	267	19
Gas separation/enrichment	5	10	20	30	12
Electrochemistry	1	5	27	144	40
Dialysis/therapeutic	100	80	80	80	0
	173	190	329	690	13.7
SUPPORT MEMBRANES					
Controlled release	80	132	354	964	22
Biotechnology/other specialty applications	3	5	22	100	35
	83	137	376	1064	22.7
Total	256	327	705	1754	18

SOURCE: CHEMICAL WEEK/SEPTEMBER 28, 1983

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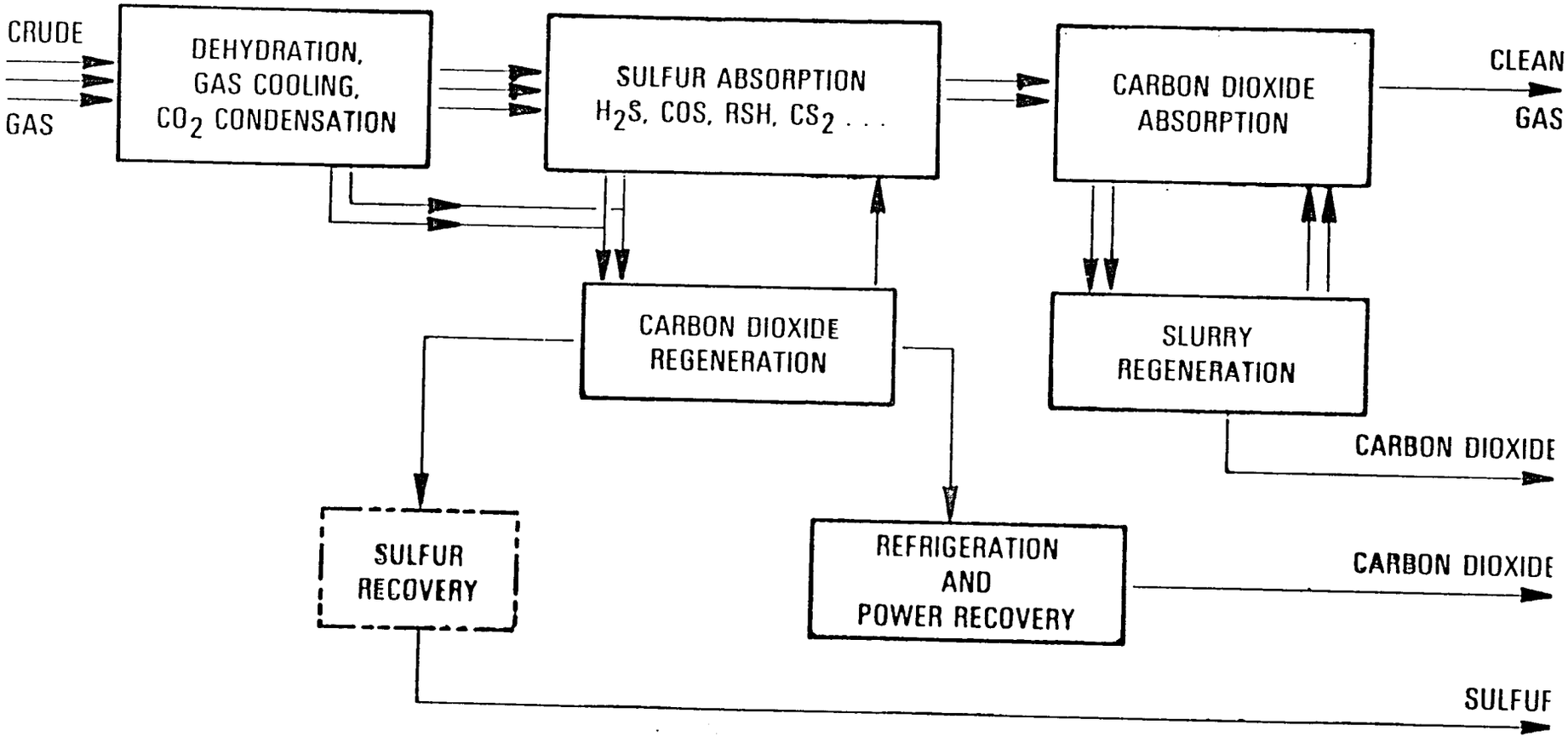
CNG PROCESS

CNG PROCESS OVERVIEW



HOT GAS CLEANUP

- GETTERS
- IRON OXIDE
- ZINC OXIDE
- CYCLONES
- GRANULAR BED FILTERS

(MOSTLY GAS/SOLID CONTACTING)

CLEAN UP NEEDS FOR FUEL CELLS
(Molten Carbonate)

CONTAMINANT	TOLERANCE LIMIT
• SULFUR COMPOUNDS	LESS THAN 1 PPM
• HALOGENS	~100 PPM IN FUEL ~10 PPM IN OXIDANT
• NITROGEN COMPOUNDS	LARGE FOR AMMONIA
• METALS (Fe, Cu, As)	VERY LOW
• TAR AND OILS	LOW
• PARTICULATES	~0.8 $lb/10^6\ ft^3$
• LIGHT HYDROCARBONS	LESS THAN 1 MOL PERCENT

MCFC HIGH TEMPERATURE CLEANUP ADVANTAGES

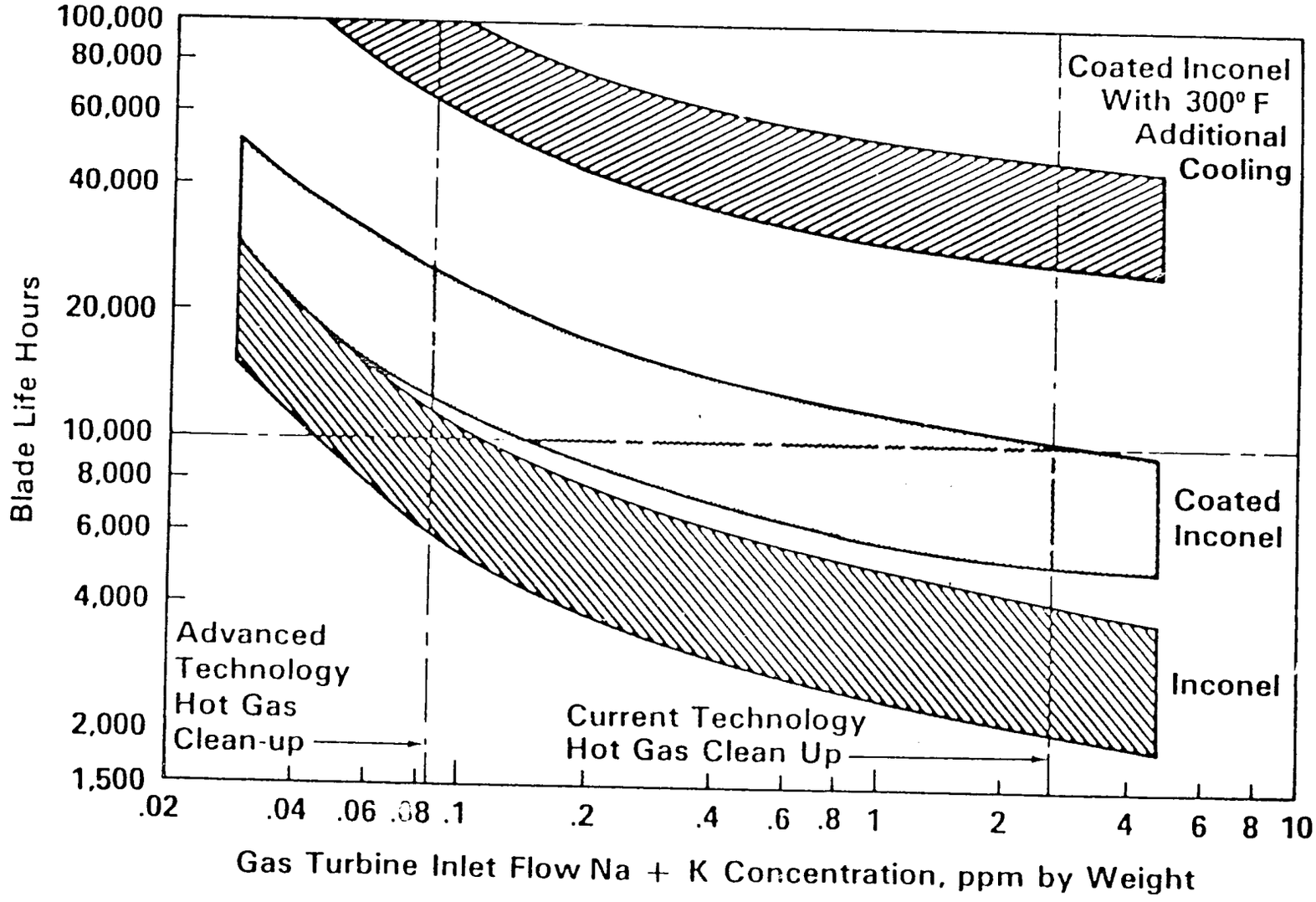
250 MWe UTILITY PLANT

	COLD CLEANUP (Ⓦ O_2, SELEXOL)	HOT CLEANUP (Ⓦ O_2, METC, FeO)
INVESTMENT COSTS (TOTAL COSTS MILLIONS)	391	358
COE (MILLS/KWHR.)	74.7	67.7
HEAT RATE BTU/KWHR.	7,660	7,823

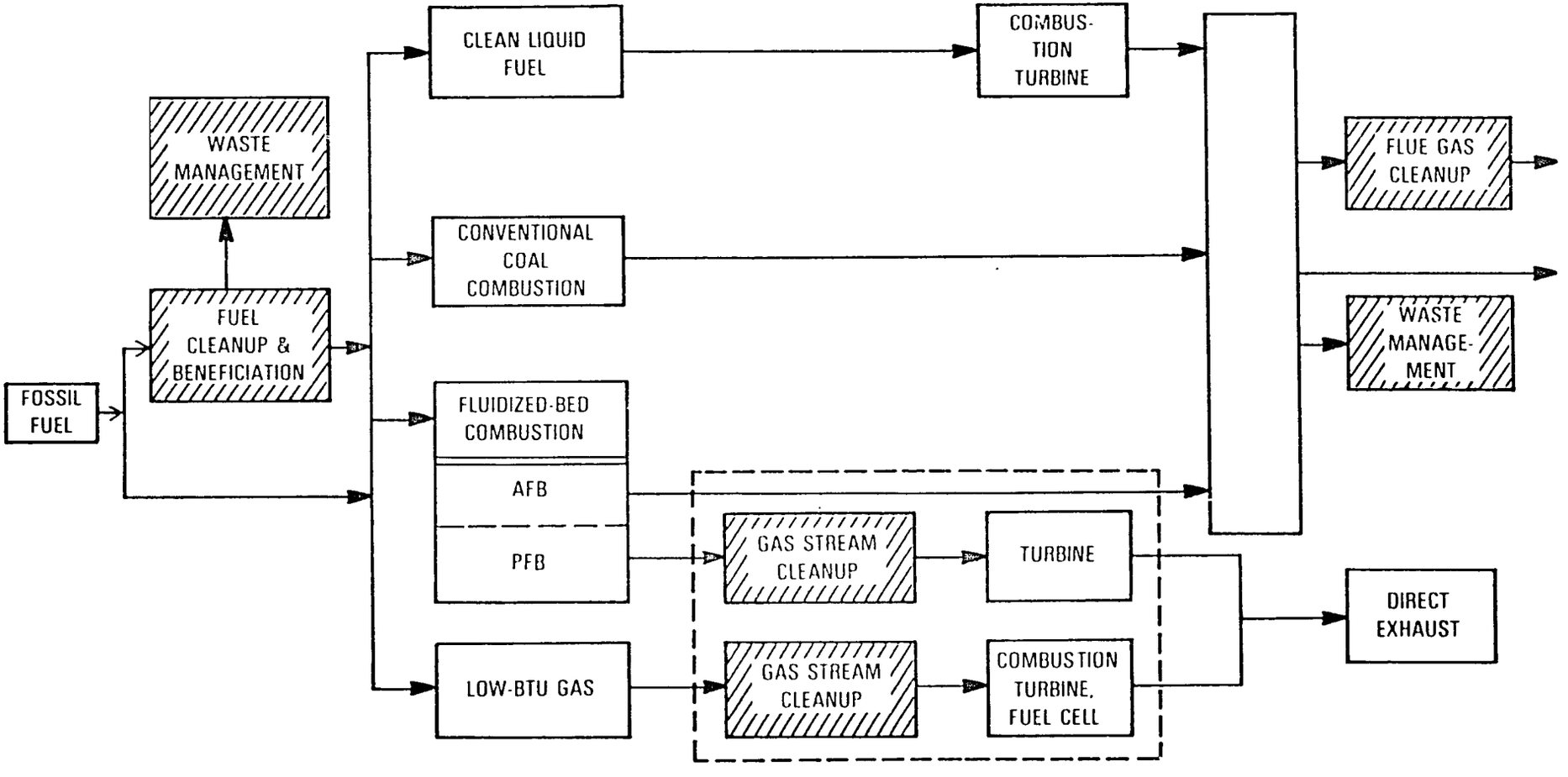
(SINGLE 250 MW FUEL CELL UTILITY PLANT INCURS $10.7 MILLION SAVINGS AT 70% UTILIZATION FACTOR AT 7 MILLS/KWHR..COE.)

REFERENCE: WESTINGHOUSE "EVALUATION OF GASIFICATION AND GAS CLEANUP FOR MCFC POWER PLANTS — DOE CONTRACT-81-MC16220

Gas Turbine Acceptance of Alkali Metals (Corrosion)



CONTROL TECHNOLOGY OPTIONS



CONCLUSIONS.

- CHOICE DEPENDS ON END USE
- ALL TECHNIQUES ENERGY INTENSIVE
- HOT GAS CLEAN UP TECHNOLOGY SHOWS CAPABILITIES TO MEET TURBINE REQUIREMENTS
- COLD GAS CLEAN UP PROCESS DO MEET CURRENT NEED AT PRICE
- NEW UNCONVENTIONAL TECHNIQUES SHOW PROMISE

A-3-1688

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TITLE:

A Summary of Gas Stream Cleanup for Coal Gasification and Combustion

METC PROGRAM AREAS (CHECK ONE OR MORE AREAS, IF APPROPRIATE):

___ Arctic/Offshore Research	X Gas Stream Cleanup	___ Low Rank Coals
___ Components	___ Gasification	___ Oil Shale
___ Enhanced Oil Recovery	___ Heat Engines	___ Tar Sands
___ Fluidized-Bed Combustion	___ Instrumentation & Control	___ Unconventional Gas Recovery
___ Fuel Cells		___ Underground Coal Gasification

A. INTRODUCTION

Contaminants from coal gasification and combustion pose environmental problems which limit the acceptability of coal as a major energy source. Also, these undesirable elements present economic difficulties affecting the feasibility of certain coal processes.

When coal is gasified or burned, contaminants such as gaseous oxides of sulfur and nitrogen, hydrocarbons, particulates, and volatile trace elements are produced. These species represent toxins, erodents, corrodants, and catalyst poisons. To meet environmental standards set by the EPA, impurities must be removed from the effluent gas stream before being released to the atmosphere. In addition, dirty gas must be purified to specific requirements which depend on the end use of the gas.

This report summarizes the effect of contaminants and the degree of purity required for various end uses of gas streams from gasification and combustion processes. Methods of particulate and NO_x reduction, various low- and high-temperature acid-gas removal processes, and some unconventional methods of gas stream cleanup are outlined.

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OUTLINE

A. INTRODUCTION

B. SUMMARY

C. CONTAMINANTS FROM COAL GASIFICATION AND COMBUSTION

D. PRODUCT GAS SPECIFICATIONS

1. Emission Standards
2. Turbines
3. Synthesis Gas
4. Fuel Cells

REMOVAL PROCESSES

1. Reduction of NO_x

   (a) Thermal NO_x
   (b) Fuel-Bound NO_x

2. Removal of Particulates

   (a) Low-Temperature Methods
   (b) High-Temperature Methods

3. Acid Gas Removal

   (a) Methods

4. Comparison of Low- and High-Temperature Processes

5. Low-Temperature Acid Gas Removal

   (a) Physical Absorption

      1. Rectisol Process
      2. Selexol Process

   (b) Chemical Absorption

      1. Benfield Process
      2. Stretford Process

6. High-Temperature Acid Gas Removal

   (a) Claus Process
   (b) Iron-Oxide Process

7. Unconventional Methods

   (a) Membrane
   (b) Supported Complexes

F. RECOMMENDATIONS AND CONCLUSIONS

B. SUMMARY

The important factors to be considered in the decision of what type of cleanup system is needed are the type of contaminants, the conditions of the stream, and the degree of purity required.

The major types of pollutants in both gasification and combustion are sulfur compounds, nitrogen compounds, carbon monoxide, and particulates. To meet air pollution standards, the particulates, nitrogen oxides, and sulfur oxides must be removed. If the gas stream is to be used for further processing, it must be purified to very low concentrations of sulfur, alkali, carbon monoxide, particulates, and in some cases carbon dioxide.

Nitrous oxide is best controlled during the combustion process by changing the ratio of air-to-coal and reducing the residence time. High-temperature cleanup processes pose the problem of fuel-bound nitrogen being released. Low-temperature cleanup systems, such as water washes and wet scrubbers, do not have this NO_x emission problem.

To remove large particulates, cyclones are effective. Since cyclonic separation efficiency decreases with temperature, the cyclones should be operated at lower temperatures. At high temperatures, filters are the best available method of removal; however, these processes are expensive and must operate under limited conditions. If small particulates are present, they can be better removed by wet scrubbers or electrostatic precipitators.

Acid gases (CO_2, H_2S, and COS) can be removed by four major methods: adsorption, physical absorption, chemical absorption, and chemical conversion. Adsorption is used to eliminate organic sulfur, CO_2, and trace amounts of H_2S. Physical absorption is most effective for high-pressure gas streams containing large amounts of sour components since the amount of acid gas absorbed is directly proportional to the acid gas partial pressure. Chemical absorption is more useful if a high degree of removal is necessary or if the acid gas partial pressure is low. Chemical conversion is used to catalytically convert impurities such as CO, CO_2, and organic sulfur compounds to other useful or easily removed substances.

Cleanup schemes can be run at either high or low temperatures. High-temperature processes are less expensive since heat exchange equipment is not needed to cool the product gas and since the thermal efficiency is about 4 percent higher than for low-temperature processes. The disadvantage is that fuel and air streams must be premixed to reduce NO_x emission. Because premixing introduces the chance of autoignition and flashback, an upper operating temperature of 1,000°F (538°C) must be set. Low-temperature processes, although less economical, are more documented and are commercially available.

C. CONTAMINANTS FROM COAL GASIFICATION AND COMBUSTION

1. Gasification

The three basic feed streams needed for the gasification of coal are coal, steam, and a source of oxygen. Oxygen can be supplied to the gasifier by either a stream of pure oxygen or a stream of air. The choice between oxygen and air is usually determined by the end use of the gas. Oxygen-blown systems produce an intermediate-Btu gas with a heating value roughly in the range of 280 to 400 Btu/cu ft. On the other hand, air-blown systems produce low-Btu fuel gas with a heating value generally in the range of 120 to 200 Btu/cu ft. The major difference in the product gas produced from using air or oxygen is the amount of nitrogen present. A comparison of air- versus oxygen-blown gasification is listed in Table 1 for a FW/BCR-type gasifier with an Illinois No. 6 feed coal.

TABLE 1 (17)

Comparison of Air- Versus Oxygen-Blown Gasification
FW/BCR-Type Gasifier
Coal -- Illinois No. 6

	Air Blown Mol %	Oxygen Blown Mol %
CH_4	3.37	6.04
H_2	13.68	29.50
CO	28.75	35.33
CO_2	3.03	12.51
H_2S	0.67	1.03
COS	0.07	0.10
N_2	48.02	0.45
NH_3	0.43	0.64
H_2O	1.98	14.40
HHV-Btu/SCR	171.2	270.8
Oxidant/Coal Ratio	2.78	0.594
Steam/Coal Ratio	0.144	0.597
Transport Gas/Coal Ratio	0.088	0.088
Cold Gas Efficiency	83%	85.7%

The major contaminants produced in the gasification of coal are listed below:

a. Sulfur is converted mainly to hydrogen sulfide (H_2S), but the gas will also contain carbonyl oxysulfide (COS), carbon disulfide (CS_2), sulfur dioxide (SO_2), sulfur trioxide (SO_3), mercaptans, and thiophene.

b. The nitrogen content in coal produces nitrogen oxides (NO_x), ammonia (NH_3), hydrogen cyanide (HCN), and sulfocyanide compounds in the gas stream.

c. The volatile matter in coal can appear as tars, oil, naptha, phenols, cresols, etc.

d. Halogens are converted to their acids.

e. Alkalis present in the ash are volatilized.

f. Reactive or readily vaporized elements such as beryllium, arsenic, selenium, cadmium, mercury, and lead are potential hazards.

g. Hydrocarbons and carbon monoxide may also have to be controlled.

2. Combustion

Burning of coal is a major source of emissions of waste materials both from the standpoint of quantity and variety of pollutants. For instance, combustion of coal for generating electricity contributes nearly 60 percent of all sulfur oxide emissions and about 25 percent of all nitrogen oxides emitted from anthropogenic sources in the United States.

Combustion of coal produces these major contaminants:

a. Particulate matter evolves during combustion and is made up of smoke (unburned solid combustible material) and ash (minerial matter from the coal).

b. Sulfur in the coal is oxidized to form sulfur dioxide (SO_2) and a small percentage of sulfur trioxide (SO_3) depending on the amount of excess air used.

c. Nitrogen oxides (NO_x) are formed both from nitrogen compounds in the coal and from the nitrogen in the combustion air.

d. Alkalis present in the coal ash are volatilized.

e. Trace elements and trace organic compounds present in the material matter of coal are emitted upon combustion.

f. Hydrocarbons and carbon monoxide may also have to be controlled.

Many factors influence the quantities and rates of emissions from coal systems. These include coal feed, efficiency of the process, emission control technology used, and the type of process employed.

Coal Feed -- The most important variables are the percentage of sulfur, the ratio of organic to inorganic sulfur, the percentage of nitrogen, the percentage of volatile matter, moisture, ash content, heating value of coal, and the range of sizes of the coal particles.

Control Technology -- Reduction of pollutants can be achieved by one or a combination of the following:

- Change the process so smaller amounts or less hazardous pollutants are produced.
- Contain the undesirable elements both within the plant and within wastes.
- Decrease amount of wastes by using them as by-products.
- Remove the pollutants by means of emission control equipment.

Process Type -- The process variables that affect the pollutants emitted are the amount of excess air used, the type of catalyst utilized, the process pressure and temperature, the reaction vessel configuration, the feed entry geometry, the cooling rate of decomposition products, the gas velocity, and the type of control equipment used.

The major emissions for a few process types are listed in Table 2.

TABLE 2 (6)

Process Type Major Emissions

Process Type[1]	Total[2] Particulates (tons/yr)	Sulfur Oxides (tons/yr)	Nitrogen Oxides (tons/yr)	Hydro-carbons (tons/yr)	Carbon Monoxide (tons/yr)
High-Btu, Fixed-Bed Gasification	770	11,910	5,340	120	395
Low-Btu Gasification	600	9,240	4,140	92	310
Coal Direct Combustion[3,4]	6,000[5]	102,000	24,000	240	600

[1] Based on 328 operating days a year.
[2] Eastern interior coal, Henderson County, Kentucky.
[3] Coal type not specified (~ 2.25 percent sulfur, 10 percent ash).
[4] 1,000 MW capacity.
[5] About 97 percent control.

D. PRODUCT GAS SPECIFICATIONS

The degree of gas purity may be fixed by environmental regulations or by downstream processing requirements. For example, stack gases from the combustion of coal to generate electricity must be sufficiently free of nitrogen oxides, sulfur oxides, and particulate matter prior to discharge to the atmosphere. This is because of their detrimental effect on the human respiratory system, their corrosive nature when in solution with water (acid rain), and their tendency to form eye-irritating photochemical smog. In the case of gasification products, downstream processing requires that corrosive and maladorous contaminants be removed. These impurities can cause damage to the processing equipment, can poison catalysts, and can produce unwanted by-products.

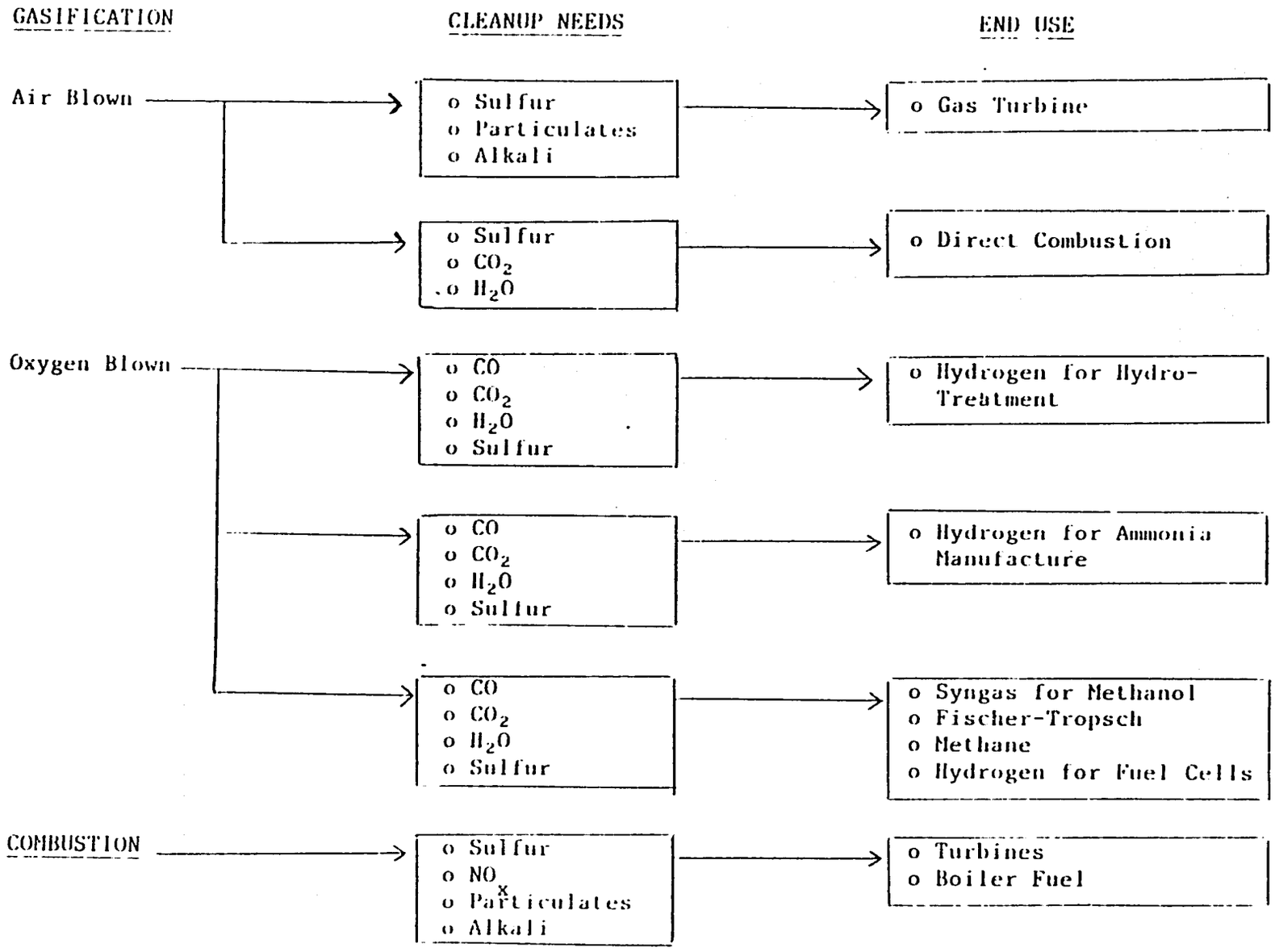
Table 3 lists the current air emission standards as set by the Environmental Protection Agency (EPA) in the Clean Air Act and its amendments. These standards are of main concern in the combustion of coal. A summary of end uses and their respective cleanup needs for various gasification routes and combustion processes are outlined in Figure 1.

Because of the great variety of gas stream cleanup processes available, it is necessary to know what contaminants need to be removed and to what degree they should be removed to effectively choose the best process. As a rule, the end use of the gas defines how pure the stream should be and consequently, which process should be employed.

1. Turbines

Steam turbines, as their name suggests, are operated by steam which is generated from the heat of combusted coal. The main restrictions for the stack or flue gases are environmental. Emissions must comply with the EPA standards listed in Table 3.

Gas turbines are driven by the hot pressurized gases produced by the combustion and gasification of coal. Usually, the turbine exhaust gas is discharged directly to the atmosphere so it, too, must meet EPA emission standards. However, strict limits on contaminant concentration in turbine fuel due to corrosive effects of the dirty gas on the material of construction, generally, exceed those set environmentally. Particulate carryover causes erosion of turbine blades. The larger particles (less than 5 to 10 microns) erode the blades at a high rate making the turbine inoperable after a relatively short time. Smaller particles (2 microns or less) adhere to the surface upon impact and cause fouling of the stationary turbine cascade. In addition, alkali, composed mainly of sodium and potassium species, are corrosive and also shorten gas turbine lifetime. The maximum allowable concentrations of contaminants in turbine fuel are given in Table 4.



End Uses and Cleanup Needs for Gasification and Combustion

TABLE 3 (17)

Current Emission Standards

Contaminant	Gas Turbines	Claus Plants	Coal-Fired Steam Units
Sulfur	0.015% vol. SO_2 (0.9 lb/10^6 Btu) or 0.8% wt S in fuel	0.025% vol. SO_2 0.001% vol. H_2S 0.030% vol. total reduced S gases	1.2 lb SO_2/10^6 Btu and 90% reduction over uncontrolled level
Nitrogen Oxides (as NO_2)	0.0075 to 0.00125% vol. 0.31 to 0.52 lb/10^6 Btu as NO_2	None	0.5 lb/10^6 Btu for subbituminous or coal-derived fuels 0.6 lb/10^6 Btu for other coals
Particulates	None	0.10 lb/10^6 Btu where fossil fuel fired in incinerator	0.03 lb/10^6 Btu

TABLE 4 (6)

Maximum Allowable Concentrations of Contaminants in Turbine Fuel

Impurity	Maximum Allowable Concentration
Particulate	0.8 lb/106 scf
Condensable Hydrocarbon	0.5 lb/106scf
Sulfur	0.18 mole percent
Metals	
V	0.1 to 0.2 ppm (wt)
Na + K	0.2 to 0.6 ppm (wt)
Ca	0.1 ppm (wt)
Pb	0.1 ppm (wt)

2. Synthesis Gas

Synthesis gas must be significantly pure to avoid catalyst poison, to prevent the formation of undesirable by-products, and to assure the maximum conversion to the desired products.

For instance, to convert syngas (CO and H_2) to pure hydrogen, the syngas must be desulfurized. Also, the CO_2 originally present in the gas and any CO_2 formed in the shift reaction of carbon monoxide and steam to hydrogen must be removed.

In the synthesis of ammonia, a stream of high-purity hydrogen and nitrogen is needed. Therefore, the gas must be 99 percent free of sulfur, carbon dioxide, and carbon monoxide.

The catalyst (Cu-Zn-Al) used in the production of methanol from syngas allows the use of milder reaction conditions. However, the catalyst requires very high degrees of purity, especially with respect to chlorine and sulfur compounds.

The production of methane from synthesis gas is achieved in the presence of a nickel catalyst. Deterioration of the catalyst can be at a minimum if carbon monoxide, hydrogen sulfide, and other organic sulfur compounds are removed and if carbon deposits resulting from the Boudouard reaction are suppressed.

Synthesis gas used in the Fischer-Tropsch process produces aliphatic hydrocarbons within a wide range of carbon numbers from gaseous products to high-boiling paraffins. The synthesis gas is made up of hydrogen and carbon monoxide and needs to be sufficiently free of sulfur compounds and carbon dioxide. Data from the SASOL I plant to convert coal to hydrocarbons and gas indicate that a clean stream containing 86 volume percent of a H_2-CO mixture and 12 volume percent CH_4 is sufficient.

3. Fuel Cells

In a fuel cell, electric current is generated by converting the chemical energy of a fuel into electrical energy. The fuel is oxidized, and the resulting chemical reaction provides the energy that is converted into electricity. High-temperature fuel cells, with a molten carbonate mixture as the electrolyte, offer the prospect for use with coal. In this case, gaseous mixtures of hydrogen and carbon monoxide can be used as the fuel.

The contaminants of concern are sulfur compounds, halogen compounds, nitrogen compounds, metal and trace elements, hydrocarbons, and particulates. Sulfur compounds cause significant performance as well as endurance penalty to the molten-carbonate fuel cell (MCFC). This occurs when the sulfur-containing contaminants corrode the electrode and the current collector, and when carbonate loss results from compositional changes in the electrolyte. Halogen compounds such as HCl and HF degrade the electrolyte and promote stress corrosion cracking. Molecular nitrogen, NH_3, and NO_x act as diluents at the anode and cathode. The effects of metal and trace elements are to change the physical properties of the electrolyte and to deposit on the anode and cathode. Also, hydrocarbons deactivate the electrodes and lead to carbon formation. Lastly, particulates can lead to partial plugging of the anode since the small particles can diffuse into the pores of the fuel cell porous nickel anode.

Therefore, the contaminant level in the fuel supplied to a MCFC must be within strict tolerance limits. Table 5 lists the effect of contaminants and the degree of purity required for a MCFC.

TABLE 5 (10)

Summary of the Effect of Impurities and Tolerance Limits for Molten Carbonate Fuel Cells

Impurity	Possible Effect	Operating Limits
Sulfur Compounds (H_2S, COS, CS_2, SO_2)	Sulfation of carbonates and increase in overpotentials.	Less than 1 ppm
	Deactivation of anode by chemisorption.	
	Sulfation of anode materials.	
	Sintering.	
	Sulfidation of cell hardware loss of strength and increase of ohmic resistance.	
Halogen Compounds (Cl_2 HCl, alkali halides)	Severe performance loss at cathode.	100 ppm in fuel
	Formation of chlorides and hardware corrosion.	10 ppm in oxidant
Nitrogen Compounds (NH_3, NO_x)	Electrolyte composition changes.	Very large for NH_3
Metals (Fe, Cu, As)	Deactivation and plugging.	Very low tolerance expected in IGT's handbook of fuel cell performance.
Heavy Metals (Hg, Sn, As)	Corrosion, alloying, and structural damages.	
Tar and Oil	Deactivation, mechanical problems.	
Particulates	Diffusion problems, blockage of flow passages.	0.8 $lb/10^6 ft^3$
Hydrocarbons	Carbon formation.	Less than 1 mol %

E. REMOVAL PROCESS

Reduction of NO_x

Nitrogen oxide emissions arise from the production of thermal NO_x and the production of NO_x from fuel-bound nitrogen. Thermal NO_x refers to those nitrogen oxides produced when the amount of excess air and the temperature are increased. The N_2 and O_2 in the air react to form NO_x at these conditions. Consequently, these emissions are a direct function of combustion temperature and stoichiometry. Fuel-bound nitrogen appears mainly as ammonia in high-temperature gas streams such as the effluent of gasifiers which will be treated by high-temperature cleanup systems. The ammonia concentration in the fuel gas can produce excessive emissions.

a. Thermal NO_x Reduction

Significant reduction in thermal NO_x can be achieved by off-stoichiometric combustion and by reduced residence time. If the fuel and air are thoroughly mixed prior to combustion, the fuel-air ratio can be adjusted to the desired level well away from stoichiometry, and a lower flame temperature will result. The mixing also reduces the actual time of combustion which lessens the production of thermal NO_x.

b. Fuel-Bound NO_x Reduction

Since the removal of nitrogen compounds from the fuel by a water scrub is done at low temperature, it usually occurs after the use of high-temperature cleanup. Therefore, fuel-bound nitrogen is still present in the gas and will produce emissions when processed through high-temperature desulfurization systems. Low-temperature systems involving water wash and subsequent sulfur scrubbers remove all of the ammonia at reduced temperatures alleviating the concern of nitrogen oxide emissions.

Furthermore, using ammonia containing fuel gas in turbine burners results in NO_x emissions. The presence of methane in the fuel gas affects the NH_3 conversion to NO_x. The more CH_4 present in the gas, the more NH_3 that is converted. It is possible to burn hot fuels containing NH_3 of less than 0.3 percent and still be within the EPA limits; however, this leaves little margin for the production of thermal NO_x.

To lower the ammonia concentration, a decomposition catalyst can be used to change NH_3 into N_2 and H_2. Materials such as iron, nickel, cobalt, platinum, and rhodium are being studied to determine the best catalysts for use in hot sulfur-bearing fuel gases. A decrease in the formation of NO_x can also be

accomplished by combustion control. The following methods have been determined to cut down on NO_x formation:

1. Staged Combustion -- a reduced amount of O_2 in the burner tends to react with the fuel rather than the N_2.

2. Decompostion of oxides -- reduce oxides to molecular N_2 with ammonia or ammonia plus a catalyst.

3. Wet scrubbing.

2. Removal of Particulates

a. Low-Temperature Particulate Removal (Temperatures less than 600°F [36°C])

(1) Cyclones

Mechanical collectors, such as cyclones, are used to remove most of the larger particles (greater than 10 microns). Cyclones are based on the principle of whirling the gas stream to impart centrifugal force to the particles. This force throws the particles out against the wall and eventually causes the particles to fall into a conical collector at the bottom of the cyclone. The average removal efficiency for conventional cyclones is 98.7 percent for particles greater than 6 microns.

(2) Wet Scrubbers

The main problem with particulate removal is effectively capturing the finer particles. Wet scrubbers, such as the venturi type, can remove the small particles adequately. In this type of scrubber, liquid is sprayed into the gas and this mixture is then passed through a constricted area. A high-velocity differential is produced between the gas and the liquid causing the liquid to break up into very fine drops. Efficiencies for a venturi-type scrubber are listed in Table 6. Wet scrubbers have the additional advantage of also removing water-soluble nitrogen compounds and water-soluble halide and alkali metal salts.

TABLE 6

Removal Efficiencies of Venturi-Type Wet Scrubbers

Removal Efficiency	Particle Size (Microns)
25%	0.1
91%	0.6
98.4%	1.0
99.99%	2.0 and larger

(3) Electrostatic Precipitators

Electrostatic precipitators can, too, be employed to remove particulates. The main concern with this method is the sulfur content in the coal. If the coal used has a sulfur content of 1.5 percent or more, the removal of particulates is high. However, if low-sulfur coal is used, the electrical resistivity of the particles becomes too high for satisfactory precipitator operation.

Normally, the gas stream enters the precipitator at a temperature of 300°F (150°C) and, depending on the type of coal used, 99% of its particulates are removed. If low-sulfur ash is present, the electrical resistivity can be made lower in order to increase the capture efficiency. This is done by decreasing the temperature to 220°F (105°C). Caution must be taken because there is danger of condensation of highly corrosive sulfuric acid at this low temperature.

b. High-Temperature Particulate Removal (Temperatures of 1200°F [649°C] to 1600°F [871°C])

(1) Cyclones

Cyclones can be used to remove particulates from high-temperature gas streams also; however, the efficiency of cyclonic separation decreases with operating temperature. Futhermore, the efficiency decreases as the cyclone diameter increases as is needed for high gas flow rates. Instead of increasing the cyclone diameter to handle these high flows, banks of small cyclones are usually arranged in parallel. Unfortunately, this arrangement is susceptible to plugging.

(2) Electrostatic Precipitators

Another high-temperature, as well as low-temperature, method of particulate capture is electrostatic precipitation. The gas streams are usually close to 700°F (370°C) At these high temperatures, the electrical resistivity of the particulates is lowered and the removal efficiency is increased. The reliability of the hot precipitator, however, is questionable since even a relatively brief outage might cause severe damage to turbines. Additionally, the upper range of temperature is set primarily by operating instabilities caused by thermal ionization which results in sparkover and loss of corona generation.

(3) Filters

The best available method for removing particulates from hot gases at present is filtering. Filters can be categorized as surface filters or depth filters.

- Surface filters

  In a surface filter, particles are collected on the face of a porous filter medium. After an initial period, the layer of collected particles becomes the effective medium. Three types of porous media are porous metal, ceramic fabrics, and ceramic membranes.

  All three filter types have very high overall filtration efficiencies ranging from 95 to 99.6 percent. Unfortunately, these processes are expensive and can operate only under limited conditions. For example, under high differential pressures, porous metal filters degrade due to irreversible capture of fine particles. This filter is not recommended for use above 572°F (300°C). The ceramic fiber filter lacks the required high-temperature inorganic fiber lubricant for the fabric to withstand fiber-to-fiber abrasion. And lastly, the ceramic membrane is susceptible to thermal shock and must be limited to temperature changes of 86°F/hr (30°C/hr) to avoid cracking.

- Depth Filters

  In a depth filter, dirty gas enters a vertical bed of of either granules or fibers through a screen which is retaining the bed. Particulates are captured in the bed and the clean gas exits at the rear of the filter. Granular filters appear to be the nearest to commercialization and are claimed to have efficiencies of 99.9 percent at 5 microns and 99.0 percent at 2 microns.

3. Acid Gas Removal

Acid gas removal can be accomplished by four methods: adsorption, physical absorption, chemical absorption, and chemical conversion. These four methods of acid gas removal are demonstrated by numerous processes. Each process type is unique in which contaminants it removes and with which catalyst or washing agent it uses to effectively remove the acid gases. Table 7 summarizes which substances are removed by which processes.

a. Adsorption

In this method, impurities are removed from the gas phase by becoming concentrated on the surface of a solid. The solid material is usually a granular particle that has been commercially prepared to have a large surface area per unit weight. Usually, a fixed bed of these granular particles is employed. In the bed, a concentration gradient exists between the gas inlet and the gas outlet with respect to the liquid and the gas phases. As time proceeds, the concentration gradient shifts toward the gas outlet as the adsorbate is picked up and held by the adsorbent.

TABLE 7 (6)

Methods of Gas Purification

Process Type	Process Name	Substances Removed	Washing Agent or Catalyst
Adsorption		Traces of H_2S + S org	Activated carbon
		CO_2 + traces of H_2O	Molecular sieves
		CO_2 + traces of H_2O	Silica
		CO_2 + H_2S	Water under pressure
Physical Adsorption			
	Selexol	CO_2 + H_2S + COS	Dimethylether or polyethylene glycol
	Rectisol	CO_2 + H_2S + S org	Methanol
	Purisol	CO_2 + H_2S	N-Methylpyrrolidone
	Fluor solvent	CO_2 + H_2S	Propylene carbonate
		CO + Ar + CH_4	Liquid nitrogen
Chemical Adsorption			
	Shell-Adip	CO_2 + H_2S + COS	Diisopropanolamine
	Alkazid DIK	H_2S	Dimethylglycine
	Alkazid M	CO_2 + H_2S	N-Methylamine
		CO_2 + H_2S	Potassium carbonate
	Benfield	CO_2 + H_2S + COS	Potassium carbonate with additive
	Giammarco-Vetrocoke	H_2S	Sodium thioarsenate
	Shell Sulfinol	CO_2 + H_2S + COS	Tetrahydrothiophene-dioxide + diisopropanolamine
	Stretford	H_2S	Sodium carbonate-anthraquinone
		CO	Copper formate-copper chloride
		Traces of CO_2	Ammonia water
		Traces of CO_2	Sodium hydroxide
		Sulfur compounds	Zinc oxide
		H_2S	Bog iron ore-luxmasse
		CO	Iron-copper-zinc catalyst
Catalytic Conversion			
		CO; CO_2	Nickel catalyst
		Organic sulfur compounds	Cobalt molybdenum catalyst

b. Absorption

The mechanism of absorption is the transfer of a substance from the gas phase, through a phase boundary, and into the liquid phase. Absorption may occur by two methods: the substance is physically dissolved in the liquid, or the substance reacts chemically with the liquid absorbent. Figure 2 shows the operating lines for physical versus chemical absorption processes for acid gas removal.

(1) Physical Absorption

Physical methods depend on the fact that the solubility of a gas in a liquid is greater at higher pressures than at lower pressures. Therefore, the contaminant is extracted from the gas under pressure by an organic solvent. When the pressure is reduced, the dissolved contaiminant is released in gaseous form from the solvent. The amount of acid gas absorbed is directly proportional to the acid gas partial pressure in the sour gas stream. These processes are most effective for high-pressure gas streams containing appreciable amounts of sour components.

(2) Chemical Absorption

In chemical methods, a chemical reaction occurs between the substance and the absorbing medium. Most chemical absorption methods depend on the use of weakly alkaline material that combines and removes the acidic contaminants. The impurities are removed from the liquid absorber by heating in a reboiler. Other processes also utilize weakly alkaline solution, but the absorbed substances are removed by oxidation. Chemical absorption is most advantageous when the partial pressure of acid gas in the feed is low, or when a high degree of removal is required.

c. Chemical Conversion

Chemical conversion of gas-phase impurities involves heterogeneous catalysis using solid catalysts. The procedure for catalytic conversion is as follows:

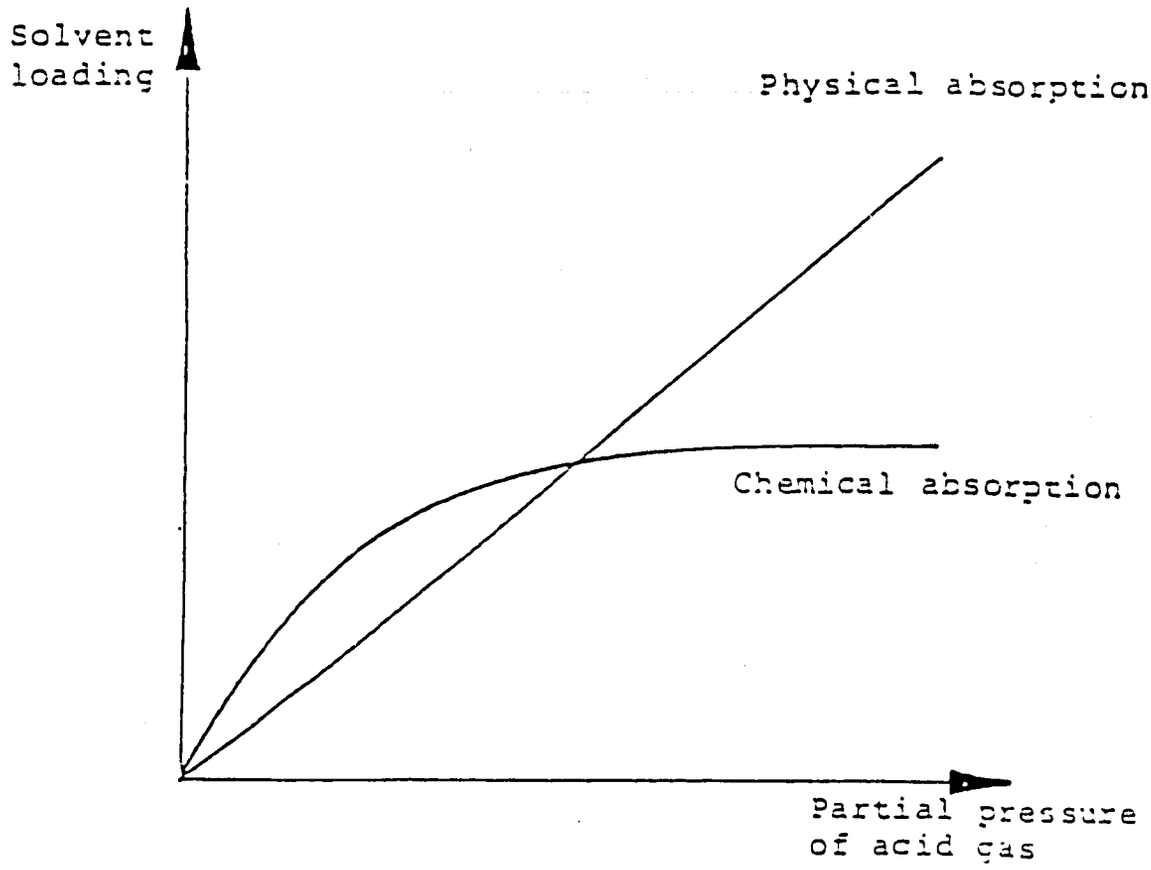
1. Reactants are transferred from the gas stream to the solid surface of the catalyst.

2. A chemical reaction on the surface forms an adsorbed product.

3. The product is desorbed.

4. The product is transferred back into the gas stream.

The most common reactor employed in this type of operation is the fixed-bed reactor.



Operating Lines for Physical Versus Chemical Absorption

Figure 2 (4)

4. Low- Versus High-Temperature Cleanup Processes

Both low- and high-temperature processes can remove acid gases satisfactorily. The main advantages of high-temperature processes are the differences in the cost of the electricity of the system due to a 4 percent higher thermal efficiency, and the lower capital costs due to the elimination of the heat exchange equipment required in low-temperature systems.

Unfortunately, nitrogen oxide emissions from fuel-bound and thermally generated NO_x are a problem in high-temperature processes. Methods of NO_x reduction for high-temperature gases generally require premixing of the fuel and air. Because there is a chance of autoignition and flashback, an upper limit of 1,000°F (538°C) for fuel gas temperature must be set.

Even though high-temperature processes can be more economical, low-temperature processes are available commercially and are much more documented.

5. Low-Temperature Acid Gas Removal

a. Physical Absorption

(1) Rectisol Process

The Rectisol process employs physical absorption in methanol at low temperatures to remove CO_2, H_2S, organic sulfur compounds, HCN, gumformers, and higher hydrocarbons.

(a) Chemistry of the Process

The process takes advantage of the fact that CO_2, H_2S, HCN, and other impurities are highly soluble in methanol at low temperatures and high pressures. These compounds are easily separated from the solvent when the pressure is reduced. Solubility increases as the temperature decreases, as the partial pressure in the feed gas increases, and as the residual content in the regenerated solvent decreases.

(b) Process Description

The inlet gas enters at the bottom of an absorber which is normally a conventional trayed or a packed column. The column operates at a pressure of 300 psig. The bulk of the CO_2, almost all of the H_2S, and appreciable amounts of hydrocarbons and organic sulfur compounds are washed from the gas as they are contacted countercurrently with methanol. This methanol stream is fed to the middle of the absorber at -100°F (38°C). Regeneration of the methanol solvent that leaves the absorber is achieved by two successive

pressure reductions and flashing of the dissolved gases. Cold regenerated solvent is fed back to the middle of the contactor even though it still contains some CO_2.

The partially purified gas flows into the top of the column and is further washed by a pure stream of methanol that enters at the top of the column at -80°F (27°C). After this second treating stage, any remaining CO_2 and almost all of the residual organic sulfur compounds are removed from the gas. At the bottom of the second stage, rich solvent is withdrawn, stripped of acid gas by heating with indirect steam, cooled, and then sent back to the top of the absorber column. A schematic flow diagram is shown in Figure 3.

(c) Process Variations

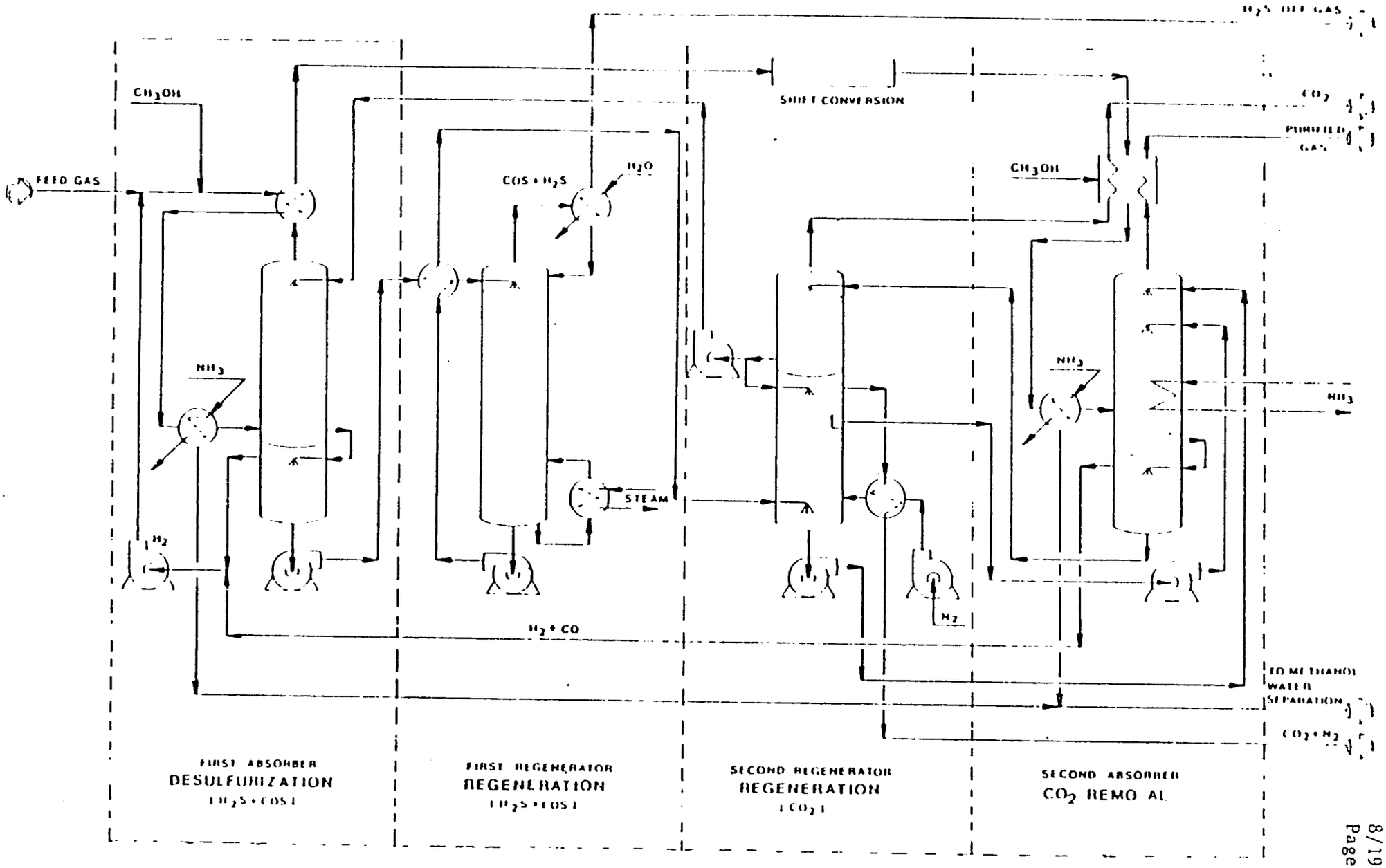
The feed gas can be precooled by heat exchange with the purified gas.

- o Flashing can be done at three different pressure levels with recycle of the gases from the first treating stage to the absorber inlet.
- o The solvent can be regenerated by using the stripping gas.
- o The solvent can be regenerated by increasing the temperature.

(d) Process Constraints

The Rectisol process yields a gas which contains less than 0.1 ppm H_2S and COS, and 1 ppm CO_2. It is best suited for the treatment of gases that contain large amounts of CO_2 and H_2S at pressures above 150 psig. The absorber temperatures range from -100° to 0°F (-73° to -18°C) and the regenerator operates up to 150°F (66°C) with the steam reboiler. Since physical absorption is higher at higher pressures, the process is best operated over a pressure range of 300 to 2,000 psig.

The off-gas contains a high concentration of H_2S and COS and must be processed in a sulfur recovery plant, such as a Claus unit. Also produced is a stream of CO_2, and N_2 which usually can be vented to the atmosphere. Or, the CO_2 can be used to synthesize urea since it is 99.5 percent pure.



Flow Diagram of the Rectisol Process

The Rectisol process can produce a very pure product stream with the following advantages:

1. Low energy consumption.

2. A single process removes undesirable elements.

3. The product gas contains very little water.

However, the process has several disadvantages:

1. A complex flow scheme which requires expensive low-temperature equipment.

2. High losses of solvent due to the high vapor pressure of methanol even at low temperatures.

(2) Selexol Process

The Selexol process utilizes physical absorption by a dimethyl ether of polyethylene glycol. Gas impurities such as H_2S, CO_2, COS, and mercaptans are absorbed. This absorption is essentially proportional to the partial pressures of the acid gases.

(a) Chemistry of the Process

The Selexol solvent has a high physical absorption capacity for sulfur-based compounds and CO_2. No solvent reclaimer is necessary since the solvent is not degraded by impurities in the raw gas. The process also removes any water present in the feed gas. The solvent is physically and chemically stable allowing plants to run on the same solvent without requiring blowdown. The process is well suited for gases at high pressures and high acid gas concentrations.

(b) Process Description

Raw feed gas enters the bottom of the absorber and H_2S, some CO_2, COS, and mercaptans are absorbed in the Selexol solvent which passes countercurrently to the gas. Since the Selexol process can selectively absorb H_2S, it can be operated to first remove all the H_2S and leave most of the CO_2 to be removed in a second unit. This is useful in coal gasification gas where the H_2S-rich stream is fed to a Claus unit, and a separate stream of CO_2 is produced.

Purified gas leaves the top of the absorber, and rich solvent exits at the bottom and is flashed. Flashing is often done in multiple stages to obtain different cuts of dissolved gases. Often, flashed gas containing

hydrocarbons and CO_2 is compressed and recycled back to the absorber to improve the selectivity of the Selexol solvent for sulfur compounds.

The bottoms from the low-pressure flash is fed to a stripper where the remaining acid gases are stripped by steam or an inert gas. Lean solvent from the bottom of the stripper is returned to the absorber. From the top of the stripper, acid gases and stripping media exit and are sent to further processing units. Figure 4 is a schematic flow diagram of the process.

The Selexol solvent does not experience degradation and is not lost due to evaporation since it has a low vapor pressure. The solvent is nontoxic and is not corrosive, so carbon steel can be used for the materials of construction.

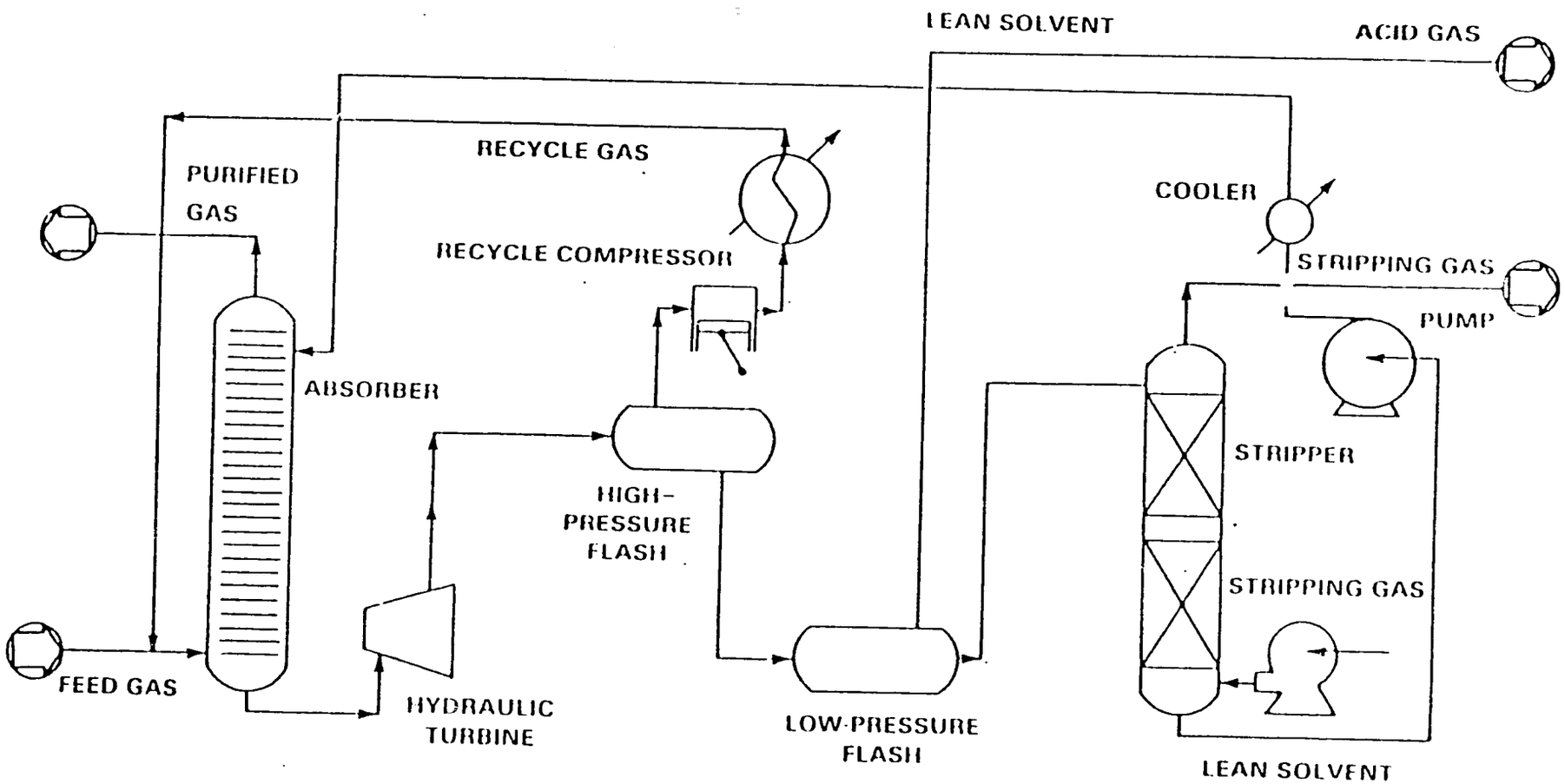
The product gas contains less than 1 ppm of total sulfur, less than 7 lbs/(MMscf gas) of water, and can remove or retain CO_2 as desired. The off-gases are a highly rich stream of sulfur compounds suitable for a Claus plant feed, a pollution-free vent gas, and a pure stream of CO_2. The process is also capable of dehydrating the gas if required.

(c) Process Constraints

Like all physical solvent processes, this process cannot be operated economically at low system pressures. The absorber normally runs between 500 and 1,000 psig. The flash stages decrease in pressure in steps from the pressure of the absorber to that of the stripper. The stripper normally operates at 0 to 5 psig.

The process also works better at lower temperatures, and it is necessary to cool the inlet gas to ambient temperature prior to processing. The absorber temperature ranges from 20° to 100°F (-7° to 38°C).

The H_2S, COS, and other sulfur compounds in the off-gas must be further processed to recover the sulfur. When scrubbing to obtain low concentrations of sulfur compounds, an inert gas must be used. In order to prevent the conversion of H_2S to free sulfur, a gas containing no oxygen is required.



Schematic Diagram of the Selexol Process

Figure 4 (17)

b. Chemical Absorption

(1) Benfield Process

The Benfield process employs gas-liquid absorption technology to remove CO_2, H_2S, and COS from sour gas with a hot potassium carbonate solution as the solvent. The process is able to reduce H_2S to 1 ppm, CO_2 to 10 ppm, and remove most of the COS.

(a) Chemistry of the Process

The chemistry of the reaction of potassium carbonate with H_2S and CO_2 is shown below:

$$K_2CO_3 + H_2S \leftrightarrow KHCO_3 + KHS$$
$$K_2CO_3 + CO_2 + H_2O \leftrightarrow 2KHCO_3$$

Hydrogen sulfide is more soluble in the carbonate solution than CO_2, so it is absorbed and stripped faster. If the operating conditions are properly adjusted, H_2S removal of 90 to 98 percent can be achieved while the removal of CO_2 is kept at 10 to 40 percent.

Equilibrium pressures of H_2S and CO_2 over the solution increase with temperature and concentration of KHS and $KHCO_3$. Therefore, the acid gas equilibrium pressures and the $KHCO_3$ concentrations must be carefully evaluated when designing the process.

Typical trace components found in coal-derived gas can also be removed by this process. Carbonyl oxysulfide (COS) can be almost completely removed with the proper selection of operating temperatures. The chemical reaction is represented as:

$$COS + H_2O \leftrightarrow H_2S + CO_2$$

Carbon disulfide (CS_2) is also hydrolyzed to H_2S, but in two steps. Therefore, it is absorbed at a slower rate than COS. Approximately 75 percent of the CS_2 in the gas stream can be removed by the following reaction sequence:

$$CS_2 + H_2O \leftrightarrow COS + H_2S$$
$$COS + H_2O \leftrightarrow CO_2 + H_2S$$

About 92 percent of the mercaptans present can be removed in the Benfield Hi Pure process. The degree of ammonia removal depends on the concentration of the NH_3 in the feed gas and the circulation rate of the Benfield solution. Since HCN is acidic, its

removal should be as high as that for H_2S or even greater. Hydrocarbons do not react with the solution, so no degradation of solution reactivity is observed.

(b) Process Description

Unrefined gas enters below a packed section and is contacted with a hot potassium carbonate solution containing proprietary additives. This absorbing solution flows countercurrently downward in the absorber column. Either a packed tower or a trayed absorber can be used. Carbon dioxide and hydrogen sulfide along with some trace elements are absorbed by the Benfield solution. Purified gas is collected at the absorber top, and the rich solution is withdrawn at the base of the absorber and sent to the stripping column.

In the stripping column, the rich solution is regenerated while passing downward through the tower against a rising flow of steam. Stripping media can either be direct process steam or steam plus reboiler vapors. The steam is condensed and separated from the regenerated solution and is recycled back to the absorber. Acid gases exiting the stripper will require further processing in a sulfur recovery unit. A flow diagram of the Benfield process is shown in Figure 5.

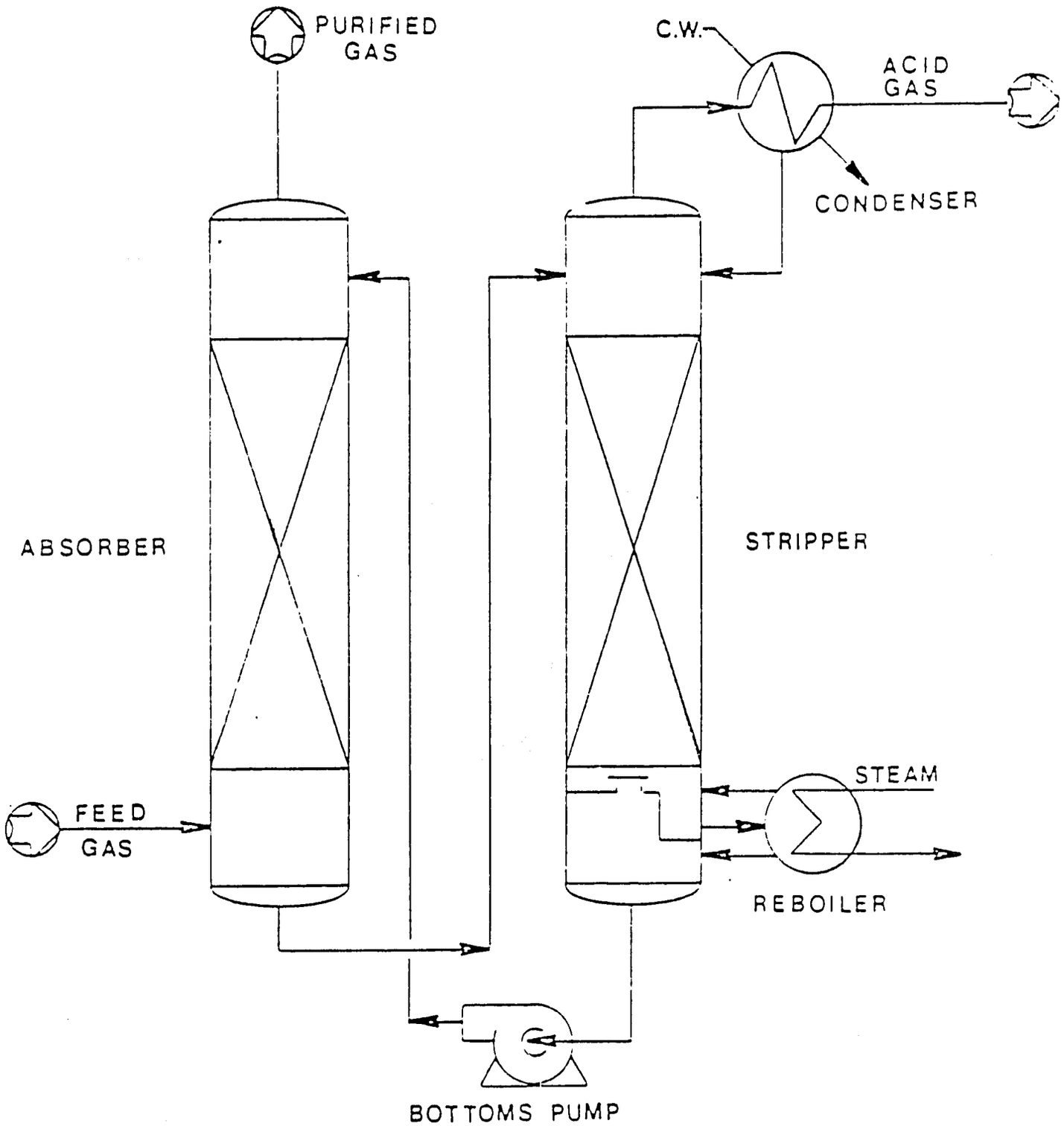
Both absorption and regeneration occur at 230°F (110°C), so no heat exchangers are needed. The higher temperature of absorption allows the use of a more concentrated solution. Consequently, the amount of acid gas that can be picked up per gallon of solution circulated is increased.

The absorber pressure ranges from 7 to 35 atm and the pressure in the stripper is near atmospheric. Generally, the feed composition is 3 to 12 percent CO_2 and 0.5 to 1.0 percent H_2S.

The Benfield process fits well with coal gas purification. The gas can be water-scrubbed and then fed directly to the absorber without extensive cooling as some of the lower temperature processes require.

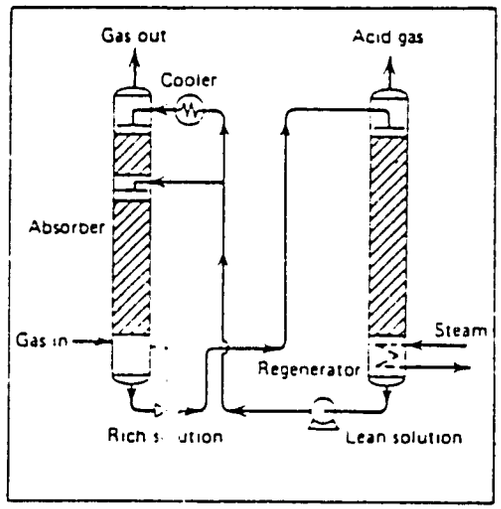
(c) Process Variations

Split-stream -- In this modification, most of the hot regenerated solution is introduced at an intermediate point in the absorber. The remaining portion is cooled and sent to the top of the absorber. A diagram of the slip-stream process is shown in Figure 6.



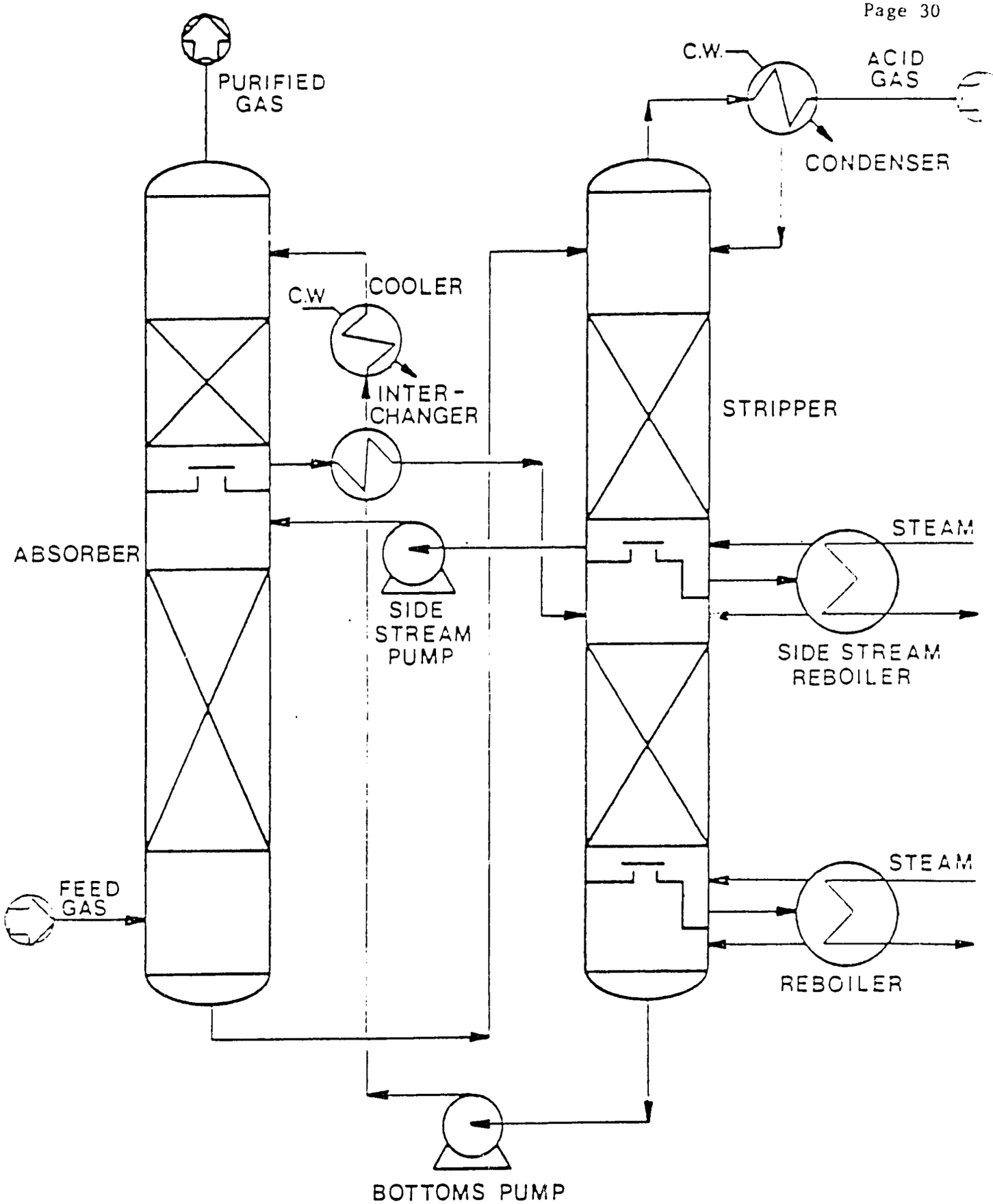
Flow Arrangement for the Benfield Process

Figure 5 (14)



Flow Scheme for the Split-Stream Variation of the Benfield Process

Figure 6 (6)



Flow Diagram for the Benfield Hi Pure Process

Figure 7 (14)

The advantage of the split-stream configuration is the higher degree of purification due to the lower equilibrium pressure of CO_2 and H_2S over the cooled solution.

Hi Pure -- The Benfield Hi Pure process removes the bulk of the CO_2 and H_2S in the first stage of the absorber and a second stage provides the final purification of the gas stream. The sulfur concentration can be reduced to the ppm level by employing these two independent countercurrent circuits. A flow arrangement for the Hi Pure process is illustrated in Figure 7.

(d) Process Constraints

The Benfield process can remove COS, H_2S, and CO_2 to ppm levels from gas streams containing up to 10 percent H_2S and 40 percent CO_2. The degree of purification is limited by design criteria. High pressure operation favors the absorption/desorption scheme because of the high partial pressures of CO_2 and H_2S.

The feed temperature is not critical, but it is usually ambient to 400°F (204°C). The economical limit of operating temperature is 280°F (138°C). Also, the process does not always remove thiophenes.

(2) Stretford Process

The Stretford process involves liquid oxidation to convert H_2S to elemental sulfur. The raw gas is contacted with a weakly alkaline solution of sodium carbonate containing sodium vanadate and the sodium salt of anthriquinone disulfonic acid (ADA). This solution dissolves the H_2S which is then oxidized to elemental sulfur by the vanadate.

(a) Chemistry of the Process

•The removal of H_2S follows these four steps:

1. Absorption of H_2S in alkali:

$$Na_2CO_3 + H_2S \rightarrow NaHS + HCO_3$$

2. Reaction of sodium hydrosulfide with metavanadate:

$$2NaHS + 4NaVO_3 + H_2O \rightarrow Na_2V_4O_9 + 4NaOH + 2S$$

3. Reduced vanadate is oxidized by ADA:

$$Na_2V_4O_9 + 2NaOH + H_2O + 2ADA \rightarrow 4NaVO_3 + 2ADA \text{ (reduced)}$$

4. Reoxidation of ADA by contact with air:

$$2ADA\ (reduced) + O_2 \rightarrow 2ADA + H_2O$$

The overall reaction is the oxidation of H_2S to sulfur:

$$2H_2S + O_2 \rightarrow 2S + H_2O$$

Hydrogen cyanide, usually present in the feed gas, reacts irreversibly the Stretford chemicals to produce sodium thiocyanate (NaCNS). It is recommended that HCN be removed from the feed by the polysulfide process prior to treatment in the Stretford unit. The removal of HCN with polysulfide ($Na_2S_{[n+1]}$) is as follows:

1. Polysulfide formation:

$$Na_2CO_3 + H_2S \rightarrow Na_2S + CO_2 + H_2O$$
$$Na_2S + nS \rightarrow Na_2S_{(n+1)}$$

2. HCN removal:

$$HCN + Na_2S_{(n+1)} + Na_2CO_3 \rightarrow NaCNS + NaHCO_3 + Na_2Sn$$

3. Polysulfide regeneration:

$$Na_2Sn + S \rightarrow Na_2S_{(n+1)}$$

Hydrogen cyanide and H_2S can also be removed simultaneously. The choice of separate or simultaneous removal depends on the concentration of HCN in the gas. A high concentration favors separate removal. In coal gasification, the HCN concentration is too low to justify a separate HCN absorber.

Other side reactions occur when SO_2 reacts with the solution to form Na_2SO_3 and when H_2S and O_2 react with the solution to form $Na_2S_2O_2$. Both compounds accumulate and must be purged from the system.

(b) Process Description

Unrefined gas enters the bottom of the packed absorber column and is contacted countercurrently with the Stretford solution. Hydrogen sulfide is absorbed along with HCN and SO_2. Purified gas leaves the top of the absorber, and the rich solution flows from the bottom of the absorber to a reaction tank where H_2S is oxidized to elemental sulfur. This tank can be at the

bottom of the absorber or can be a separate vessel. Then the reduced solution flows to the oxidizers where air is blown through to reoxidize ADA and separate the sulfur by froth flotation. Oxidizers are commonly cylindrical vertical tanks containing a device at the bottom for effective air distribution. The froth is filtered, washed, and melted to yield high-quality sulfur. The relatively sulfur-free regenerated solution is recycled to the absorber. Figure 8 shows a typical flow diagram of a Stretford process.

Waste streams are treated by one of the following proprietary schemes:

- reductive incineration
- oxidative combustion
- biological degradation
- evaporative or spray drying

The most promising method seems to be reductive incineration since all the products are recycled leaving no wastes to deal with. In reductive incineration, the effluent is burned with deficient air and a small stream of the main feed under proprietary combustion conditions. The products (CO, CO_2, N_2, and H_2S) are returned to the absorber gas inlet. Regenerated salts are returned to the solution in the absorber base.

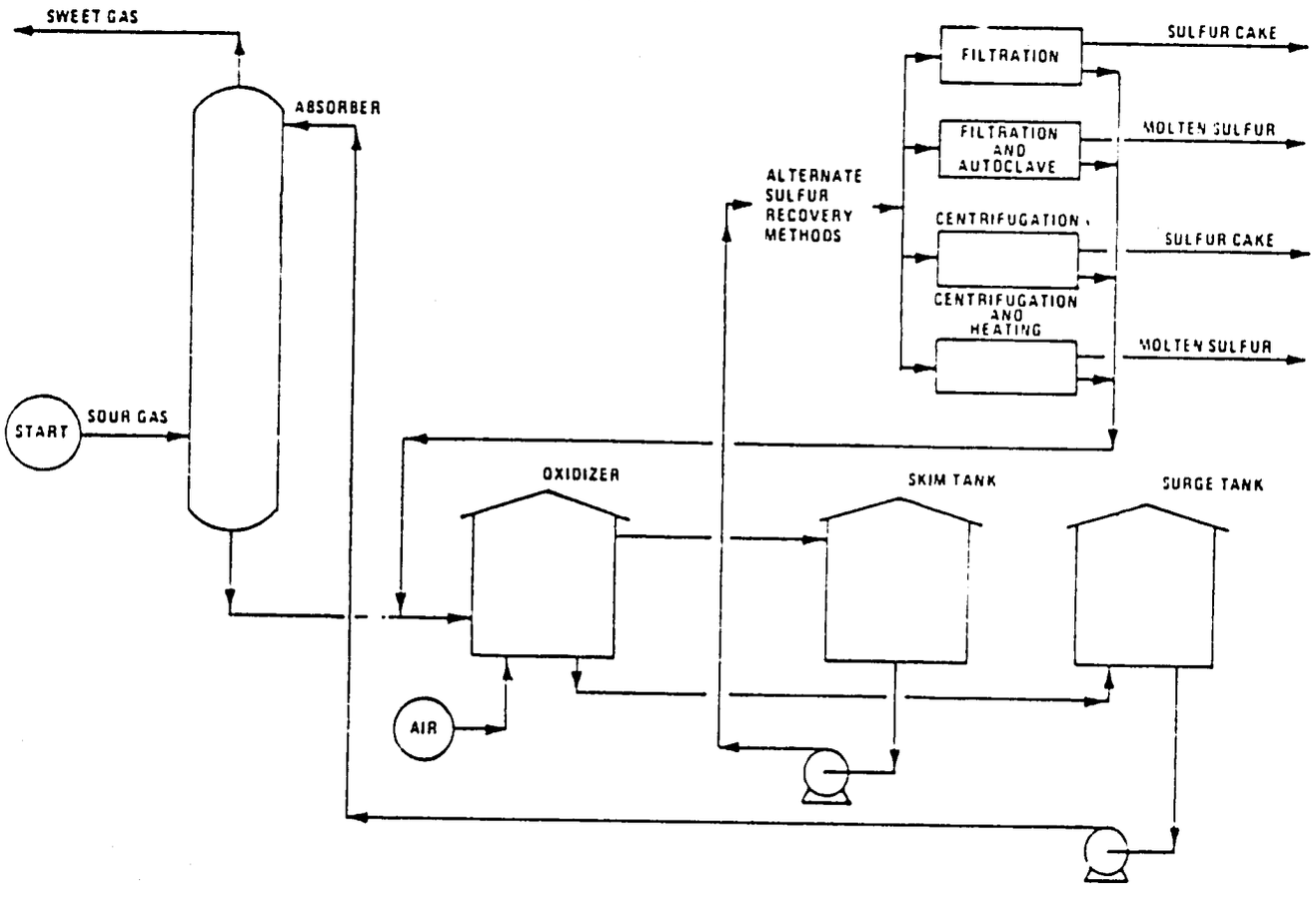
(c) Process Constraints

The disposal of effluent streams containing sodium thiocyanate, sodium thiosulfate, and sodium sulfate is a serious problem.

Temperature range is 70° to 110°F (21° to 43°C). Operating pressures vary from atmospheric to 100 psig in the absorber. The oxidizer and recovery vessel operate at atmospheric pressure.

Hydrogen sulfide concentrations as low as 300 ppm and as high as 95 percent can be purified to less than 1 ppm. Carbon dioxide is not significantly removed; however, the process can tolerate it in any amount. Organic sulfur compounds, such as COS and CS_2, are not reduced, but minor quantities of methyl mercaptan can be removed. Concentrations of HCN as high as 2,000 ppm can be virtually completely removed.

The system is best operated at a pH of 8.5 to 9.5. A high CO_2 partial pressure in the feed can cause the system to operate at a lower pH which reduces the efficiency.



Typical Flow Diagram of Stretford Process

Figure 8 (11)

bottom of the absorber or can be a separate vessel. Then the reduced solution flows to the oxidizers where air is blown through to reoxidize ADA and separate the sulfur by froth flotation. Oxidizers are commonly cylindrical vertical tanks containing a device at the bottom for effective air distribution. The froth is filtered, washed, and melted to yield high-quality sulfur. The relatively sulfur-free regenerated solution is recycled to the absorber. Figure 8 shows a typical flow diagram of a Stretford process.

Waste streams are treated by one of the following proprietary schemes:

- o reductive incineration
- o oxidative combustion
- o biological degradation
- o evaporative or spray drying

The most promising method seems to be reductive incineration since all the products are recycled leaving no wastes to deal with. In reductive incineration, the effluent is burned with deficient air and a small stream of the main feed under proprietary combustion conditions. The products (CO, CO_2, N_2, and H_2S) are returned to the absorber gas inlet. Regenerated salts are returned to the solution in the absorber base.

(c) Process Constraints

The disposal of effluent streams containing sodium thiocyanate, sodium thiosulfate, and sodium sulfate is a serious problem.

Temperature range is 70° to 110°F (21° to 43°C). Operating pressures vary from atmospheric to 100 psig in the absorber. The oxidizer and recovery vessel operate at atmospheric pressure.

Hydrogen sulfide concentrations as low as 300 ppm and as high as 95 percent can be purified to less than 1 ppm. Carbon dioxide is not significantly removed; however, the process can tolerate it in any amount. Organic sulfur compounds, such as COS and CS_2, are not reduced, but minor quantities of methyl mercaptan can be removed. Concentrations of HCN as high as 2,000 ppm can be virtually completely removed.

The system is best operated at a pH of 8.5 to 9.5. A high CO_2 partial pressure in the feed can cause the system to operate at a lower pH which reduces the efficiency.

6. High-Temperature Acid Gas Removal

a. Claus Process

The Claus process is not truly a gas purification process since its purpose it to recover sulfur from pure or highly concentrated sulfur bearing gases that are products of a previous gas purification process. The process yields sulfur of extremely good quality.

(1) Chemistry of the Process

The main reactions for the recovery of sulfur are:

$$H_2S + 3/2\ O_2 \rightarrow H_2O + SO_2$$
$$2H_2S + SO_2 \xrightarrow{catalyst} 3S + 2H_2O$$

The catalyst used in the second reaction is either alumina or natural bauxite in the form of pellets. Because the total conversion is limited by chemical equilibrium, the process may not be adequate to meet air pollution regulations. In this case, an add-on process to treat the tail gas (such as SCOT or Beavon) must be employed.

If any COS or CS_2 is present in the feed gas, they are hydrolyzed by the following reactions if the temperature is sufficiently high:

$$COS + H_2O \leftrightarrow CO_2 + H_2S$$
$$CS_2 + 2H_2O \leftrightarrow CO_2 + 2H_2S$$

(2) Process Description

The Claus process is conducted in two stages: a thermal (high-temperature) stage at 1,000°F (538°C) followed by a catalytic (low-temperature) stage at close to 700°F (371°C). There are two basic forms of the process. These forms are partial combustion and split stream.

- Partial Combustion

  The entire acid gas stream and a stoichiometric amount of air to burn one-third of the H_2S to SO_2 is fed through a burner to the reactor furnace. In this furnace, a large amount of elemental sulfur is formed and condensed after being cooled in a waste heat boiler and a sulfur condenser. The gases leaving the condenser are reheated and sent to a catalytic converter for additional sulfur recovery by the reaction of H_2S with SO_2.

Recovery is limited if only one converter is used, so modern plants use 2, 3, or even 4 converters in series each operating at successively lower temperatures. The process of reheating, catalytically reacting, and sulfur condensing repetitively increases the conversion. The exhaust gases from the last converter are further treated to remove any residual sulfur. The partial combustion process is used for streams containing over 50 percent H_2S. See Figure 9 for a typical diagram of a two-stage Claus process plant.

o Split Stream

In this configuration, one-third of the acid gas is sent to the furnace, and the other two-thirds is mixed with exit gas from the waste heat exchanger just before entering the first converter. The production of elemental sulfur in the furnace is insignificant. The rest of the process is the same as the partial combustion process.

This method suits acid gas streams containing H_2S in low concentrations. A split stream flow is shown in Figure 10.

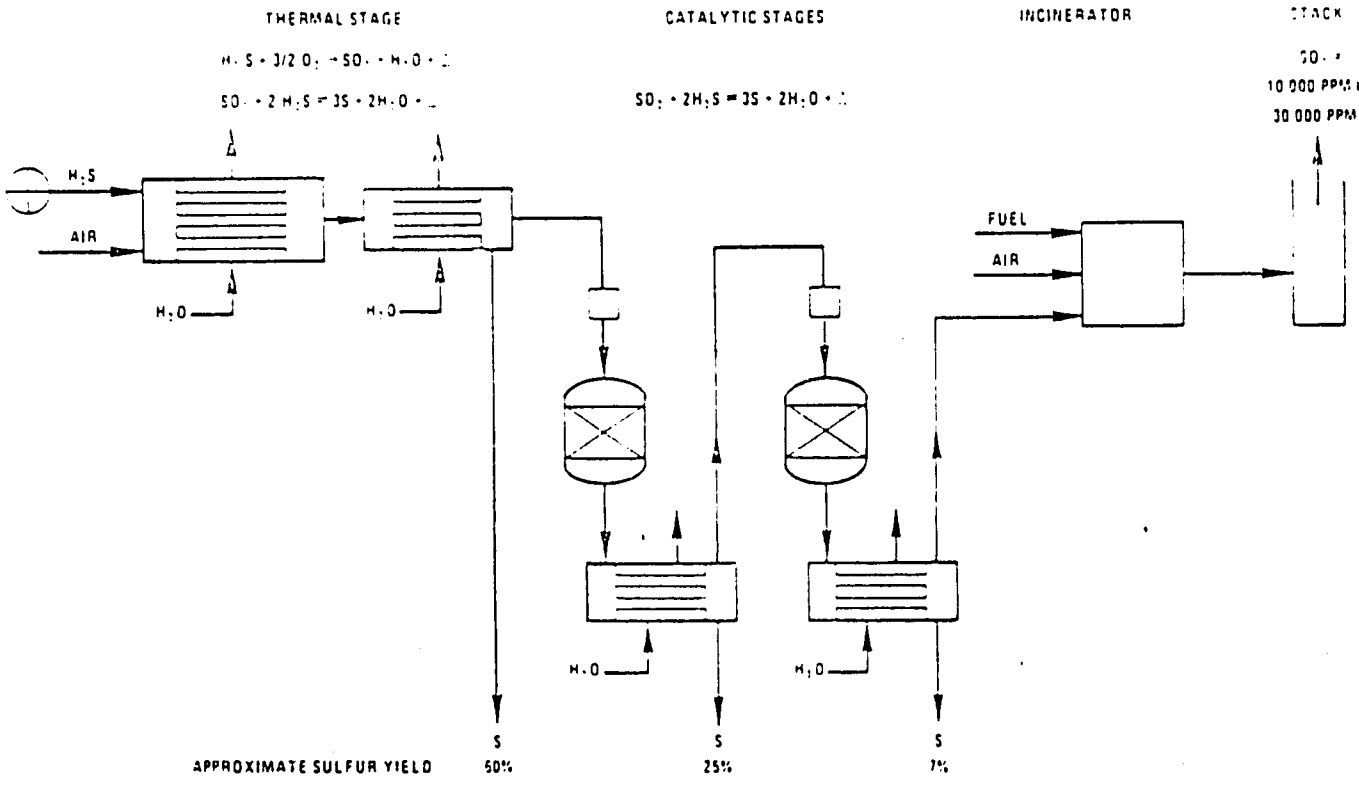
In the Claus sulfur recovery process, the furnace is normally a combustion chamber and a waste heat boiler in one vessel. The catalyst beds are arranged either vertically or horizontally with more than one bed located in one vessel. Usually a mist eliminating device is installed after the last condenser to minimize entrainment of sulfur droplets into the incinerator. This sulfur deactivates the catalyst.

(3) Process Constraints

Since the heat for the Claus process is supplied by burning part of the H_2S, the H_2S concentration is the most important parameter in plant operation. If the H_2S concentration is less than 20 percent, O_2 or O_2-enriched air is needed for combustion, or a suitable fuel gas must be added to the gas stream.

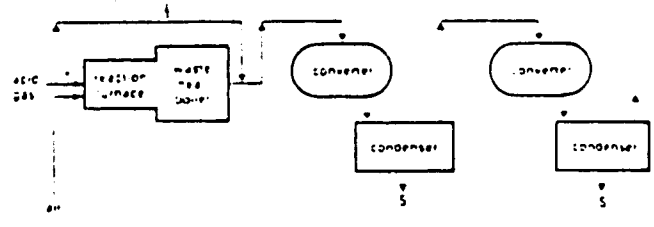
Removal efficiencies of 98 percent can be attained depending on the H_2S level, the number of catalytic converters, and the quality of the catalyst.

Since the tail gas normally contains SO_2, H_2S, COS, CS_2, and sulfur vapor, it must be treated in an add-on facility before discharge into the atmosphere.



Typical Flow Diagram of a Two-Bed Claus Process Plant

Figure 9 (11)



Split Stream Configuration of the Claus Process

Figure 10 (15)

b. Iron Oxide Process

The iron oxide process is one of the oldest methods used to remove sulfur compounds from industrial gases. The process is well suited for sweetening small volumes of gas with low H_2S concentration. If mercaptans are present, they are also removed effectively. Iron oxide boxes are highly selective, removing only sulfur compounds from the raw feed gas. However, carbon oxysulfide is not completely removed.

(1) Chemistry of the Process

The iron oxide bed adsorbs H_2S by the following reaction:

$$Fe_2O_3 + 3H_2S \rightarrow Fe_2S_3 + 3H_2O$$

The bed is regenerated by exposure to air:

$$2Fe_2S_3 + 3O_2 \rightarrow 2Fe_2O_3 + 6S$$

The overall process for adsorption of H_2S and conversion to elemental sulfur is represented by this chemical equation:

$$6H_2S + 3O_2 \rightarrow 6H_2O + 6S$$

These equations represent a simplified mechanism. Many other side reactions can occur depending on the temperature, moisture content, and pH of the system.

(2) Process Description

Raw feed gas which contains H_2S is fed to a bed containing hydrated iron oxide. Hydrogen sulfide is adsorbed. By exposing the iron sulfide to atmospheric oxygen, it is oxidized to produce elemental sulfur and regenerated iron oxide.

Regeneration can be done after the oxide is discharged from the bed. Another more common method is to simultaneously adsorb H_2S and regenerate oxide by allowing a small amount of air to continuously enter with the feed. A third method utilizes more than one bed. One bed is regenerated by a recirculating gas containing some air, while the other bed is in use for sweetening. A flow arrangement of a two-bed iron oxide process is illustrated in Figure 11.

The iron oxides are either mixed (finely divided iron oxide is supported on materials with large surface areas and loose textures) or unmixed (prepared from iron ore or metallic iron). The vessels that contain the iron oxide can be either the conventional box, the deep box, the tower, or the tower box. The design is based on the superficial linear velocity and on contact time. The bed

should be designed to allow a space velocity of 60 cubic feet per hour per cubic foot of bed for each grain of H_2S in the raw gas. Pressure drop should not exceed 1 to 2 psi per foot of bed depth.

Iron oxide plants can be operated at atmospheric pressure or at pressures of 100 to 325 psig. Operating temperatures range from 80° to 120°F (27° to 49°C). The process is capable of removing H_2S to the ppm level along with removing much of the mercaptans. A H_2S removal of 80 percent in the first box is considered satisfactory.

(3) Process Variations

The Morgantown Energy Research Center studied a hot purification process to adsorb H_2S on iron oxide. The process operated at 1,000° to 1,500°F (538° to 816°C) and regeneration was accomplished with air below 1,500°F. The sulfur was oxidized to SO_2 and then used to synthesize sulfuric acid. The process reactions are the following:

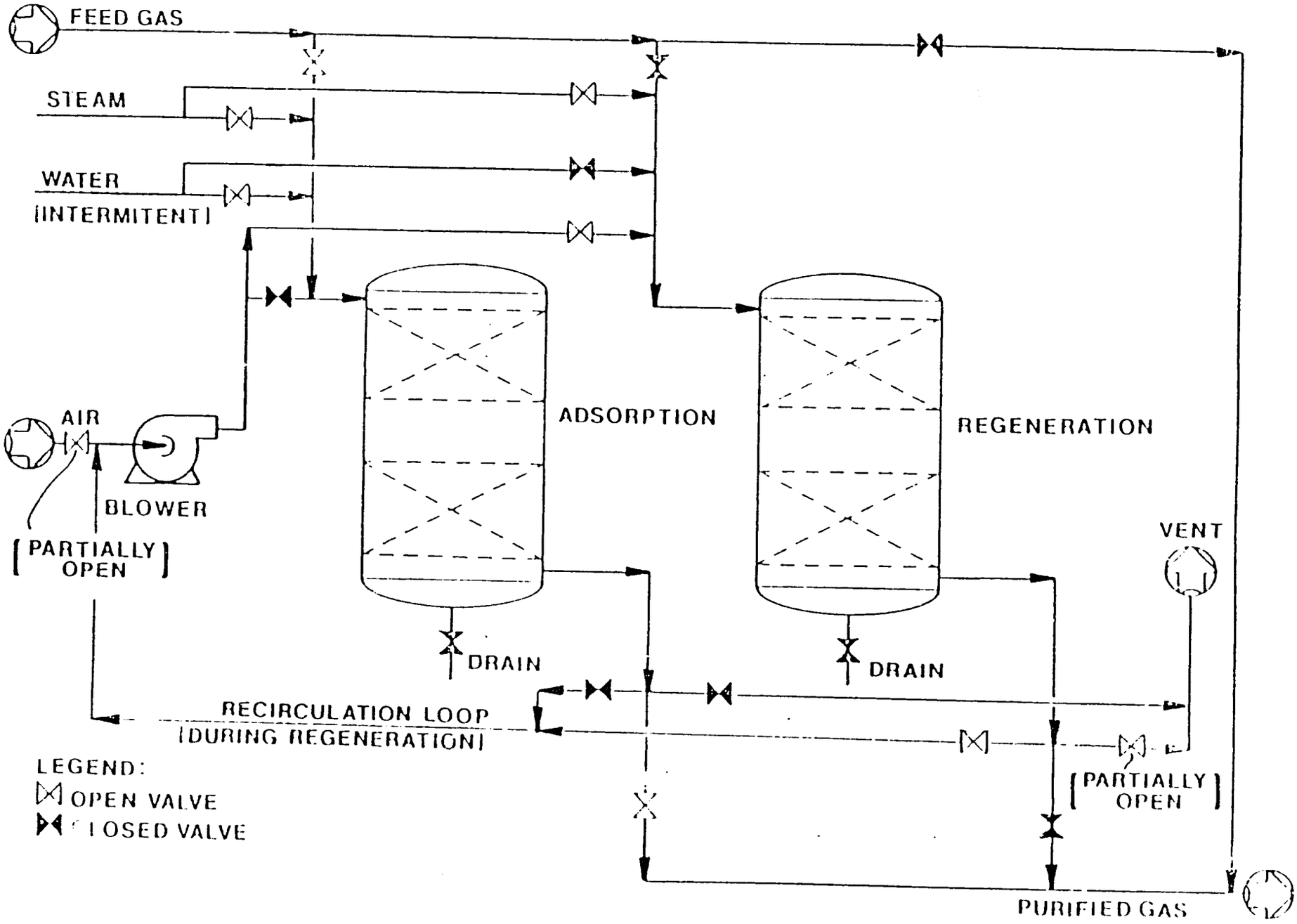
$$3Fe_2O_3 + 9H_2S \rightarrow 3Fe_2S_3 + 9H_2O$$
$$6FeS_{1.5} + 13O_2 \rightarrow 2Fe_3O_4 + 9SO_2$$
$$2Fe_3O_4 + \tfrac{1}{2}O_2 \rightarrow 3Fe_2O_3$$

Removal efficiencies of 92 to 97 percent were obtained when using fly ash and silica supports for the iron oxide and binding materials.

Hot gases have a problem with tar formation. In addition, obtaining a final product of sulfuric acid is not as attractive as recovering elemental sulfur.

(4) Process Constraints

Iron oxide processes are limited to gases having 10 to 75 grains of H_2S/100 scf of gas so that bed life is not too short to be economical. The bed can be repeatedly regenerated before it becomes fully loaded with sulfur and must be discarded. The spent iron oxide sponge is usually covered with soil to render it inert.



Two Bed Iron Oxide Process

Acid gas removal can be accomplished by a great number of processes. Only a few of the typical and well-known systems have been discussed in this section to illustrate the basic strategies of gas sweetening. To summarize the processes discussed in this section, information, such as operating conditions and purification limits, is tabulated in Table 8.

PROCESS	Input H_2S	Output H_2S	Sorbent	Operating Temperature	Operating Pressure	Product	Remarks
aus	>20%	15,000 ppm (SO_2)		2000°-3000°F. (burner) <200°F. (catalytic stage)	atmospheric	elemental sulfur	1) 94-98% of removed S converted to elemental S 2) needs a tail gas clean-
Carbonate enfield)	100,000 ppm	<1 ppm	hot aqueous potassium carbonate	250°-280°F.	200-60. psig	H_2S	1) feed composition not cr 2) needs Claus 3) Does not dissolve hydro
on Oxide	1000 ppm	4 ppm	hydrated iron oxides	80-120°F.	100-100 psig	elemental sulfur	1) can be regenerated if SO no problem 2) sulfur discarded with so
ectfsol	1%	0.1 ppm	methanol	-100°-0°F. (absorber) -150°F. (stripper)	300-20 psig (absor atom. eric (str pper)	H_2S	1) requires external refr 2) needs Claus
lexol	any	1 ppm	dimethyl ether of polyethylene glycol	20-100°F.	500-1000 psig (absorber) 0-5 psig (stripper)	H_2S	1) needs Claus
retford	300 ppm to 95%	1 ppm	anthraculnone-disulfonic acid sodium metavanadate citric acit sodium carbonate	80-120°F.	0-100 psig	elemental sulfur	1) doesn't remove COS or CS 2) needs special disposal c cyanates, thiosalts, & vanadium salts
nc Oxide	50 ppm	0.02 ppm	zinc oxide	660-840°F.	0-750 psig	zinc sulfide	1) sulfur discarded with sa 2) zinc recovery extremely

Summary of Processes for Acid Gas Removal

TABLE 8 (18)

7. Unconventional Methods

a. Membranes

Gas separation by membranes is based on the principle that different components of a gas mixture permeate across a membrane at different rates. The driving force is the partial pressure of the gas. Separation, therefore, can occur over a range of conditions. The only limitations are the physical properties of the membrane. In gas separation, a combination of high flux and high separation factor make a membrane economically feasible. Membranes can be made from a number of materials including rubber and polymer. Each membrane has its own characteristics and is more suited than others for certain applications.

In membrane separation, acid gases are removed from the sour gas stream by a membrane that is more permeable to the acid gases than to the hydrocarbons. A differential acid gas partial pressure across the membrane causes the acid gas to flow to the side of lower pressure. The result is a stream rich in acid gas and a stream of sweetened gas. A diagram of a membrane separation process is illustrated in Figure 12.

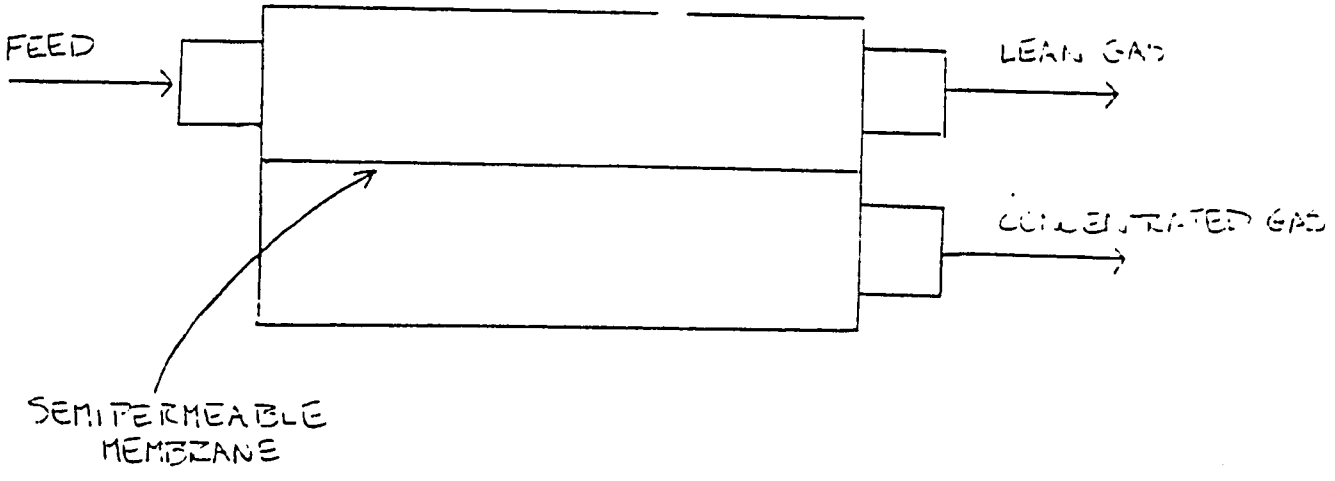


Figure 12

Membrane Separation Process

The advantages that membrane separation has over other methods of gas separation are the reduced capital costs, reduced utility requirements, lower fuel consumption, and lower space requirements for the unit. Additionally, modular units can be employed to minimize downtime.

Unfortunately, the membrane has the disadvantage of not obtaining gases of high purity at a reasonable cost. The most economical way to utilize membrane separation is to combine it with another conventional technique.

b. Supported Complexes

Metal complexes can be used to separate gases in order to recover valuable components and remove undesirable contaminants from a gas stream. Pacific Northwest Laboratory (PNL) is studying organometallic complexes and is researching the incorporation of these complexes with polymeric supports.

The supporting matrices were selected from a group that included organic polymers, silica gel, and glass beads. Polystyrene was the preferred choice due to the previous experience with it at PNL and of other gas separation specialists.

The organometallic complexes that were selected for further study were ($Pd_2[dpm]_2Cl_2$), (where dpm = $Ph_2PCH_2PPh_2$) for CO sorption, ($Ir[Me_2PCH_2CH_2PMe_2]_2$)CL for CO_2 sorption, and $Ru(CO_2)(PPh_3)_3$ for H_2 sorption. The most promising is ($Pd_2[dpm]_2Cl_2$) since it reversibly sorbs CO with ease even in the presence of CO_2, O_2, N_2, and H_2. All three complexes have rapid and quantitative uptake of gas.

PNL is now working on the development of a means for chemical attachment of these complexes to the polymeric support. This study holds substantial promise for the development of a significantly novel concept to separate gas mixtures.

F. RECOMMENDATIONS AND CONCLUSIONS

- To reduce nitrous oxide emissions, the first step should be to modify the combustion or gasification process conditions.

- For particulates greater than 5 microns, cyclones should be used at low temperatures, and filters should be used at high pressures. Smaller particulates are most effectively removed by wet scrubbers and electrostatic precipitators.

- Gas streams at high pressures containing relatively large amounts of sour components are better cleaned by physical absorption processes such as the Rectisol and Selexol processes.

- Gas streams containing small amounts of sour components are purified effectively by chemical absorption processes such as the Benfield and Stretford processes.

- High-temperature acid gas removal systems are usually more economical because of their increased thermal efficiency. However, there is a problem from fuel-bound nitrogen and thermally generated NO_x. Low-temperature processes have the advantage of being more available and more experimentally tested.

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Q. Since your primary product is coke because you need it at the steel plants, you recover -- or try to -- every ounce of it. Therefore, is it correct to assume that you have other ways of utilizing the rejects, such as producing gas, here and in the U.S.?

A1. The rejects obtained by washing coking coal have some caking properties. This caking property is useful in making agglomerated domestic fuel, that is, water-resistant hard domestic fuel.

A2. In the U.S. we don't make a middlings product. I showed a flow sheet here and that one does, but it's a unique case. There are generally only one or two of these plants. Generally we don't make a middlings product because we throw away the rock product. We separate at about 160-170; it's a black and white separation, and we throw away the rock. Nobody has really done much in the way of economic studies on gasification of this and so on. Now, once we start going deeper and start producing middlings material, these things would need to be studied. Certainly fluidized bed combustion has studied it to some degree, but gasification I am not aware of.

Q. In one of the slides, the trace element is reduced by washing; that is, the trace element concentration is less, but will this be applicable to Indian coals?

A1. What we have found is that the trace elements are associated quite often with the mineral matter, particularly with the pyrite. So, where we get exceptionally good pyrite reduction, we seem to get good trace element reduction. That being the case, Indian coals would respond well, if you could take the pyrite out.

A2. While I agree almost 100% with Deurbrouck's anticipation that the trace elements could be removed from the American coals by about 50-60-70 or even 80% -- about 80% of the lead could be removed -- the same would be the case for Indian coal washing if we do this work, but we have not.

I have one apprehension -- elements may be part of the organic matter. In fact, Americans have seen the presence of uranium in some low rank coals -- sub-bituminous coals and lignites. The low rank coals have catalytic properties. If lead and other elements are held back into this coal matrix, naturally the physical process will not remove them. But I agree that most of the mineral matter -- if not 100% -- including the trace elements in much coals, are held in physical association and are likely to be removed.

A3. Just another point on trace elements. Interestingly, in the U.S. if the coal happens to be in Missouri where we have a lot of lead, we may have a lot of lead-zinc concentration associated with that coal. I don't know if we will ever look for secondary recovery of lead-zinc, but it is at least being considered. What apparently happens is that, in the formation of coal, the coal absorbs anything around it and we can have ppm up in the thousands of zinc and lead in specific coals, as in your state. So trace element concentration could be another way to come up with a secondary product also, someday down the road.

A4. Trace elements in coal are sometimes a blessing. In fact, in India our soil is deficient in zinc and some zinc is required for cultivation of rice and vegetables, particularly cabbage. So they deliberately add zinc for cultivation. The coal ash is found to be rich in zinc, 60-100 ppm, and it is the amount required in the soil for vegetative growth.

Q. What is the mining status in the country? Does it have a bearing on the ash content in the coal?

A. In India, besides the high ash and inferior quality of coal, there is one other problem, the small output from individual colleries. In the early days, washeries were planned and set up based on supply from a number of colleries, and central washeries were set up to receive coals from different seams and locations. But, in the future, washeries will be placed at the pit itself.

Q. This question is directed to Dr. Ghate. For gas cleanup, fabric filters, cyclones and other equipment for dust cleaning are used, but no use of electrostatic precipitators for dust cleaning has been referred to. I am emphasizing this because a German delegation earlier had said that electrostatic precipitators for high temperature operations are in an advanced stage. Could you provide additional information?

A. We have used electrostatic precipitators (ESP) in six runs. Every single run failed. So I don't know whether we can say anything positive about ESP at this stage.

Q. Do the ash characteristics have a bearing on the performance of the ESP?

A. In the case of the use of ESPs, the ash characteristics are very important. In one place it may succeed and in another it may fail. Going into ESP is going to be complicated, especially for 1000°C. A lot of studies need to be performed, and we are open to such development at a later stage.

Q. This refers to Ghate's presentation. He enumerated the list of elements, constituents, which need to be cleaned up. However, he did not discuss the removal of tar. Tar in gas can create trouble in the end uses. How will it be cleaned up?

A. For tar removal, physical abosrption methods are the only methods, talking about trace quantities of tar. Bulk quantities of tar are normally removed by quench and conventional inorganic and organic phase separations. You pass the gas liquor over conventional pebble beds, and separate by gravity separators. Trace quantities are separated by physical absorption, in methanol and silexol, and there is less than a fraction of a ppm of hydrocarbon in the cleaned-up gas. If you use aqueous chemical absorption systems you have a problem. We cannot remove all tars.

Q. If you quench, the tar will be removed. But -- hot gas cleanup -- under such conditions how do you do it?

A. We have a unique process. We inject just sufficient steam to bring the gas to the dew point of tar so that it is condensed out, but it does lower the gas temperature from 1000 to 700.

Q. Supposing the tar formation could be prevented altogether. This may be the best thing. From studies on coal pyrolysis, we are of the opinion that part of the coal structure, hydroaromatic, is a precursor to the formation of primary tar. Before the pyrolysis of coal becomes active, 380 - 400, if we do a prior treatment -- a condensation reaction between the aromatic and hydroaromatic parts -- the real pyrolysis would not give any tar. You remove 10% hydrogen from coal by selective dehydrogenation, which can be done below the pyrolysis point of coal, then the rest of the coal remains intact and will not give you any tar. Have such attempts been made anywhere in the world?

A1. We are taking a different approach. We are trying to take the gasification products and pass them over calcium oxide beds. We have found that CaO does show some catalytic activity to convert all the tar into the C_1-C_4 compounds, and the CaO was obtained from the FBC, in spent rocks.

A2. The Germans have been able to do it in a fixed bed gas producer, hot producer gas, without any tar. The principle is simple. In the producer we have the oxidation, primary and secondary reduction and stabilization zones. They separate two zones and make an annulus. The secondary and the stabilization zones are in the other annulus from which the gases going out contain only tar. Through steam ejectors they put that tar back into the gasifier. The actual producer gas from the annulus is tapped from just after the primary zone. This gives only a gas temperature of 500°C but the technique is very good.

A3. The German KGN blast coal gassing plant had, about three years ago, a fixed bed where they gasified the coal and the devolatilized products were ejected through the steam injection system, whereby the tar itself was gassified and you got a higher caloric value gas. In addition

to this, we can also have two-stage gasifiers, wherein you do not inject the devolatilized product into the system but then, on the other hand, you need to have a high calorific value raw gas. You separate the devolatilized products out the top of the gasifier and, in the middle section, you separate the gas free of tar.

A4. As an extension of this, we are operating at 1000°C and at this temperature we do not expect any tar formation. It is only at lower temperatures that the tar exits and hence hot gas cleanup does not require tar removal, unlike in the fixed bed gasifiers.

A5. At 1050°C the tar quantity would be small, but some higher hydrocarbons may exist. This is a speculation based on the fact that KOPTZEK gasifiers are operated at 1350-1600°C, essentially to eliminate the tar formation and eliminate the damage to the ammonia catalyst.

APPENDIX A

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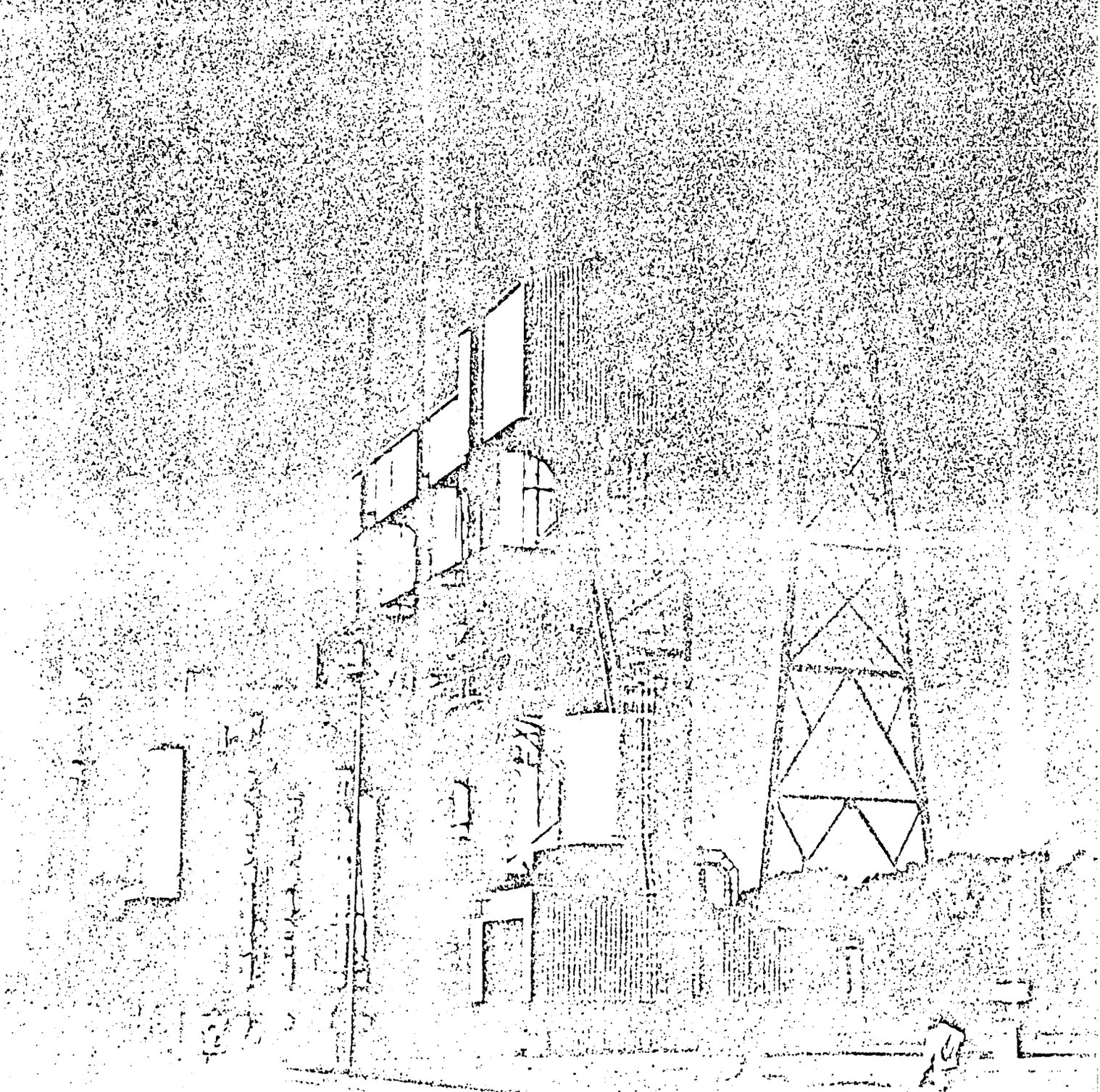
APPENDIX "B"

FOSTER WHEELER POWER PRODUCTS LTD.

FOSTER WHEELER

FW-STOIC TWO-STAGE GASIFIER

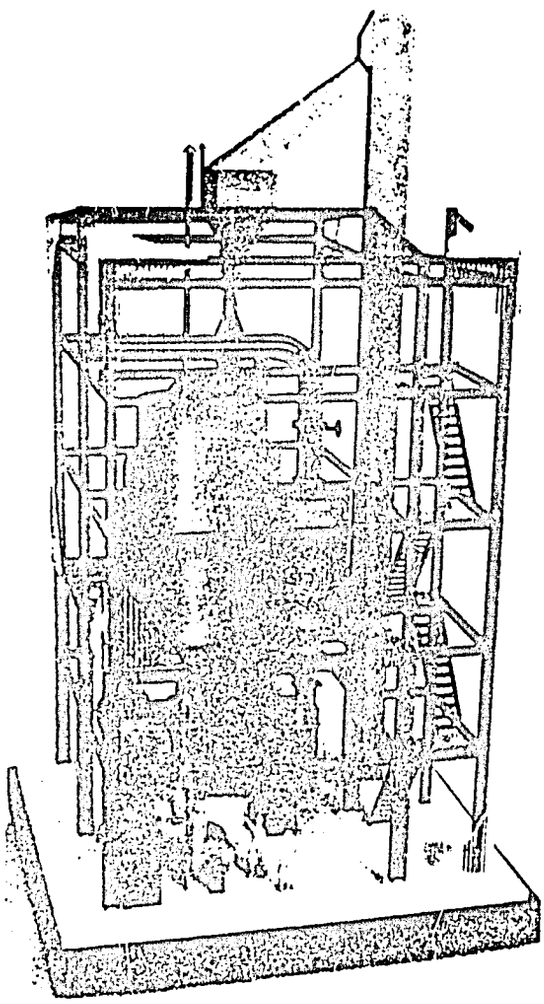


Make your plant self-sufficient in gas

FW-STOIC TWO-STAGE GASIFIER

More and more industrial and institutional fuel oil and natural gas consumers are considering the use of coal gasification. The FW-Stoic gasifier offers a reliable on-site source of clean, easy to burn fuel gas...150 to 200 Btu scf

This modernized, commercially proven unit is simple to operate and maintain. At the same time, it is environmentally sound...ash disposal is simple. And, you won't have to wait years for your FW-Stoic gasifier...you can be operating in 14 to 16 months.



Modular Design

- Simple to operate and maintain
- Can be retrofitted to existing furnaces and boilers
- Modules can be added to increase capacity without delay in production
- Compact—the largest module uses only 30 ft by 35 ft and is 85 ft high
- Consumes only 150 kw of electric power and 450 gph of softened water

Reliability

- Commercially proven over the past 35 years
- 96 percent service factor achievable
- Rugged construction, low maintenance cost

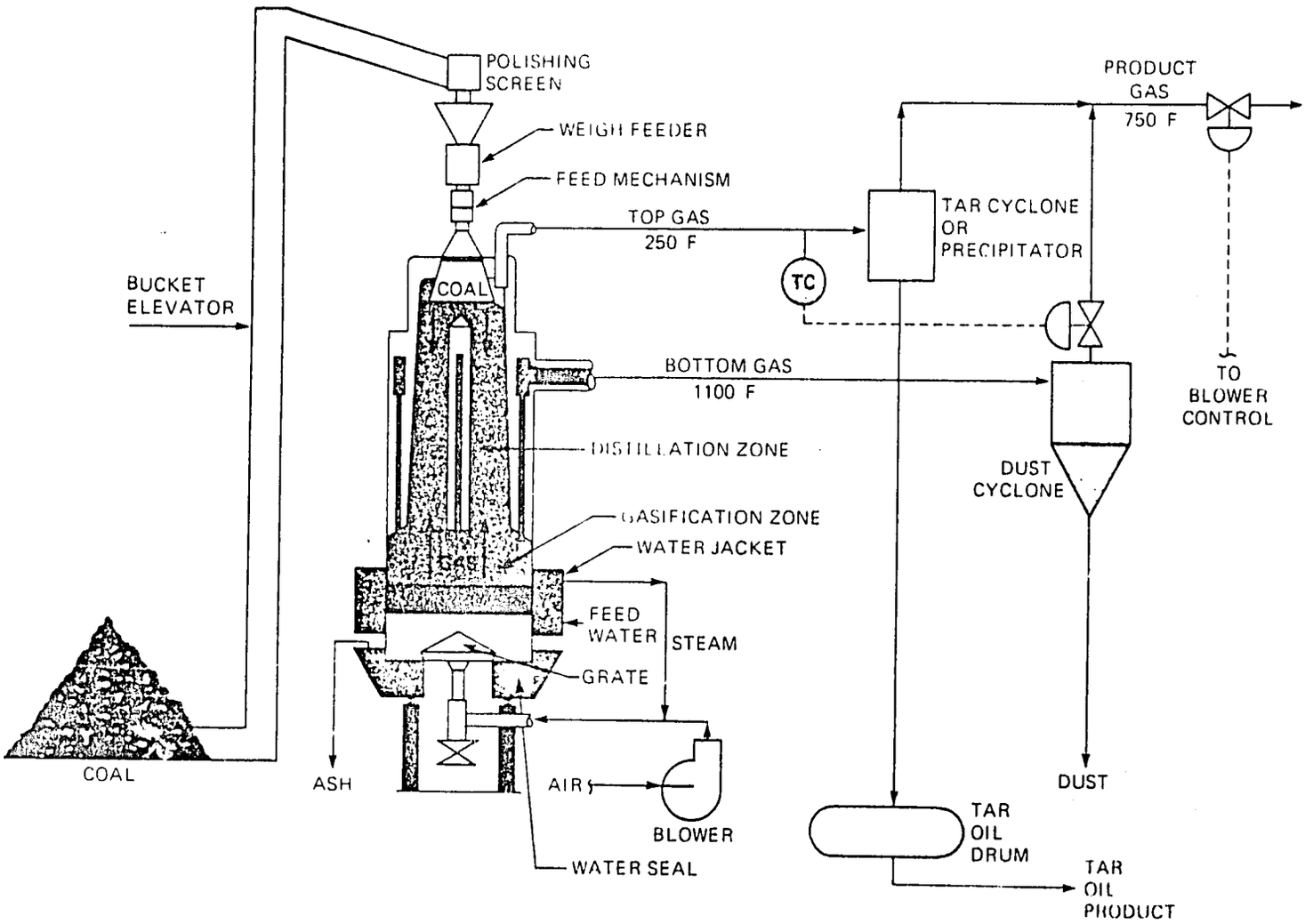
Environmentally Sound

- Gasifier performs partial desulfurization
- No gaseous emissions or liquid discharges
- Ash produced in an environmentally acceptable form

Operations

- High thermal efficiency
- Provides stable fuel delivery under varying loads.
- Produces good quality tar oil co-product
- Rapid response to load changes
- Under your direct control

Process Description



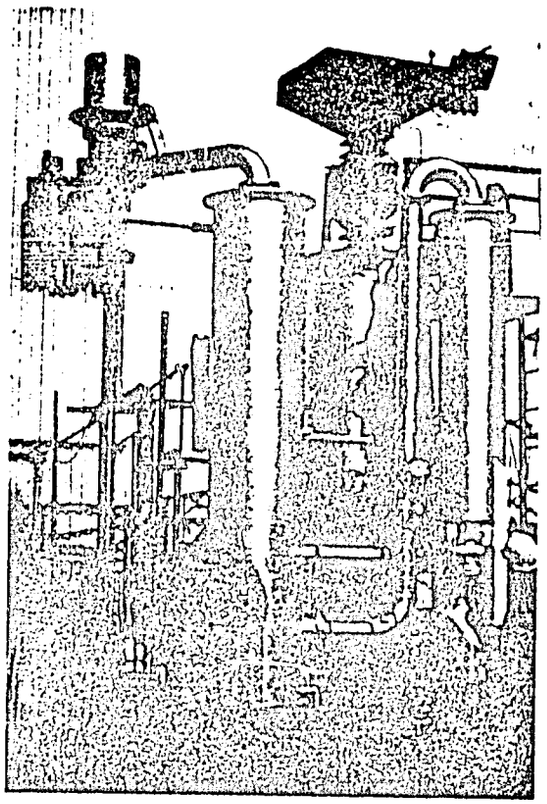
Coal is moved by elevator to a final screening atop the gasifier and is fed into the distillation zone by means of a weigh feeder. Proper levels of coal in both the gasifier and bunker are maintained automatically. A portion of the hot gas produced in the gasification zone below flows upward through the distillation zone to drive the volatiles from the descending coal. As the coal moves to the bottom of the distillation zone, it is converted into coke, which is then gasified in the zone below. Air and steam are distributed through a rotating grate at the bottom of the gasifier bed. Sufficient carbon is oxidized in the fire zone by the incoming air to sustain the system heat balance. The steam reacts with carbon in the gasification zone to form carbon monoxide, hydrogen and methane. Ash is discharged through the water seal at the base of the gasifier. A water jacket surrounding the gasification zone cools the shell and simultaneously generates the steam required for the gasification reaction.

Gas produced in the gasifier exits as top gas, which is automatically controlled at about 250F and as bottom gas at about 1100F. After cleanup, the two streams are combined and the resulting product gas is about 750F.

When a precipitator is used in the top gas stream, the product is hot detarred gas, containing 160-180 Btu scf, which may be transmitted up to 1000 feet. For certain close-coupled applications, a tar cyclone may be used to produce hot raw gas containing 180-200 Btu/scf. A third mode of operation entails additional equipment to produce a lower Btu cold, clean gas suitable for desulfurization.

The gas production rate is automatically regulated to maintain constant pressure in the gas transmission line to the user by adjusting air and steam flows to the bottom of the gasifier as the fuel demand changes.

Tar oil recovered from the top gas of the gasifier is equivalent to a good quality No. 6 fuel oil. It can be stored indefinitely and utilized for peak load requirements, or when the gasifier is undergoing scheduled maintenance.

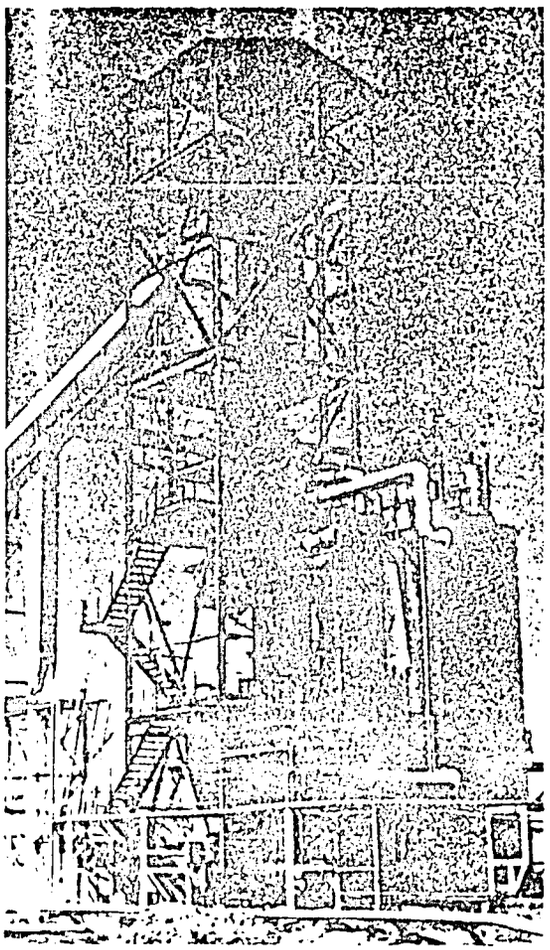


FW-Stoic Pilot Plant Gasifier

Located at Foster Wheeler's Research Center, adjacent to our world headquarters in Livingston, New Jersey, this two-foot diameter, two-stage pilot unit is used to demonstrate the gasification of coals and waste materials under a wide variety of operating conditions. The unit consists of a gasification reactor with a cyclone and hot oil scrubber for dust and tar removal, together with a water-irrigated packed scrubber for light oil removal and further gas cleanup.

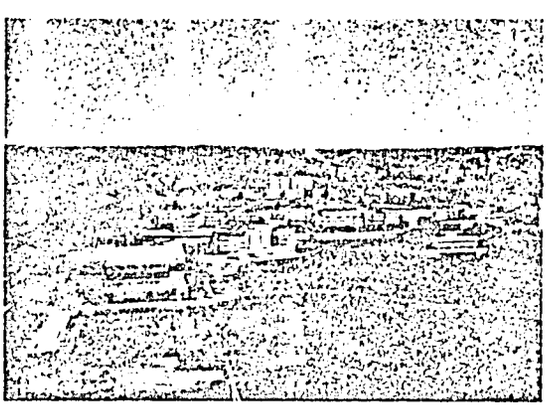
Also available is a bench scale test gasifier for preliminary evaluation of coals for gasification.

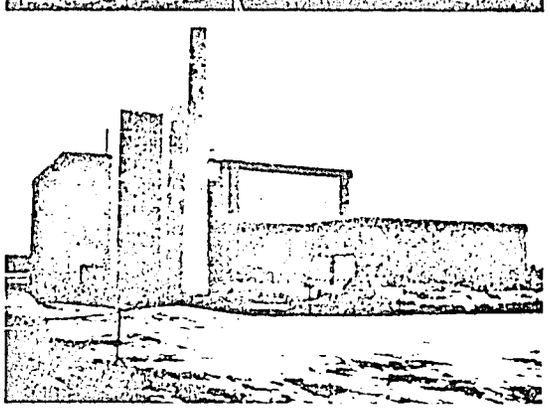
PROVEN EXPERIENCE



The FW-Stoic two-stage gasifier is commercially proven and is based on designs developed by Stoic Combustion Limited (Pty.), Johannesburg, South Africa. Stoic developed and patented numerous design improvements. Fourteen gasifiers are in operation in commercial installations involving a variety of applications such as bakery ovens, brick kilns, boiler retrofits, reformer furnaces, etc.

We have modernized and improved a basic system design applied for 35 years in industry. In undertaking the first U.S. commercial-scale installation at the University of Minnesota, Foster Wheeler successfully transferred that technology and know-how into a facility reflecting U S standards and requirements. The most recent installations have included these improvements.





Duluth, Minnesota

A FW-Stoic gasifier has been supplying clean gas to heat the 30-building University of Minnesota, Duluth campus since 1979. This plant includes a 10-foot diameter gasifier which produces 60 million Btu hr output in hot clean gas and product oil. These fuels are burned in two 25,000 lb hr boilers retrofitted to handle the FW-Stoic product. In addition to supplying the campus heating loads, the installation demonstrates operating reliability and suitability of a coal gasifier for U.S. industrial use.

Foster Wheeler's on-going hands-on experience at Duluth enables us to offer a proven design with:

- Local components and hardware
- Established control logic
- Demonstrated ability to handle a range of coals
- Documented capability to meet U.S. environmental requirements

COMPLETED STOIC GASIFIER COMMERCIAL INSTALLATIONS

Location	Company	Units	Size	Application	Start-Up
Driefontein, SA	Brickor	One	10 ft	Brick Kiln	1974
Lydenberg, SA	JCI Mining	One	8 ft-6 in	Metals Drying	1977
Duluth, USA	Univ of Minnesota	One	10 ft	Boiler Retrofit	1979
Pretoria, SA	Associated Bakeries	One	4 ft-6 in	Bake Ovens	1979
Nigel, SA	Power Lines	One	8 ft-6 in	Metals Heating, Melting	1980
Capetown, SA	Fedmis	Three	10 ft-6 in	Ammonia Reformer Furnace	1981
Pretoria, SA	Metal Box	One	8 ft-6 in	Paint and Metal Drying	1981
Vereeninging, SA	Rand Water Board	Two	6 ft-6 in	Lime Kiln	1981
Howick, Natal, SA	South African Rubber	One	4 ft-6 in	Rubber Manufacturing	1981
Durban, SA	South African Railways	Two	8 ft-6 in	Heat Treating	1982

THE FW-STOIC GASIFIER

Foster Wheeler Energy Corporation offers the FW-Stoic two-stage coal gasifier having as principle advantages the following:

simple, and compact design

high thermal efficiency

proven commercial operation

reliability

low capital cost

Depending on the mode of operation, Btu content of gas ranges from about 160 to 205 btu/SCF. The gasifier operates essentially at atmospheric pressure, but the product gas may be compressed if required. The range of capacities make it suitable for use as an "in-plant" gasifier for a manufacturing plant.

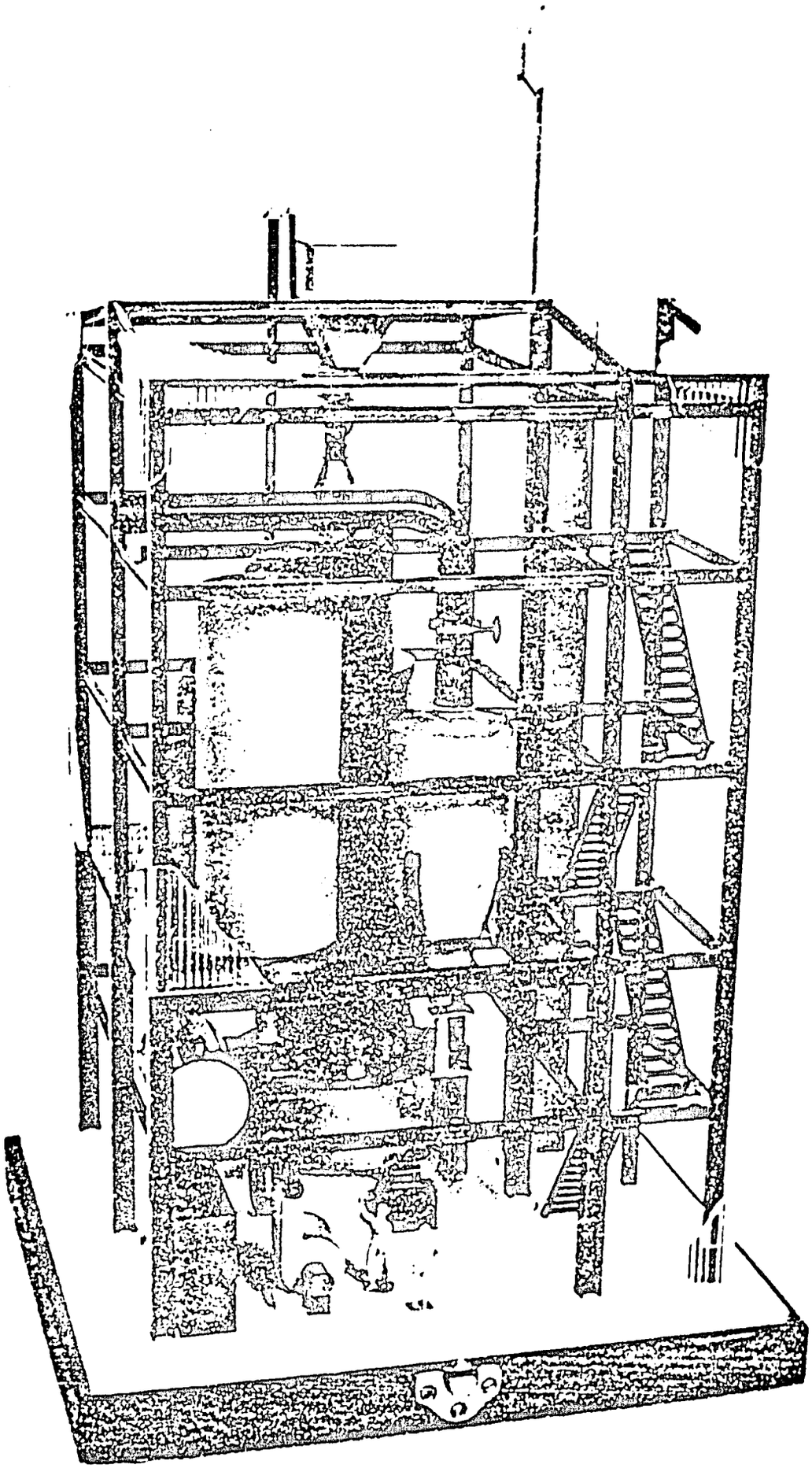
The design of these units has been provided to Foster Wheeler by Stoic Combustion Pty Ltd of Johannesburg. Stoic is currently active in the design and construction of two stage gasifiers which have been operating in areas outside the US for over three decades.

DESCRIPTION OF GASIFIER

Figure 1 illustrates the FW-Stoic two-stage fixed bed gasifier. The upper stage of this gasifier is the distillation stage, or zone, and the lower is the gasification zone. Coal enters the top of the vessel and passes into the distillation zone. A portion of the hot gas produced in the gasification zone is routed up through the distillation zone, and provides the heat for the distilling operation. As the coal reaches the bottom of the distillation zone it has been reduced to coke.

A mixture of air and steam is fed to the bottom of the gasification zone. After being preheated by passing through the bed of hot ash, the steam-air mix enters the fire zone where a partial oxidation reaction takes place. This step produces CO, and some CO_2, and generates the heat for the balance of the gasification reactions to take place above the fire zone.

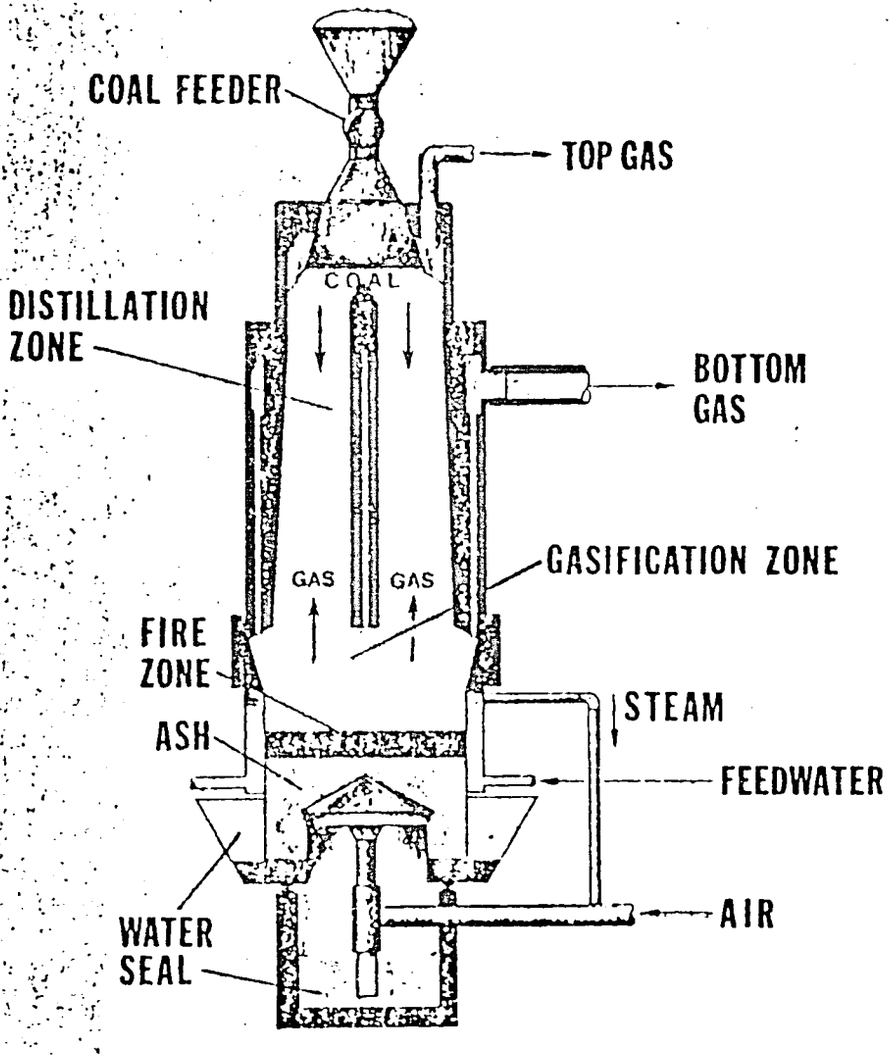
The gas exiting the distillation zone is "top gas" and is at 250°F. The gas leaving the gasification zone is called "bottom gas" and is at 1200°F. The sensible heat in the bottom gas entering the distillation zone provides the heat for driving the volatiles off the coal. This step is accomplished slowly and gently without cracking, repolymerizing, or otherwise forming undersirable byproducts.



DESCRIPTION OF GASIFIER - (CONT'D)

The coke is reduced to ash in the fire zone. Ash moves down onto the grate and out of the gasifier via the water seal. The bed of ash between the fire zone and the grate is cooled by the incoming blast of air and steam. Water jacketing is used in the gasification zone to cool the shell and at the same time generate the steam required for the gasification reaction.

FW-STOIC 2-STAGE GASIFIER



- WATER
- CONCRETE
- FIRE ZONE
- COAL
- ASH
- ASH & WATER
- LINING

90-55

DESCRIPTION OF FLOW

Figure 2 illustrates the flow for the FW-Stoic gasification process.

A sized coal of 3/4"-1-1/2" or 1-1/2"-3" is given a final screening at ground level to remove fines and then is moved by bucket elevator to a bunker atop the gasifier. Coal feeds down from the bunker to the top of the gasifier by means of a drum feeder. The levels of coal in the top of both the gasifier and the bunker are maintained automatically.

Top gas exits the gasifier at about 250°F and the bottom gas exits about 1200°F. After minor cleanup steps on each stream, they are combined and the resulting gas temperature is about 750°F.

Temperature of the top gas is controlled by means of a butterfly valve mounted in the gasifier bottom gas outlet line, which allows more or less bottom gas to flow upwards thru the distillation zone.

Fine droplets of tar-oil in the top gas are removed in a cyclone and the resulting mixture of top and bottom gas is called "hot raw gas" having the highest btu content for product gas. Additional tar-oil may be removed by the inclusion of an electrostatic precipitator. In this optional case the combined stream of top and bottom gas product is then referred to as "hot detarred

DESCRIPTION OF FLOW - (CONT'D)

gas" having a slightly lower Btu content than that of "hot raw gas"

The tar-oil recovered by the cyclone or the precipitator is collected in a tank, and is similar to #6 fuel oil. Table 4 gives the properties of a typical tar-oil.

The bottom gas exiting the gasifier flows thru a cyclone for removal of dust and then joins the top gas stream.

The make rate of product gas is regulated by a pressure controller on the product gas line. As line pressure falls, more air and steam flow to the bottom of the gasifier thereby increasing gas make.

The steam generated in the gasifier water jacket is at atmospheric pressure, and is added to the air entering the gasifier from an air blower. The ratio of steam to air is varied to control the quality of the ash.

The gasifier, and its bed of coal, coke and ash are stationary. The water seal and ash removal facilities rotate to drive the ash through the water seal on to the ash conveyors.

DESCRIPTION OF FLOW - (CONT'D)

As a further option of producing hot "raw gas" or "hot detarred gas" there is a third mode of operation for the FW-Stoic Gasifier which produces cold clean gas having a lower Btu content. The bottom and top gas stream are water cooled to remove condensibles. Most of the condensibles are recoverable as liquid fuel and the balance are incinerated.

A sulfur removal system can be incorporated into the plant design if required although it is not necessary for normal plant operation.

The various optional types of gas which can be produced are summarized in Table 1. Table 2 shows the Btu content and overall process thermal efficiency for the various types of gas. Table 3 shows the typical range of gas compositions for a hot detarred gas.

TABLE 1

PRODUCT GAS TYPES

Gas Type	Temperature of Product Gas, °F	Heat Values Removed From the Gas
Hot Raw Gas	750	Base Case
Hot Detarred Gas	750	Some Tar
Cold Clean Gas	100	Tar, Oils, Sensible Heat
Cold Clean Desulfurized Gas	100	Tar, Oils, Sensible Heat Suflur

TABLE 2

COMPARISON OF PROCESSES

Type Gas	Process Thermal Efficiency	Approximate Btu of Product Gas
Hot Raw Gas	85-93%	186-207
Hot Detarred Gas	77-87%*	175-195
Cold Clean Gas	69-76%	160-175

* Excluding tar-oil production

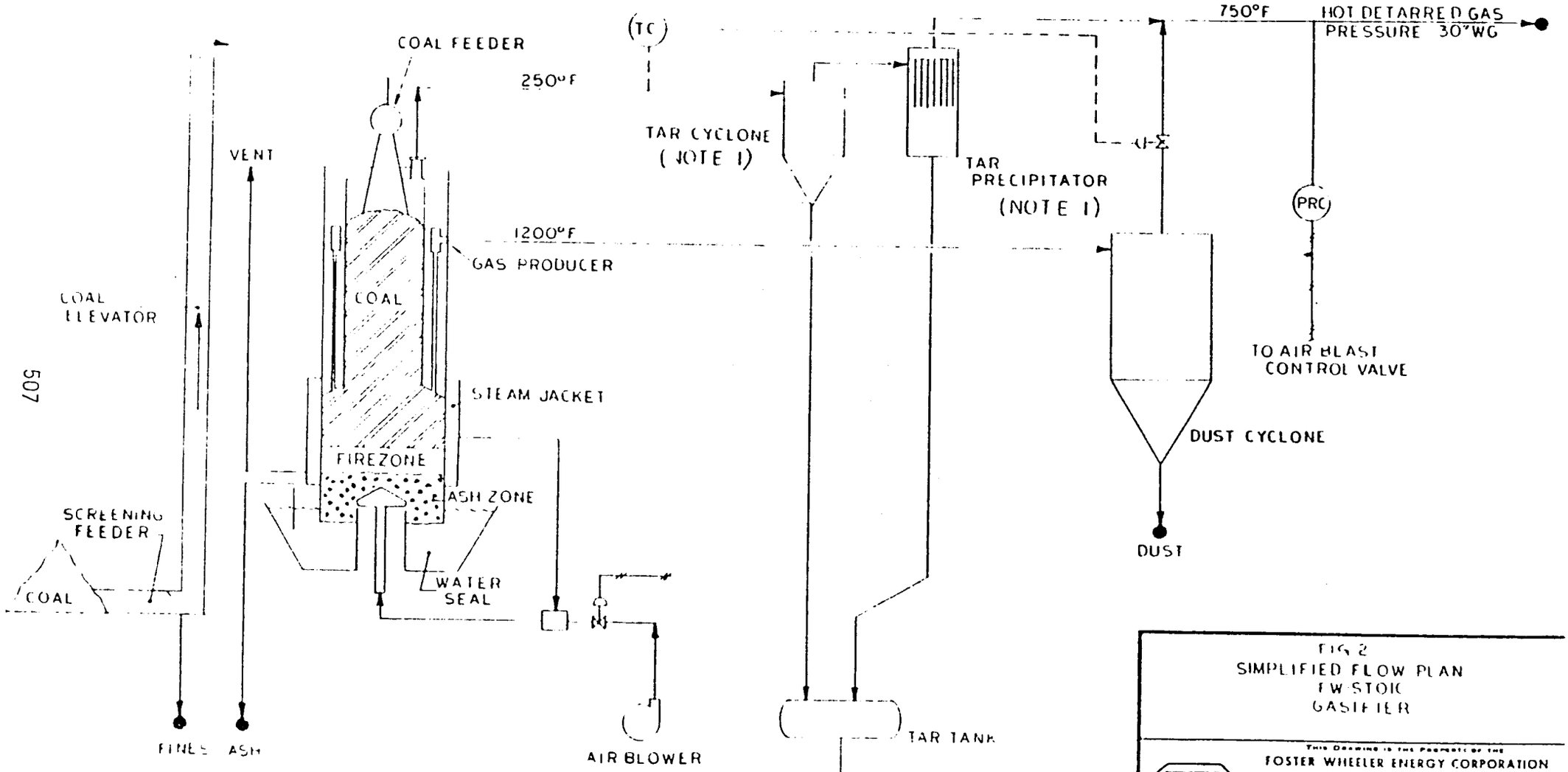
TABLE 3

APPROXIMATE ANALYSIS

HOT RAW GAS*

Component	Volume %
H_2	14.0-16.0
CH_4	2.6-3.0
CO	29.0-30.0
CO_2	3.0-4.0
N_2	47.6-51.4

* excludes light oil and tar-oil content



NOTE 1 - FOR HOT RAW GAS PRODUCTION, ONLY TAR CYCLONE IS REQUIRED. FOR HOT DETARRED GAS PRODUCTION, BOTH TAR CYCLONE & TAR PRECIPITATOR IS REQUIRED.

FIG 2
SIMPLIFIED FLOW PLAN
FW-STOIC
GASIFIER

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TABLE 4

ANALYSIS OF TYPICAL TAR-OIL

Physical Properties

Specific Gravity	1.0855
Viscosity, Centistokes, 122°F	555.4
" , 210°F	21.35
Pour Point, °F	80
Flash Point, C.O.C., °F	315
Higher heating value, Btu/gal	148,265

Chemical Composition

Component	%
Carbon	85.92
Hydrogen	7.92
Oxygen	4.18
Nitrogen	1.05
Sulfur	0.22
Ash	0.11
Moisture	0.60
Total	100.00

GENERAL DISCUSSION

The FW-Stoic Gasifiers are designed for four sizes: 12'6", 10'0", 8'6" and 6'6" I.D. The capacities and nominal coal feed rates for these gasifiers are given in Table 5. The nominal coal feed rates are based on a coal having a btu content of about 12,000 btu/lb with the gasifier producing hot detarred gas. It is feasible to manifold any number of gasifiers together in one production facility.

The FW-Stoic gasifier is very simple, and compact requiring only limited equipment and control instrumentation. A 10' gasifier module can be erected on a plot 25 ft wide by 30 ft long for a structure about 80 ft high. To insure reliability the coal elevators, drum feeders, and air blowers may be spared.

When the gasifier is operating at capacity, its coal holdup is 8 hours. System response to an increase or decrease in fuel demand is relatively fast. In manufacturing operations it has not been necessary to use an intermediate gas holder.

Each individual gasifier has a turndown ratio of about 5 to 1. A gasifier is easily put on standby. In this case the necessary

air for maintaining the large mass of gasifier refractory and carbonaceous contents at temperature is furnished by natural draft. Turn down can be substantially increased in the case of manifolded gasifiers.

The product gas is normally produced at a pressure of 30" W.G. but can be compressed to a higher pressure if necessary. Water consumption - a major problem in large gas plants - is low for the FW-Stoic Gasifier. A 10ft gasifier, operating at capacity and making hot detarred gas, for example, consumes about 300 gal/hr of water.

For the "hot raw gas" and "hot detarred gas" operations there are no aqueous effluents requiring treatment or dust produced in the system.

For the cold clean gas operation the effluent streams would consist of an oil stream, which can be recovered and utilized as fuel, phenolic water and quench blowdown.

The flow rates for the phenolic water and quench blowdown streams are very small; it is likely these two streams can be fed to existing plant treatment facilities.

GENERAL DISCUSSION - (CONT'D)

The FW-Stoic gasifier, in its present form is suitable for operation on western sub-bituminous or anthracite coal.

TABLE 5

AVAILABLE SIZES

OF

FW-STOIC GASIFIERS

Diameter of Gasifier	MM Btu/hr, Maximum	B Btu/day, Maximum	Approximate Coal Rate T/hr
6'6"	22.5	.54	1.3
8'6"	40	.96	2.2
10'	60	1.44	3.0
12'6"	90	2.16	4.5

Foster Wheeler Coal Water Fuels

Foster Wheeler, in maintaining its position at the forefront of combustion technology, has been investigating the potential of Coal Water Fuels (CWF) and regard this development in fuel technology as an important step in the World's search for an alternative to reduce fuel oil dependence.

By mixing a pulverised coal with water and a small proportion of suitable additive it is possible to produce a stable mixture which is fluid at room temperature and can be transported, stored, pumped and burnt like fuel oil. A further advantage is that a stage can be incorporated in the preparation process which, providing the parent coal is suitable, can reduce the ash and sulphur content to low levels, thus making it more environmentally acceptable.

Foster Wheeler's activities and experience over the years make it one of the World leaders in this field:

1. Through association with the developers of a CWF preparation process, we are capable of building an operating plant for the manufacture of CWF.
2. Economic evaluations have been carried out for the manufacture and supply of CWF and boiler conversion to utilise CWF. This base provides the data to enable us to evaluate the potential benefits of conversion to CWF. From inputs such as boiler specification, location and environmental constraints suitable parent coals may be selected, the cost and properties of CWF determined, cost of conversion estimated, the location of CWF preparation plant optimised and economic factors such as payback and return of an investment derived.
3. Forney International (a member of the Foster Wheeler organisation) have developed a burner for firing CWF which has been extensively tested in a flame tunnel. A commercial system has now been installed in a utility boiler for demonstration firing trials.
4. Studies to evaluate the potential for the conversion of industrial and utility oil fired boilers have been carried out with consideration of engineering details as well as economics.
5. Data obtained from current and future boiler plant firing trials will enable the design parameters for purpose designed boilers firing CWF to be optimised.
6. Test facilities have been built for the evaluation of CWF produced from different parent coals.

The above summarises Foster Wheeler's current experience in Coal Water Fuel technology. For further information contact:

FOSTER WHEELER POWER PRODUCTS LTD.
P.O. Box 160, Greater London House, Hampstead Road, London NW1 7QN
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APPENDIX C

INDIAN BIOMASS CONVERSION EXPERIENCE

R. C. MAHESHWARI

SUMMARY AND CONCLUSIONS OF THE REPORT ON ENERGY CENSUS AND RESOURCE ASSESSMENT OF VILLAGE ISLAMNAGAR IN THE DISTRICT OF BHOPAL

BY

R.C. Maheshwari

P.K. Srivastava

C.P. Bohra

S.S. Tomar

B.P. Nema

OCTOBER, 1981

ELECTRO-MECHANICAL ENGINEERING DIVISION

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SUMMARY AND CONCLUSIONS

Presented in this report (Part I) are the results of a survey for assessment of resource availability and total energy needs of a village considering it as a whole ecosystem. Self-sufficiency with regard to food, fodder and fuels has been assessed. The present utilization pattern as well as potential of plant, animal and human biomass for preservation of ecological balance in the village biosphere has been determined. Also the extent of solar energy harvested in the form of agricultural and forestry products and its future potential has been estimated. This report will be the basis of developing a model of rural energy supply system which is being worked out by matching the energy needs(arranged according to priority) with the best feasible technological option considering the economics and energy conversion efficiencies and shall be presented in Part II of this report.

The general information of Islamnagar village is given in Appendix I. A proforma questionnaire (Appendix II) was prepared to assess the resource availability and energy needs of the village community for various farm operations, transport, post-harvest operations, animal raising and domestic/household activities. The methodology adopted for achieving the objectives (listed in Chapter I) is described in Chapter II. The observations on the resource availability and consumption in the village community for various activities have been collected and presented in Chapter III. Certain energy constants were developed; which are enumerated in Chapter IV. Chapter V presents the results and discussion with respect to self-sufficiency with regard to food, fodder, firewood and dung and also energy needs for various activities. The extent of solar energy harvested in the form of agricultural and forestry products is analysed in Chapter VI. In order to study the energy consumption

patterns in other regions of the country, the results of the present energy census have been compared with that of ASTRA, Indian Institute of Science, Bangalore and Punjab Agricultural Univeristy, Ludhiana and the discussion has been presented in Chapter VII.

A. The following are the salient features of the village Islamnagar :

1. The village has 224 households with a total population of 1529 consisting of 31.5 % male, 25.8 % female, 42.7 % children (below 14 years).

2. Landless constitute 36.56 %, marginal 15.83 %, small 11.18 % medium 11.58 % and large farmers 24.85 percent of the population. Out of large farmers, 30 percent have tractor operated farms (TOF) and 70 percent bullock operated farms (BOF).

3. The total livestock population is 1436, out of which 1100 are cattles, 241 goats and sheep and 83 poultry birds. The draught animals constitute 16.2 percent. It is interesting to note that man and animal co-exist in the village ecosystem in the ratio of about 1 : 1.

4. The village ecosystem is currently bearing a population density of 3.78 persons/ha of cropped land which is slightly higher than its theoretical carrying capacity with respect to the major cereals like wheat and paddy.

5. Human to draught animal pair ratio is about 12 : 1 and DAP density as 0.32 DAP/ha of cropped land.

6. Forest and pasture(waste) land constitute 8.6 and 18.6 percent of the total ecosystem or 15.2 and 48.0 percent of the total cultivated land which constitute 56.1 percent of the total ecosystem surveyed.

7. Thirty one percent of households under marginal farmers own only about 6 percent of the land, while one-fourth households having large farms own 67 percent of the land.

8. About 48.6 percent of the total cropped area is under irrigation and 51.4 percent is rainfed.

9. Largest number (25 %) of hand tools is possessed by landless, followed by marginal and large (BOF) farmers (20 %)

10. Rabi is the major sowing season accounting for 78.6 percent of the cropped area and only 21.4 percent is sown under kharif crop. During rabi, about 86.3 percent of the area is under wheat. In kharif season, paddy is themajor crop which is sown over 38.7 percent of the area.

11. Chemical fertilizer use per hectare of cropped land on an average is 14 kg of Nitrogen, 3 kg of P_2O_5 and 0.9 kg K_2O while that of Farm Yard Manure is 12.5 quintals/hectare.

12. The village is self-sufficient with regard to cereals, vegetables sugarcane and milk production. The village is surplus in cereals (41 %), vegetables (110 %), Sugarcane (4.2 %) and milk (290 %). However, thevillage is in deficient in pulse and oil seed production by 32 and 71 percent, respectively.

13. The shortfall in animal feed is estimated to be 29.05 percent, taking into consideration total number of animals, production of fodder, grasses and crop residue(suitable for cattle feed) and the standard feed requirement as per the body weight of animals.

14. The shortage of fuelfood in thevillage ecosystem is of the order of 20 percent taking into consideration fuelwood consumption for cooking and for wooden tools and availability from the forest and trees owned by the farmers. Felling and collection of tree leaves couldnot be taken into consideration.

15. Composting for farm yard manure (FYM) and making of dung cakes for cooking account for 32.2 and 42.3 percent, respectively,

of the total animal dung production (dry basis) in the village. The remaining 27.8 percent of dung is presumed to be excreted by the animals in the field while grazing. A total of 60 percent of animal and 6.2 percent of crop residue is recycled back to the soil (Roots of plants left in the soil are not included).

16. Energy for crop production is provided by human (1.21 %), animal (4.21 %), diesel (19.26 %), electricity (6.57 %), seed (33. 61 %), fertilizer (19.85 %), machinery (15. 29 %).

17. Tractor operated farms (TOF) consume 52.14 % energy while bullock operated farms (BOF) consume only 47.86 %. Energy input/ha on BOF and TOF is 996.28 x 10^3 kcal and 2367.13 x 10^3 kcal, respectively. Output/input ratios for the two farming systems are 18.01 on BOF and 9.57 on TOF with an overall ratio of 13.72. Fig. 1 illustrates the energy use versus population under various categories of farmers while Fig. 2 illustrates the effect of energy input on yield under various categories of farms.

18. In post-harvest operations, milling operation consumes the maximum energy (44.15 %) followed by transport and handling (41.35 %), manufacture of milling machinery (13.4 %), and drying and storage (1 %). Fig. 3 illustrates the energy mix for post-harvest operations, i.e , human energy (3.13 %), animal energy (4.67 %), electrical (43.82 %) and diesel (34.89 %). The energy required for manufacture of milling machinery is listed under 'others' (13.4%).

19. Energy required per quintal of grain milling for wheat, paddy, sorghum, maize and gram are 4306, 3690, 6459, 8611 and 5382 kcal, respectively.

20. Out of the total energy consumed for animal raising, 56.12 % is provided by human energy, 35.26 % by animal energy and only

3.43 % from diesel. The animal raising activity required almost 2.6 times more-man-hours than that required for crop raising. Fig. 4 illustrates the energy required for various activities for animal raising. Fig. 5 depicts the energy flow in the village ecosystem for animal raising and utilization of animal output both in terms of work and by-products.

21. Per capita consumption of various domestic fuels is 3.10 q of firewood, 3.20 q of dung cakes, 5.10 litres of kerosene and 21.26 kWh of electricity.

22. The annual per capita requirement of energy for domestic activities is 2.10×10^6 kcal, out of which the share of firewood alone is 59.14 % followed by 37.20 % from dung cakes. Fig. 6 illustrates the source-wise energy use for domestic activities.

23. The average per capita human energy requirement for domestic activities is about 425 man-hrs where as 398 man-hrs/ha for crop production and 312 man-hrs/cattle for animal raising are required.

24. Two-third of animal pair-hrs are used for crop production and a little less than one-third for animal raising activity. Fig. 7 illustrates the activitywise utilisation of various energy sources.

25. Ninety-two percent of diesel and fifty percent of electricity in thevillage are used for agricultural operations for crop raising. Firewood, dung and kerosene are used for domestic activities only.

26. The survey reveals that out of the total energy consumed in the village; about 33.76 percent is used for domestic activities such as cooking, fetching water, gathering firewood, washing and cleaning etc; 10.25 percent for inputs for agriculture like seed, fertilizer and machinery; 4.66 percent for farm

operations for raising crops; 0.49 percent for post-harvest operations; and 0.34 percent for cattle raising (Fig. 7).

27. About 30.69 percent of energy in the village ecosystem comes from non-commercial (renewable) sources of energy, 16.97 percent from commercial energy and 2.34 percent from animate (human and animal) energy sources.

28. Fig. 8 illustrates the energy use patterns of different categories of farmers for the four major activities. For domestic activities (mostly cooking) alone, landless use 98 % of total energy, marginal (90 %), small (87 %), medium (82 %), Large BOF (80 %) and large TOF (42 %).

29. The largest population of 36.56 % constituting landless labour account for the largest share of total energy consumption (29.44 %) which is largely for cooking purposes. Fig. 9 illustrates the total energy use by different segments of the society.

30. Fig. 10 illustrates the total energy and material flow in the village ecosystem at a glance. Fig. 11 depicts the utlization of solar energy and its flow in the village ecosystem through various stages.

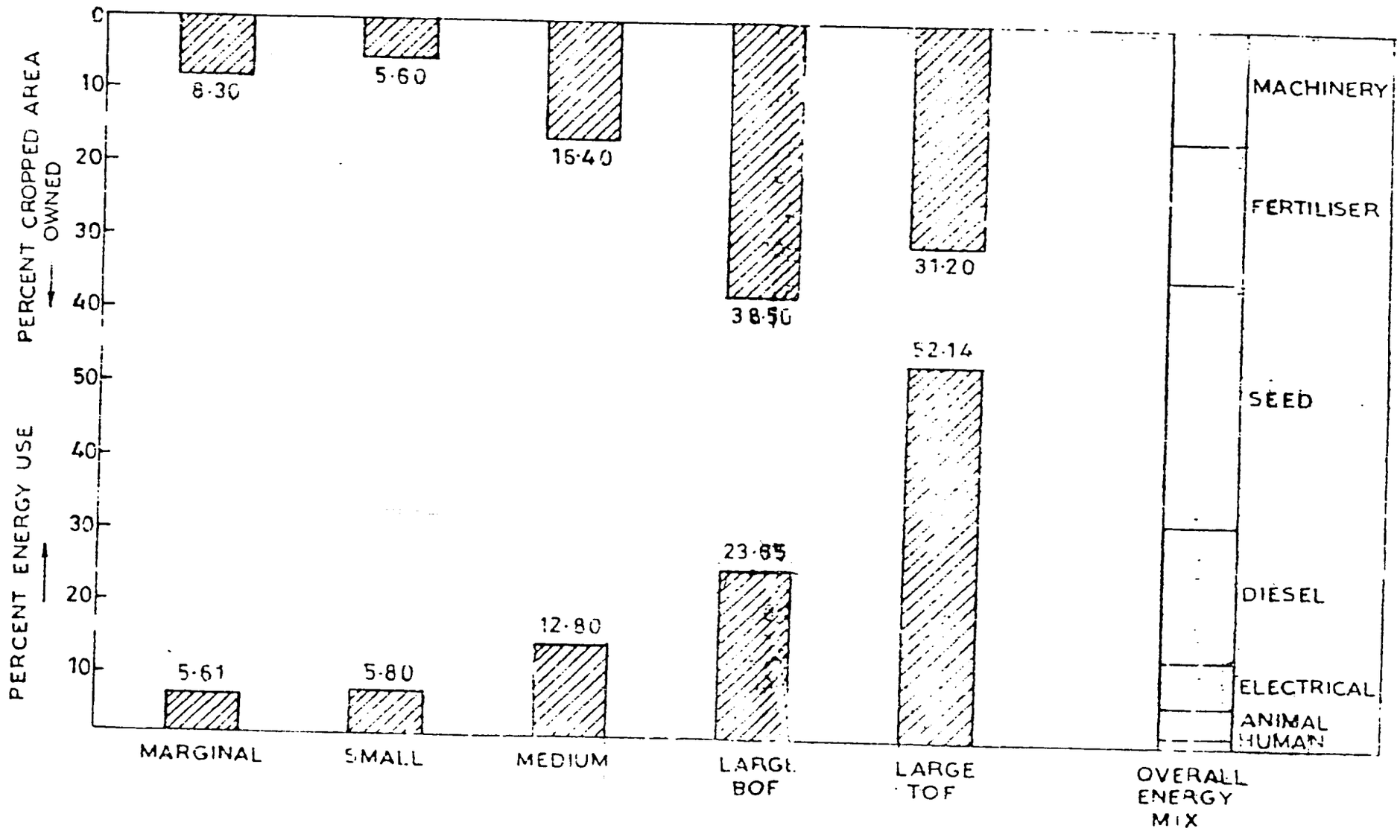


FIG 1 ENERGY USE IN CROP PRODUCTION BY VARIOUS CATEGORIES OF FARMERS

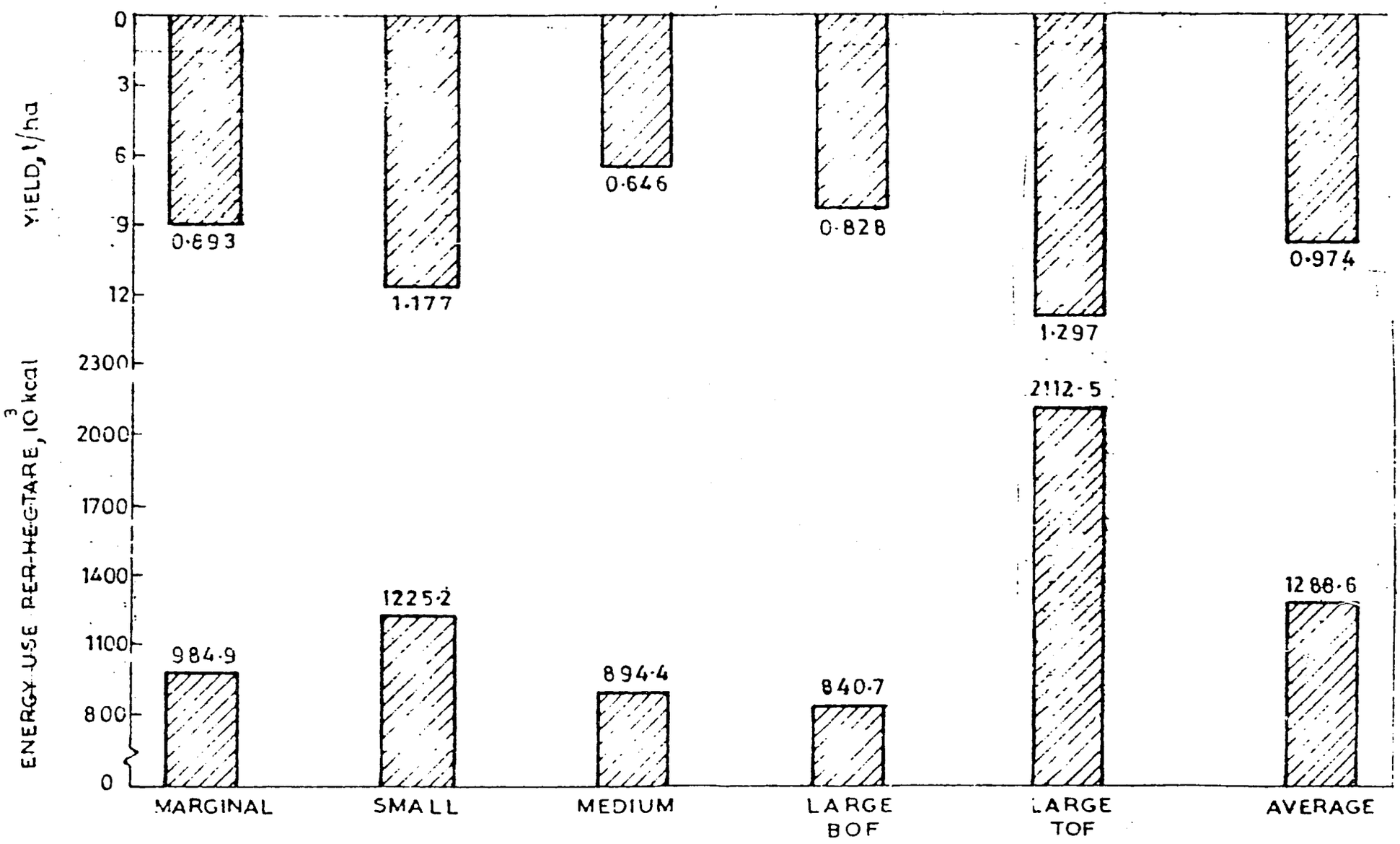


FIG EFFECT OF ENERGY INPUT ON YIELD UNDER VARIOUS FARMING SYSTEMS.

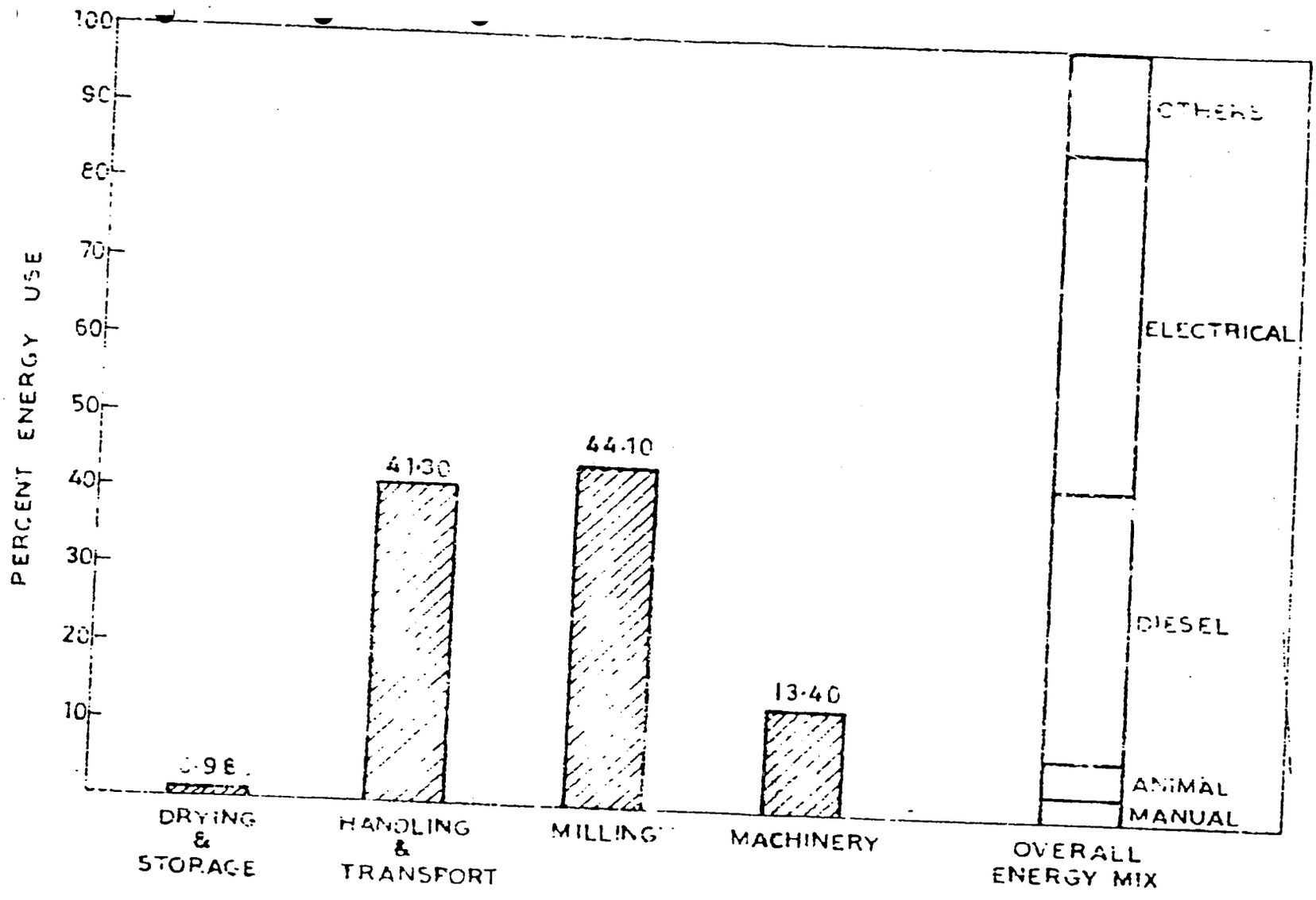


FIG .3 ENERGY USE FOR POST-HARVEST OPERATIONS

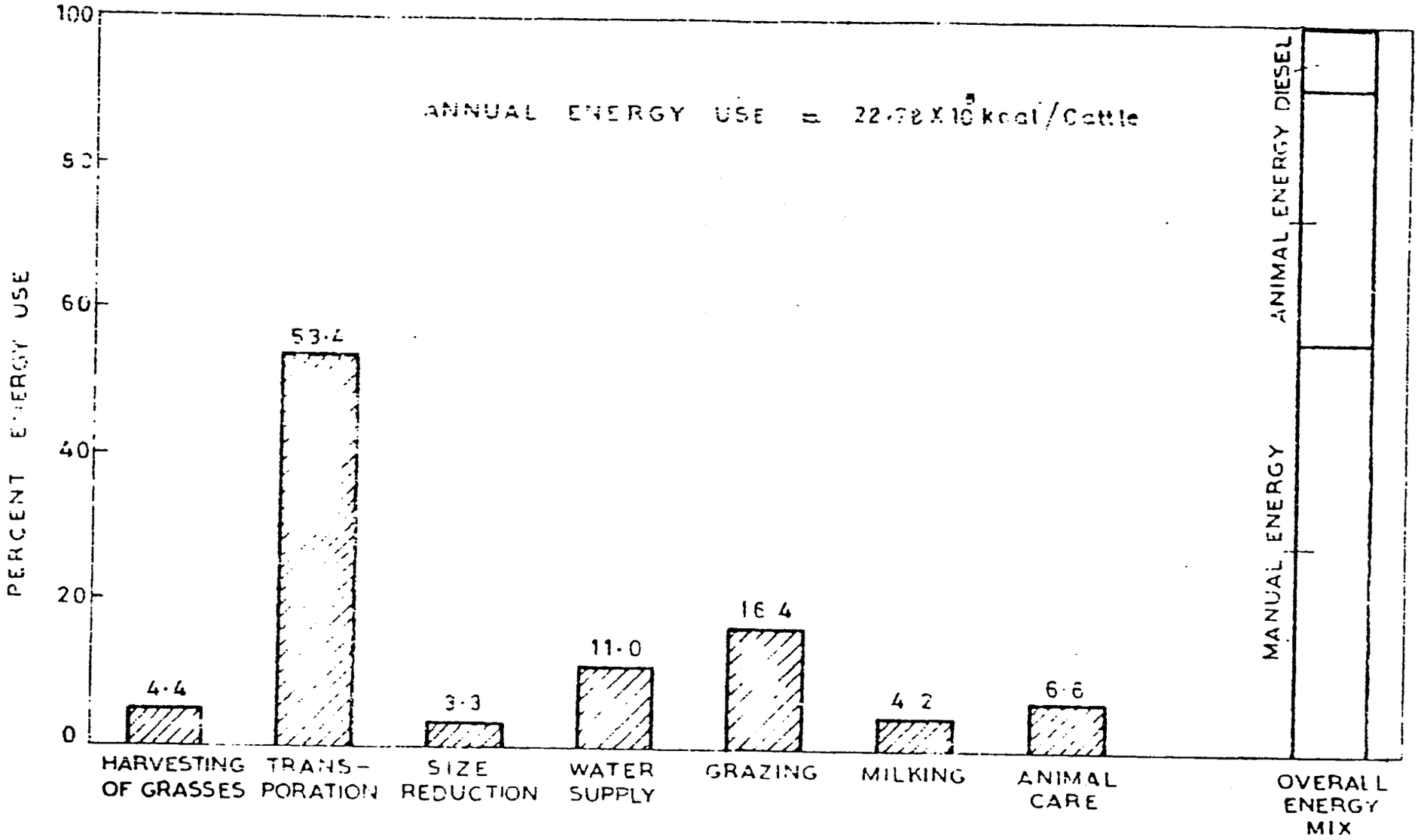


FIG .4 ENERGY USE FOR ANIMAL RAISING

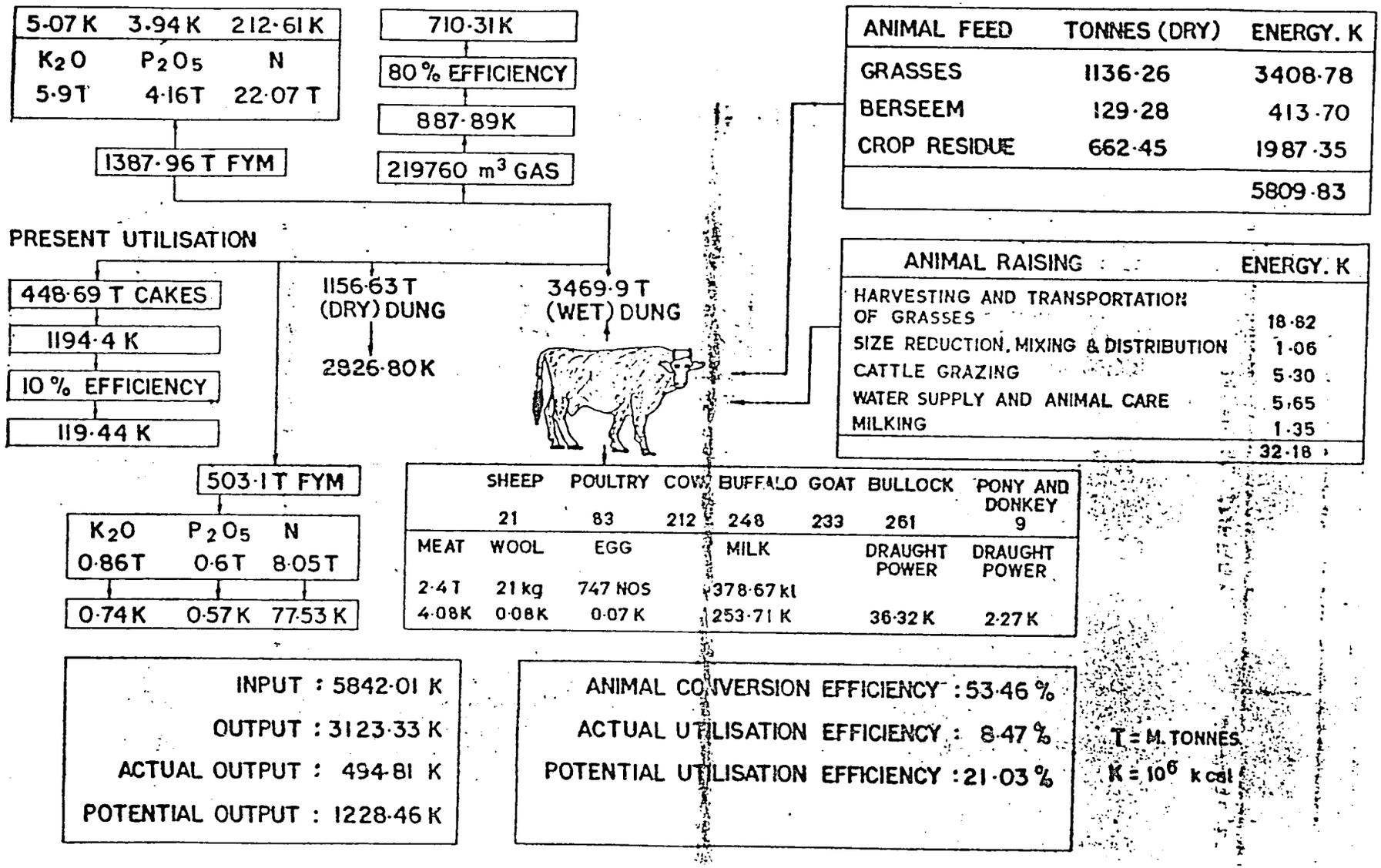


FIG. 5·5 ANNUAL ENERGY FLOW IN ANIMAL RAISING

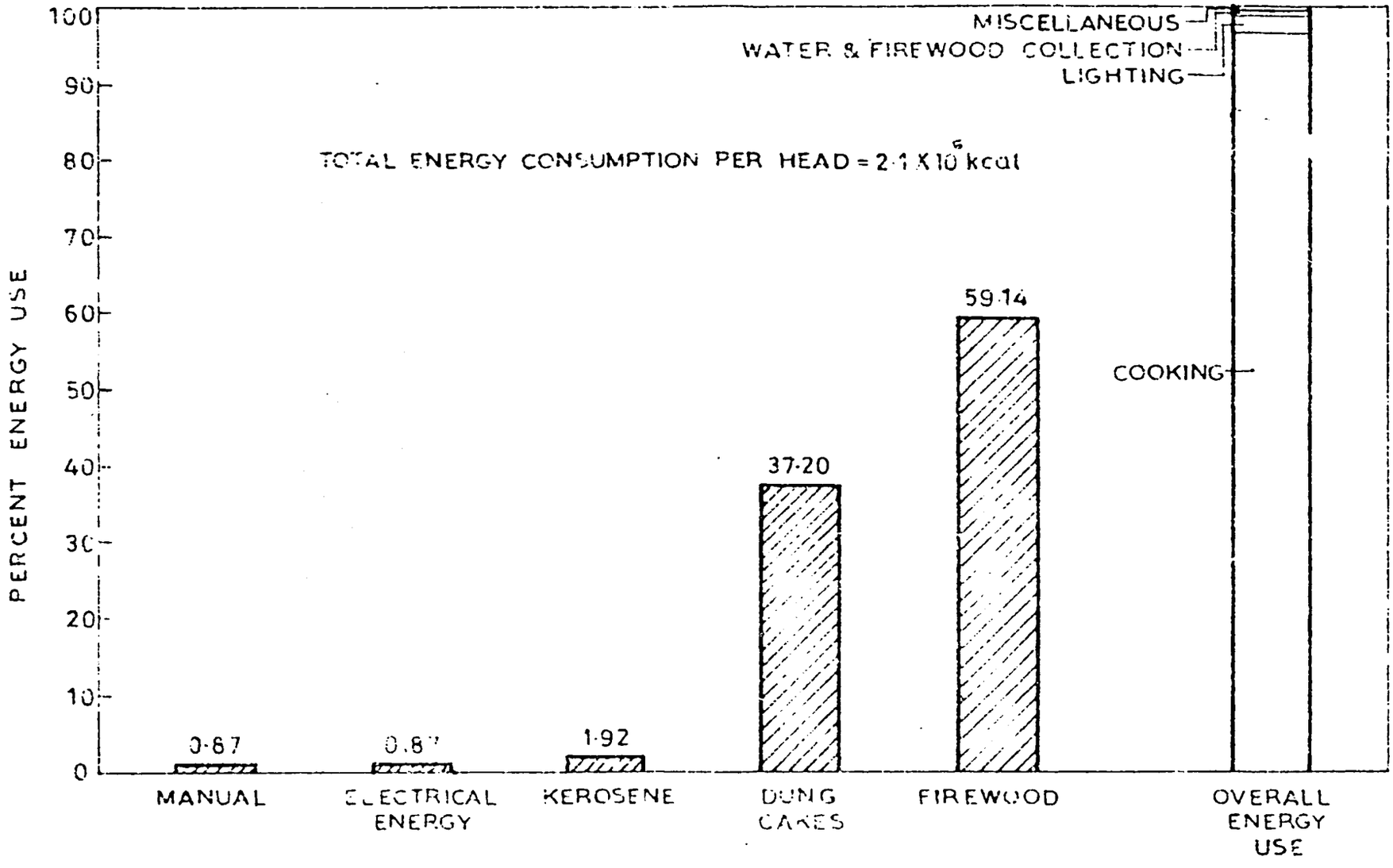


FIG. 6 ANNUAL ENERGY USE FOR HOUSEHOLD ACTIVITIES

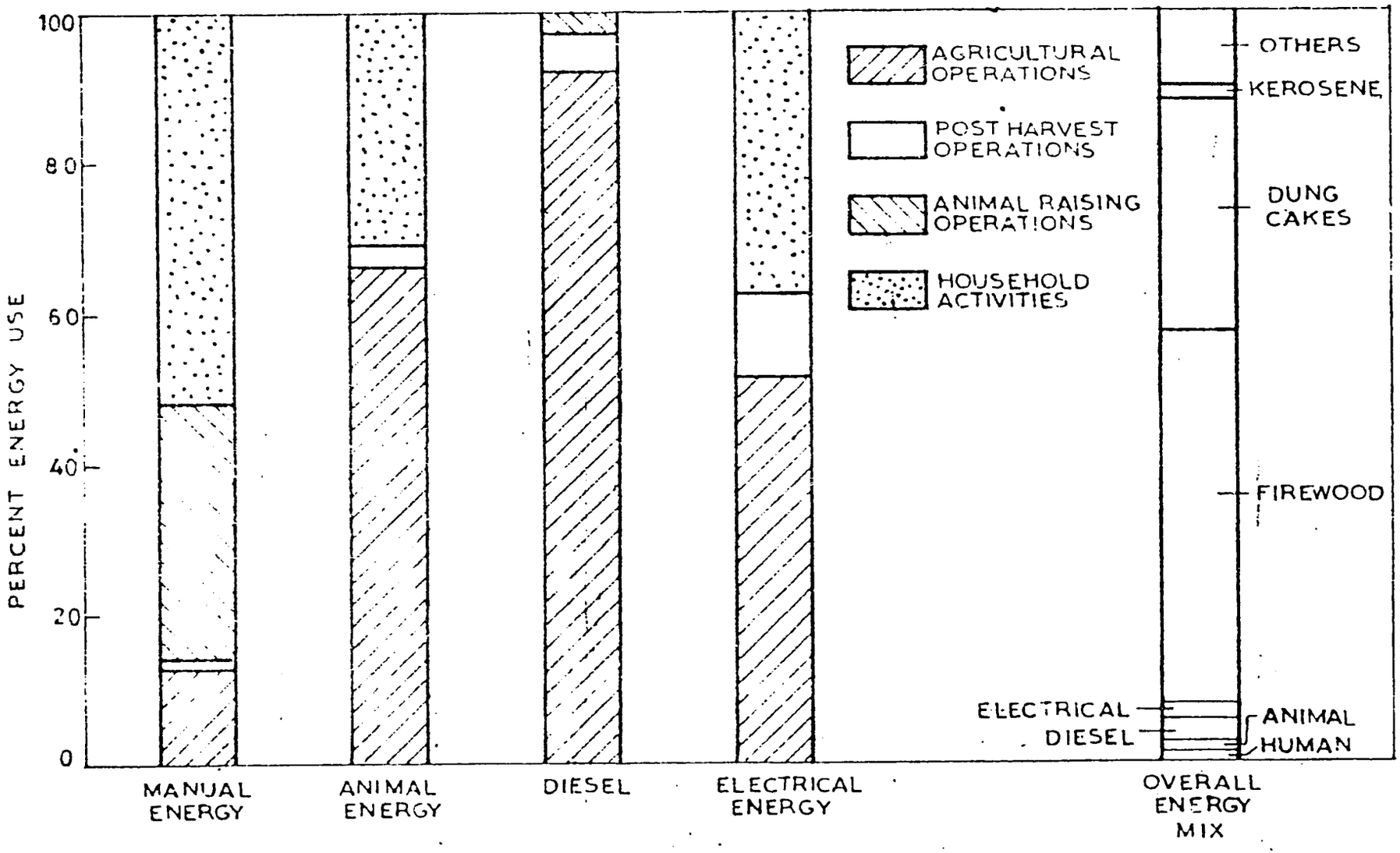


FIG. 7 ENERGY UTILISATION IN THE VILLAGE ECOSYSTEM

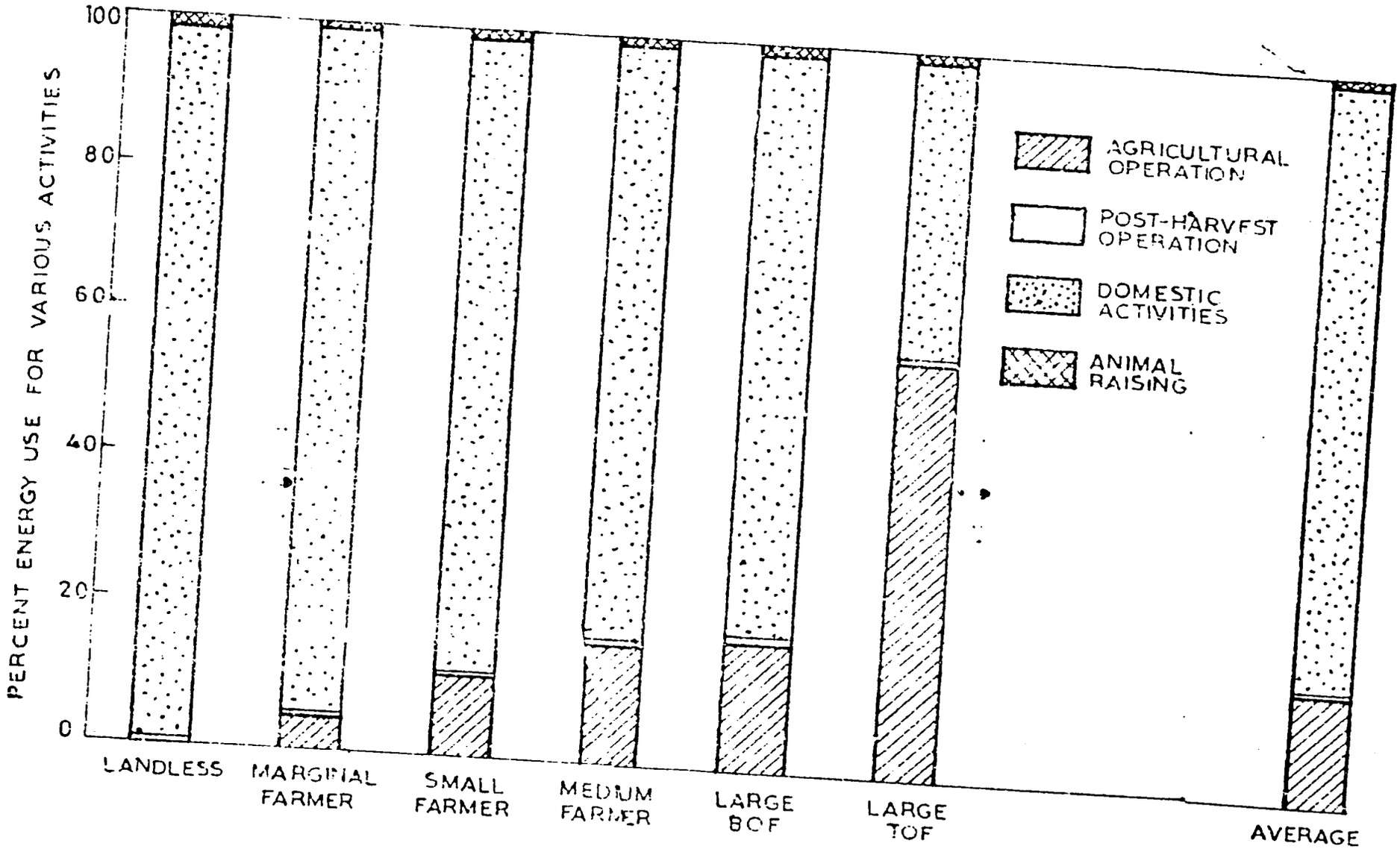


FIG. 68 ENERGY USE PATTERN OF VARIOUS CATEGORIES OF FARMERS

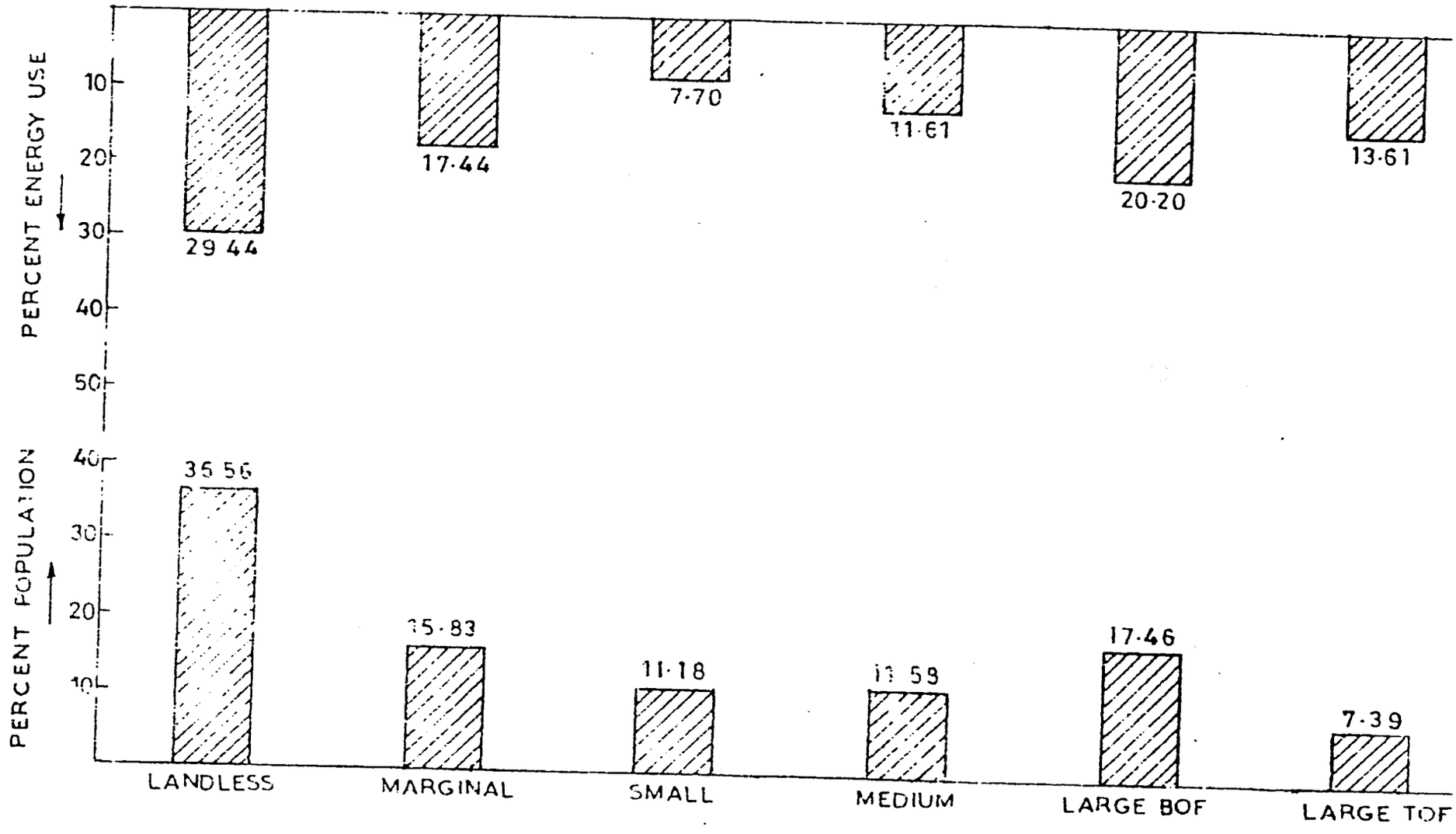
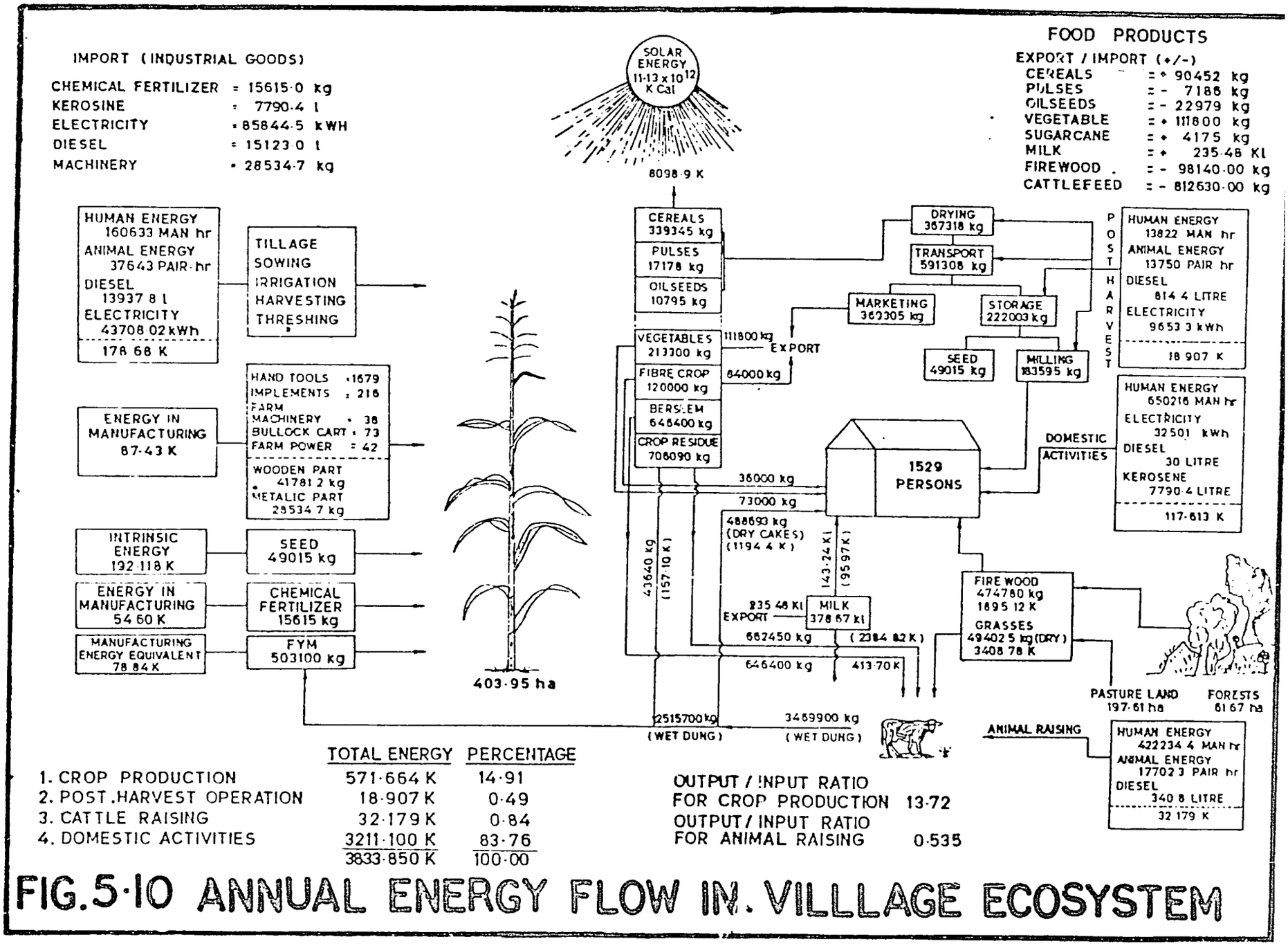


FIG 9 ENERGY USE VERSUS POPULATION OF VARIOUS CATEGORIES OF FARMERS



	TOTAL ENERGY	PERCENTAGE
1. CROP PRODUCTION	571·664 K	14·91
2. POST.HARVEST OPERATION	18·907 K	0·49
3. CATTLE RAISING	32·179 K	0·84
4. DOMESTIC ACTIVITIES	3211·100 K	83·76
	3833·850 K	100·00

OUTPUT / INPUT RATIO FOR CROP PRODUCTION 13·72

OUTPUT / INPUT RATIO FOR ANIMAL RAISING 0·535

FIG.5·10 ANNUAL ENERGY FLOW IN. VILLLAGE ECOSYSTEM

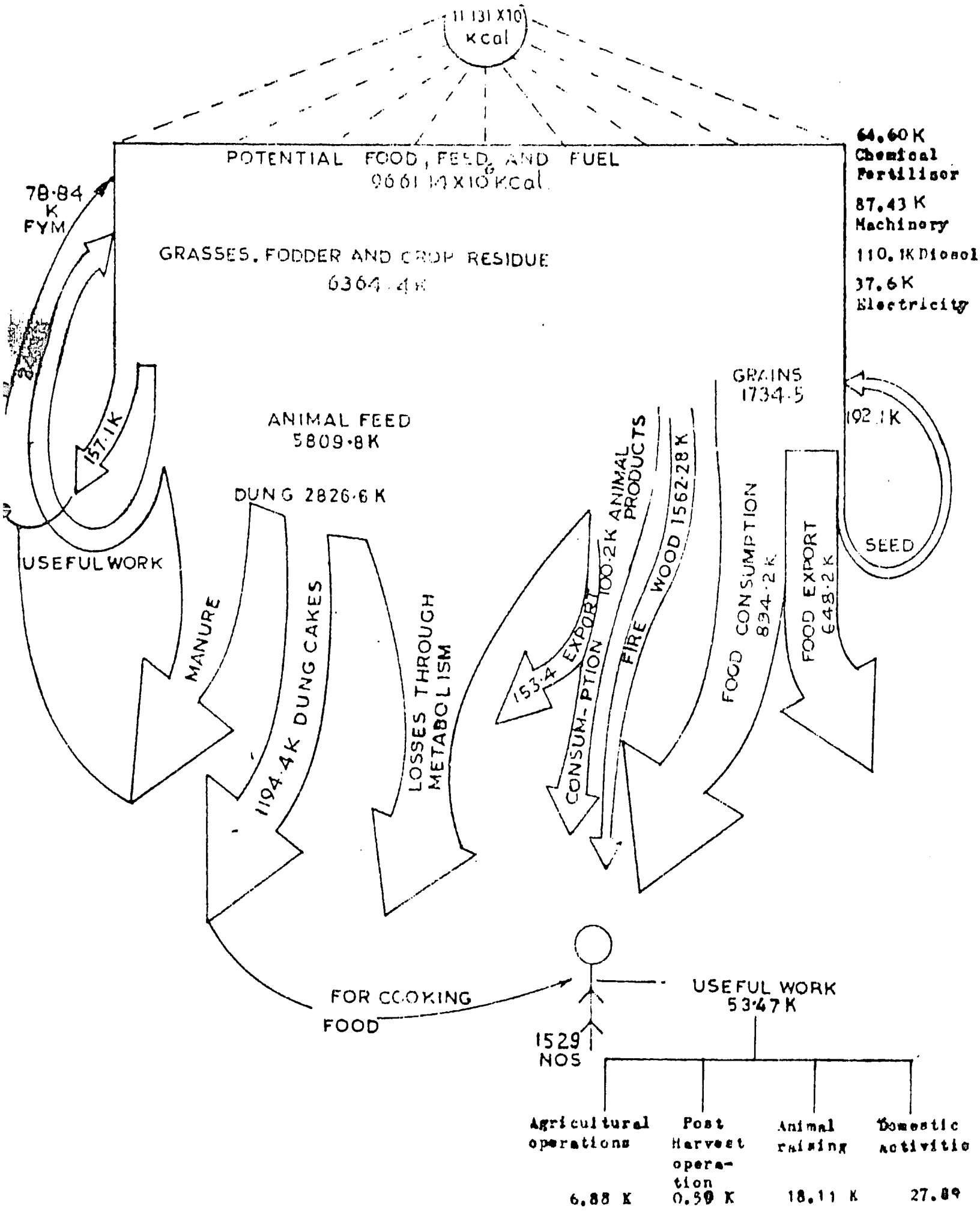


FIG 6·2 SANKEY DIA ILLUSTRATING SOLAR ENERGY FLOW IN THE VILLAGE ECOSYSTEM

ENERGY RESOURCES

Efficient Use of Agricultural Wastes for Energy Production

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Introduction

Agricultural wastes like rice husk, groundnut shells, paddy straw, cotton sticks, etc., represent some of the most renewable agricultural-based fuel materials in the world. India produces about 14 million m.t. of rice husk, 150 million m.t. of paddy straw and 2 million m.t. of groundnut shells. The other agricultural wastes, such as cotton sticks, corn cobs, bagasse, etc., represent a huge amount of offal. It is estimated, that this may represent an energy source equivalent to about 24 million m.t. of coal every year, worth 465 crores of rupees.

Rice husk and other agricultural wastes are efficient fuel for drying purposes of all types. The modern rice processing industry requires heat energy for mechanical drying of raw or parboiled paddy and for generating steam which can be used for parboiling process and for power generation to operate rice mills.

Unprecedented world energy crisis triggered by the continued rise in oil price has changed the aspect of global economic balance and has driven the non-oil producing countries to seek alternative sources of energy. In consequence, the status of rice husk has undergone a change from a disposal nuisance to that of an important raw material. To illustrate its value in today's economy 3 kg of rice husk equal to 1 kg of fuel oil.

In order to exploit the potential benefits of this value, the authors undertook the present study on utilizing energy from agricultural wastes.

Acknowledgement: The authors are very much thankful to Messrs. P.K. Jana, J.K. Chatterjee, P.C. Singha and S.C. Sarkar for their help in fabrication, erection and testing of these experimental units.

Chemical Composition of Rice Husk and Groundnut Shell

The chemical composition of rice husk and groundnut shell is necessary for the computation of air requirements and the volume of products of combustion which, in turn, determines the size of blowers. The sensible heat carried away by the flue gases at different temperatures may be obtained from the nomographs based on the chemical composition. Similarly,

Table 1. Composition of Rice Husk and Groundnut Shell

Component	Molecular Weight	Rice Husk		Groundnut Shell	
		wt. in kg	mole	wt. in kg	mole
Carbon	12	39.26	3.271	45.92	3.826
Hydrogen	2	4.99	2.495	5.37	2.685
Oxygen	32	32.70	1.022	36.31	1.134
Nitrogen	28	1.99	0.071	1.09	0.0389
Sulphur	32	0.10	0.003	0.11	0.0034
Moisture	18	3.56	0.198	7.30	0.4055
Ash		17.40		3.90	

the Ostwald charts for assessing the state of combustion, i.e., the excess or deficiency of air during combustion, are based on the chemical composition.

Ultimate analysis gives the chemical constituents which take part in combustion, i.e., total carbon, hydrogen, nitrogen, sulphur and oxygen. The total carbon includes both the fixed carbon and the carbon in volatile matter. All this carbon appears in the products of combustion as carbon dioxide when the fuel is completely burnt. The chemical compositions of rice husk and groundnut shell are given in Table 1.

Tables 2 and 3 illustrate the theoretical computation of requirement and products of complete combustion of rice husk and groundnut shell. The calculations are based on chemical reaction of different constituents with oxygen during the combustion process. The minus sign in Table 2 indicates the oxygen present in the fuel which reduces the total air requirement for combustion. Thus, combustion of 1 kg of husk requires 4.807 kg of air (3.733 m^3) and yields 5.632 kg (4.302 m^3) of products of combustion. Tables 4 and 5 illustrate the material balance for complete combustion of 100 kg of husk and groundnut shell, respectively.

Table 6 gives the chemical composition of various kinds of fuel.

Table 2. Determination of Theoretical Air Requirement and Products of Complete Combusiton, 100 kg Rice Husk.

Component	Mole	Requirement Mole		Produced Mole			
		O_2	N_2	CO_2	H_2O	SO_2	N_2
C	3.271	3.271	12.3095	3.271	–	–	–
H_2	2.495	1.248	4.6949	-	2.495	–	–
O_2	1.022	- 1.022	- 3.8447	–	–	–	–
N_2	0.071		–		-	–	0.071 +13.167
S	0.0031	0.003	0.0113		–	0.0031	
H_2O	0.193		-	-	0.198	–	
Total		3.500	13.167	3.271	2.693	0.0031	13.238

Air required
= 3.5 × 32 + 13.167 × 28 = 480.7 kg of air/100 kg of husk = 373.3 m^3/100 kg of husk
Total quantity of combustion products
= 3.271 + 2.693 + 0.0031 + 13.238 = 19.2051 mole/100 kg of husk
Hence, total volume
= 19.2051 × 22.4 ÷ 100 = 4.3018 m^3/kg of husk
By multiplying their molecular weight, the total weight of these gases
= 143.924 + 48.470 + 370.664 + 0.1984 = 563.2564/100 kg of husk
Thus the specific weight of flue gases
= 563.2564/430.18 = 1.3093 kg/m^3 = 1.31 kg/m^3

Table 3. Theoretical Air Requirement and Products of Complete Combustion, 100 kg Groundnut Shell

Component	Mole	Requirement Mole		Produced Mole			
		O_2	N_2	CO_2	H_2O	SO_2	N_2
C	3.826	3.826	14.3857	3.826		–	
H_2	2.685	1.342	5.0459		2.685	-	
O_2	1.134	1.134	4.2633		-	–	
N_2	0.0389					-	0.0389 +15.1305
S	0.0034	0.0034	0.0127			0.0034	
H_2O	0.4055	–	–	-	0.4055	–	-
Total		4.0374	15.1805	3.826	3.0905	0.0034	15.2194

Air required
= 4.0374 × 32 + 15.1805 × 28 = 554.25 kg of air/100 kg of groundnut shell = 5.542 kg/kg of shell = 4.303 m^3/kg of shell
Total quantity of combustion products
= 3.826 + 3.0905 + 0.0034 + 15.2194 = 22.1393 mol/100 kg of grundnut shell
Hence, the total volume
= 22.1383 × 22.4/100 = 4.9613 m^3/kg
By multiplying the molecular weight, the total weight of these gases
= 168.388 + 525.409 + 0.2176 + 55.620 = 749.59 kg/100 kg of groundnut shell
Thus, the specific weight of flue gases
= 749.59/496.13 = 1.5108 kg/m^3

Ostwald Charts

The modified Ostwald charts were prepared for rice husk and groundnut shells for use on furnace test. Figs. 1 and 2 illustrate the Ostwald charts for rice husk and groundnut shell. This chart allows a very close estimate of the excess air from a flue gas analysis for carbon dioxide and oxygen.

Table 4. Materail Balance for Complete Combustion, 100 kg Rice Husk

Input		Output	
Husk containing	Air:		
C = 39,260	O_2 = 112.000	CO_2 = 143.926	
H_2 = 4.990	N_2 = 368.676	N_2 = 370.664	
O_2 = 32.700		H_2O = 48.470	
N_2 = 1.990		SO_2 = 0.198	
S = 0.100		Ash = 17.400	
H_2O = 3.560			
Ash = 17.400			
Total = 580.676 (Husk + Air)		580.648	

Table 5. Material Balance for Complete Combustion, 100 kg Groundnut Shell

Input		Output	
Shell Containing			
C = 45.92	O_2 = 129.21	CO_2 = 168.344	
H_2 = 5.37	N_2 = 425.32	N_2 = 425.409	
O_2 = 36.31		SO_2 = 0.2176	
N_2 = 1.09		H_2O = 55.620	
S = 0.11		Ash = 3.90	
H_2O = 7.30			
Ash = 3.90			
Total = 654.53 (Shell + Air)		653.49	

Table 6. Chemical Composition of Various Kinds of Fuel

Fuel	C	Percent by Weight				Ash	Moisture Content
		H_2	N_2	O_2	S		
Fire wood	35.0	4.3	0.4	29.6	0.0	0.7	30.0
Peat	30.0	3.2	1.3	17.8	0.4	6.6	40.0
Straw	36.0	5.0	0.5	38.0	0.0	4.7	15.8
Oat	41.0	5.2	0.7	36.7	0.2	6.3	10.0
Corn	38.0	4.8	0.5	34.9	0.4	1.6	20.0
Rice husk	39.2	5.0	2.0	32.7	0.1	17.4	3.6
Groundnut shell	45.9	5.4	1.1	36.3	0.1	3.9	7.3
Coal	70.5	5.1	1.2	3.4	1.3	18.4*	-
Liquid fuel	84.8	12.7	-	1.4	1.1	-	-
Producer gas	CH	CO	CO_2	N_2	C_2H_4	O_2	-
	15.2	20.0	8.0	54.0	1.3	0.5	-

* Moisture + Ash

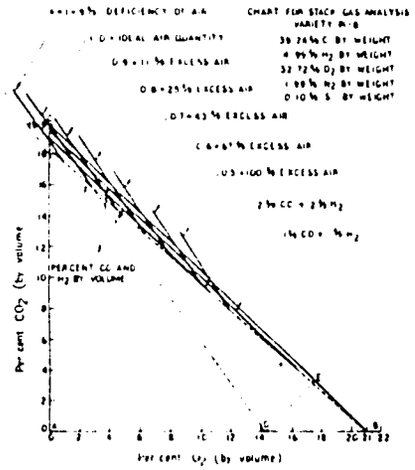

Fig. 1 Ostwald's chart for rice husks-IR-8

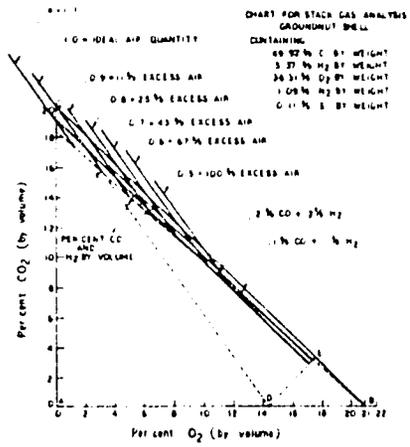

Fig. 2 Ostwald's chart for groundnut shells

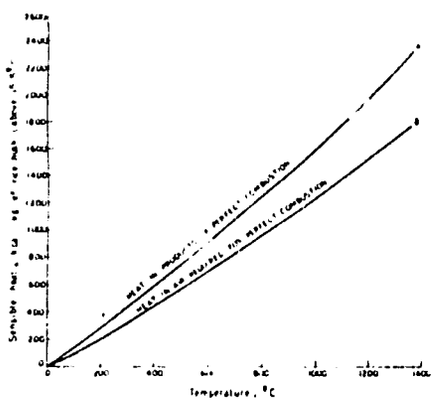

Fig. 3 Heat in products of combustion of IR-8 rice husks

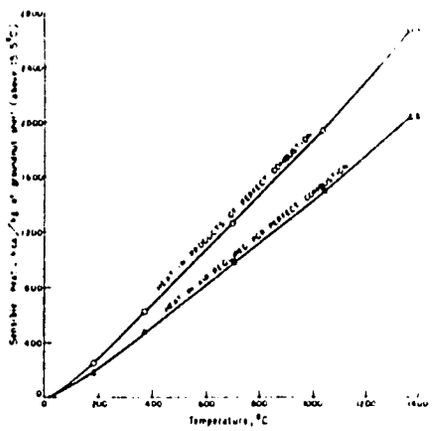

Fig. 4 Heat in products of combustion of groundnut shells

Nomograph for Heat Balance Computation

The nomographs (Figs. 3 and 4) for determining the heat carried away by flue gases from the burning rice husk and groundnut shell and the heat loss due to CO and H_2 in flue gases were prepared. Curve A in Fig. 3, furnishes the sensible heat content (above 15.5°C or 60°F) in the products of perfect combustion without excess air of unit quantity of fuel. It does not include the latent heat of the water vapour. For this reason, the heating value that should be used in the calculation of the curve is the lower heating value. If the higher heating value is used instead, then the latent heat of the water vapour (which is the difference between higher and the lower heating values, should be added to the heat content as read from the curve A.

Curve B represents the heat in that quantity of air which is required to burn a unit quantity of fuel, plotted as a function of the temperature of air.

Burning Characteristics of Rice Husk

The next step in developing a suitable machinery (furnace) for husk energy utilization involves the combustion studies on husk to study its behaviour when combustion takes place. Preliminary combustion studies were carried out with combustion pot technique, prior to large scale burning, so as to obtain practical information which would be useful in designing a husk-fired furnace. The maximum rate of combustion of 69.79 kg per sq. m of grate area per hour for IR-8 rice husk occurred at an air flow rate of 532.42 kg/m^2 hr. The optimum thermal grate load for husk-fired furnace is recommended as 184,000 kcal/m^{2}hr.

The effect of physical factors such as air flow rate, fuel bed height and particle size of husk on the rate of combustion and fuel bed temperature were studied for husk of IR-8 and Patnai 23 rice varieties. The average combustion rates increased with the increase in air flow rate till a maximum value is reached. A further increase in the air supply resulted in lifting the fine particles of husk from the bed, thereby lowering the combustion rate. Patnai 23 rice husk exhibited higher rates of combustion than IR-8 rice husk. The combustion rate was found to increase with the increase in fuel bed height. The experimental results are compared with the computed results from Thring's theory and a considerable

deviation was observed since the theory is concerned with carbon air reaction only.

Development of Grate Type Husk-Fired Furnace

Taking into consideration the functional requirement of furnaces for grain drying, data obtained from the above mentioned studies and the known principles of furnace design, a husk-fired furnace was designed and developed to match a 1.25 m.t. capacity dryer. The box type furnace (Fig. 5) is equipped with an inclined grate adjustable at 40, 45 and 50° angle of inclination, and consists of cast iron bars arranged in a staircase fashion. At the bottom of the inclined grate there is a horizontal revolving grate which disposes off the accumulated ash periodically. In order to prevent any fly ash or unburnt husk from going into the outlet with the hot gases, a curtain wall was installed throughout the width of the furnace at the end of the horizontal grate. The husk is fed into the furnace at the top of the inclined grate with the help of a fluted roller placed at the bottom of the hopper itself. The husk is spread in thin layer on the steps of the grate and it slides down by gravity while combustion takes place. The air necessary for combustion is sucked in through the opening for feeding the husk and partly through the grate openings. In order to reduce the flue gas temperature to the drying temperature level for paddy drying, additional air is introduced through the secondary inlet to the blower. The blower delivers the flue gas air mixture to the dryer with a by-pass arrangement to the chimney. The furnace was coupled with RPEC recirculatory paddy dryer. The highest furnace efficiency (64.5%) occurred at the feed rate

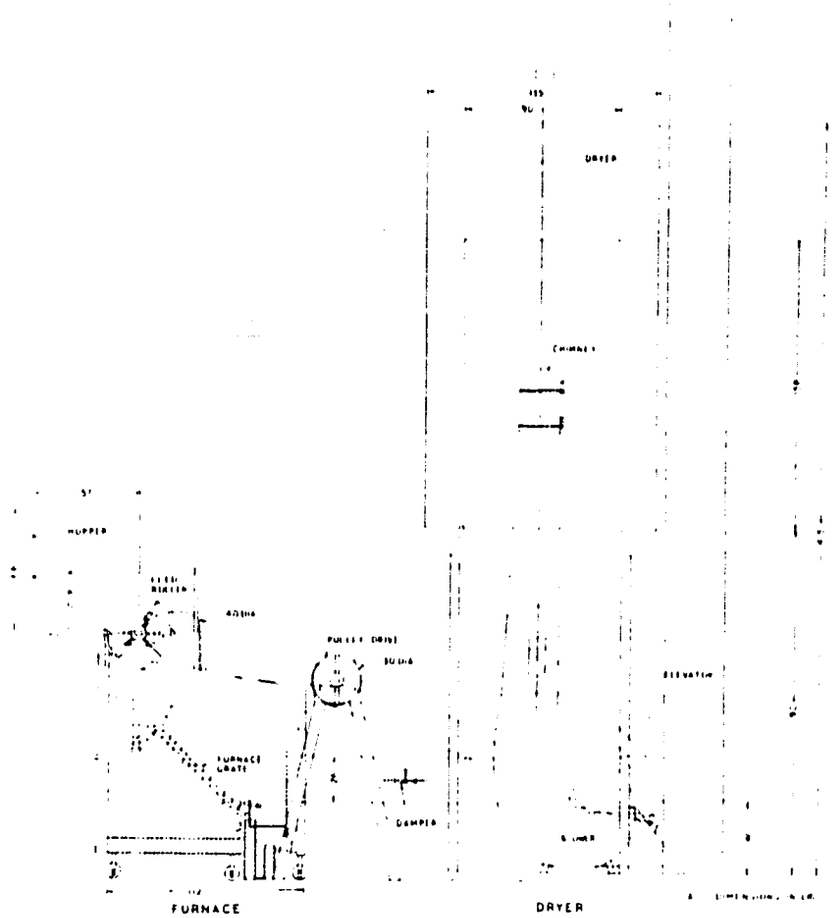

Fig. 5 Grate type husk-fired furnace coupled with dryer

of 14.25 kg/hr with excess air of 285.7 per cent. The flue gas analysis, at the highest furnace efficiency showed CO_2 as 4.0 per cent, O_2 as 15.8 per cent and with absence of CO. The rest is inert nitrogen constituting about 80 per cent of flue gases. Hence, it can be concluded that the flue gas air mixture can be used for drying purposes and it has no undesirable consequences on the milled rice. The furnace has been adopted by various rice millers and pulse millers to provide heat energy to the dryers for drying moist grains, including parboiled paddy in more than 30 mills in India.

Development and Testing of Husk-Fired Parboiling System

An experimental unit comprising of a parboiling tank and a husk-fired furnace with chimney has been designd and fabricated for parboiling of paddy. The present system eliminates the boiler of high initial cost and needs no electric power for its operation. The hot water soaking and steaming of paddy is carried out in the same parboiling tank. The proposed system is an improvement over the traditional system of parboiling used in some parts of South India and Sri Lanka. The performance tests on the unit include the furnace efficiency and the milling quality of the parboiled paddy.

A husk-fired furnace for parboiling 100 kg of raw paddy was designed from the known principle of furnace design. The furnace was equipped with an inclined grate (0.5 Sq.m.) at 45° angle of inclination, and consisted of cast iron bars (60 x 5 x 1 cm) arranged in a staircase fashion. Admission of air to the furnace and subsequent movement of gases

throughout the system are brought in by the natural draft of 2.86 mm. w.g., created by the 5.5 m high chimney. A rectangular parboiling tank was fabricated of 3 mm. thick mild steel sheet It is divided into upper and lower compartments. These compartments are separated by 1.6 mm. thick mild steel perforated sheet. The capacity of the upper compartment is 100 kg of paddy whereas the lower compartment is filled with water for producing steam at atmospheric pressure. The tank is provided with necessary free board along with a discharge gate for paddy and a drainage outlet for water. A glass tube was attached to the tank to see the water level in the tank. The husk-fired parboiling system is illustrated in **Fig. 6**.

The highest thermal efficiency of parboiling system was obtained as 21.4 per cent at the husk feed rate of 15 kg/hr. and 143.23 per cent excess air. The temperature of water (300 litres) during one hour of the experiment reached to 87°C at the husk feed rate of 35 kg/hr.

There is a considerable saving in the investment for this system of parboiling since it eliminates the need for boiler. Steaming was uniform and no discolouration due to prolonged steaming (as in the case with traditional process) occurred. A battery of these parboiling units may be installed in a commercial rice mill to match the parboiling capacity with mill capacity. Of course, a single unit can be an excellent aid for parboiling at the village to serve a community of farmers.

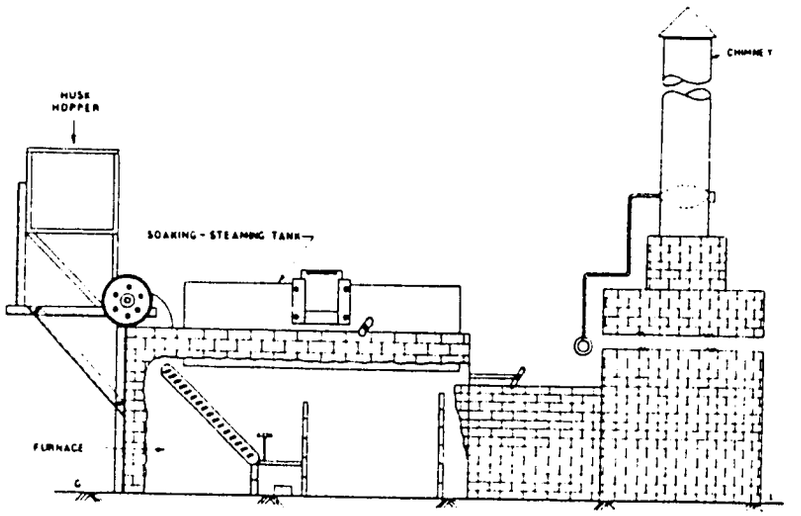

Fig. 6 Boilerless parboiling system

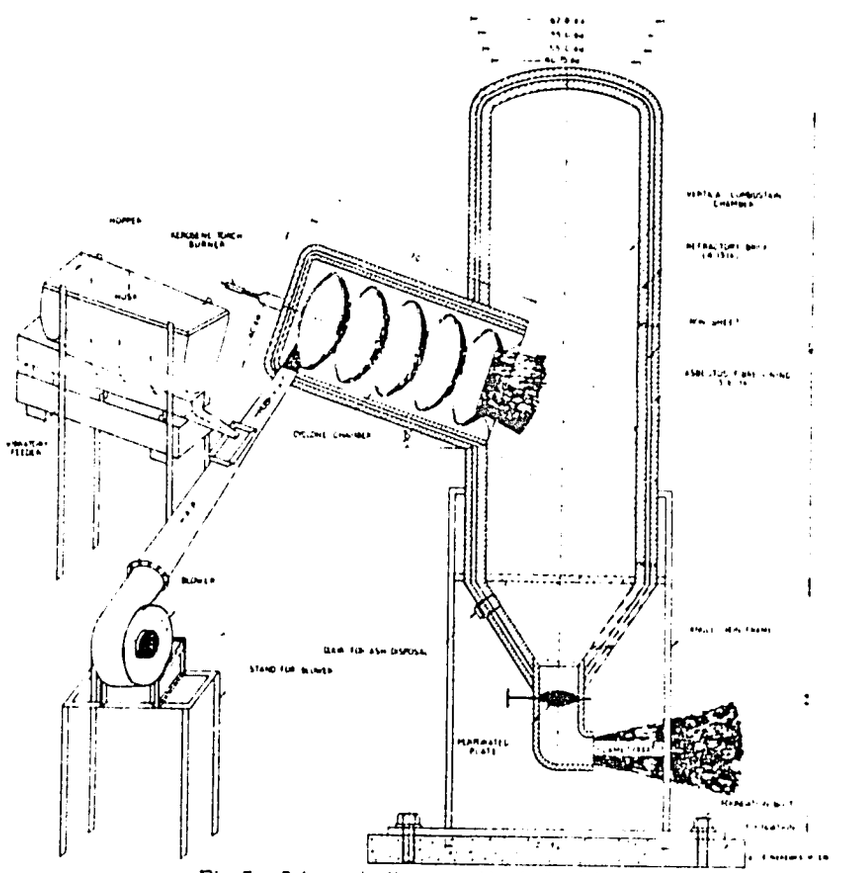

Fig. 7 Schematic diagram of husk-fired furnace

Development of Cyclone Furnaces

In order to burn the husk and other agricultural wastes efficiently experiments were carried out firing rice husk, groundnut shells and paddy straw in a cyclone furnace. These are described as follows:

Vertical Cyclone Furnace – The furnace (**Fig. 7**) was fabricated out used oil barrel (55 x 140 cm) having a conical bottom (40°) and a cyclone chamber at its side at an angle of 30°. The total volume of the furnace was 0.34 m^3 (12 cft). An exit pipe at the bottom provided an outlet for the flue gas as well as for the ash.

The husk was introduced tangentially at the outer end of the cyclone. For the insulation of furnace wall, the mixture of fire-clay and refractory bricks was pasted inside the furnace. A blower of 220 cfm (6.25 m^3/min) capacity was selected for the experiments. The highest furnace efficiency (80%) occurred at the feed rate of 20 kg/hr and

air flow rate of 2.83 m^3/min (100 cfm). The maximum temperature of flue gas was obtained at about 1000°C. The furnace was also operated on firing rice husk, groundnut shell and paddy straw.

Groundnut Shell-Fired Furnace – The horizontal groundnut shell-fired cyclone furnace was fabricated from two oil barrels in which one barrel was placed at an inclination of 15° to the horizontal and other was placed vertically (Fig. 8). The horizontal chamber was made of M.S. sheet, 58 cm in diameter and 87 cm in length. The conical end made of 0.3175 cm (1/8") thick M.S sheet was welded to the open end of the horizontal chamber with a 14 cm. outlet for the exit of flue gases and ash. The vertical chamber was attached to the horizontal combustion chamber to trap the ash. The furnace was tested at various feed rates and air flow rates and the highest furnace efficiency (63%) was obtained at the feed rate of 21.5 kg/hr. and 2.3 m^3/min air flow rate.

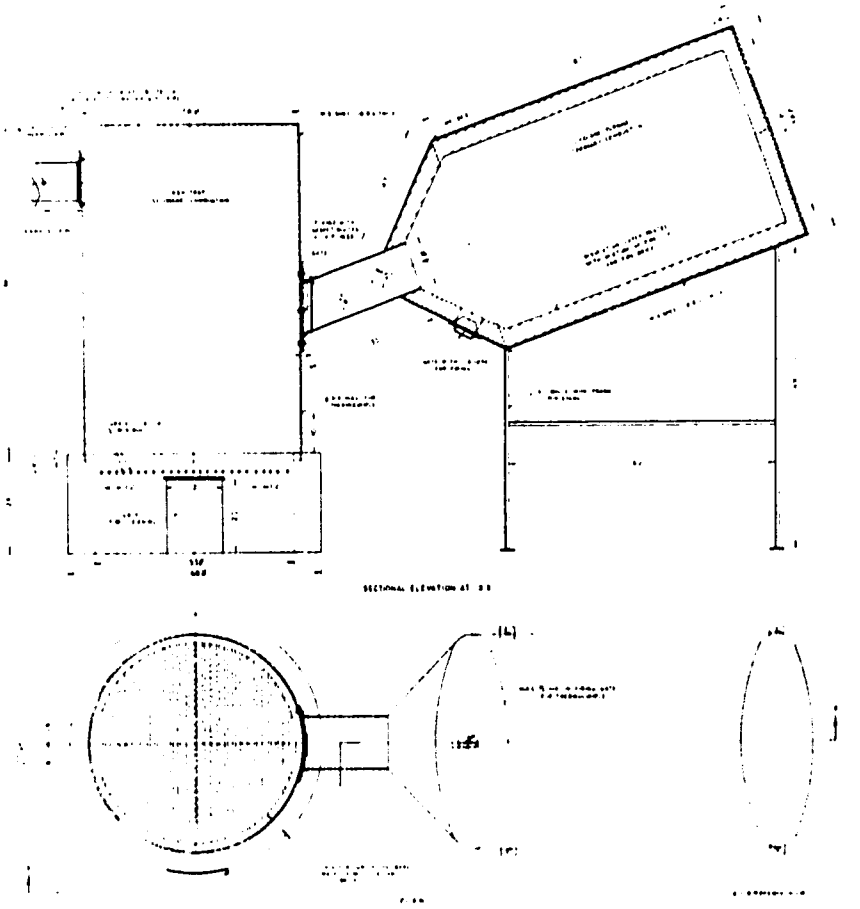

Fig. 8 Cyclone type groundnut shell-fired furnace

Horizontal Cyclone Furnace Coupled with Steam Generator and Grain Dryer

Keeping in view the design requirements and on the basis of preliminary experiments on various models, a pilot plant was worked out in which steam was produced by burning agricultural wastes in the horizontal cyclone furnace. The heat content in exhaust gases from the steam generator were utilized for drying in a dryer by eliminating the stack losses. The engineering drawing of the system is illustrated in Fig. 9.

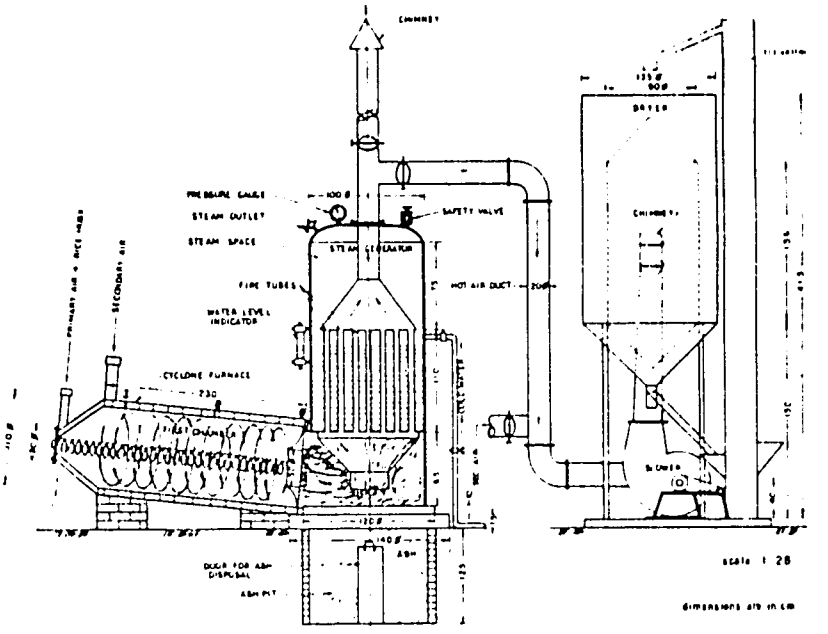

Fig. 9 Engineering details of horizontal cyclone furnace, steam generator and paddy dryer

The cyclone furnace was equipped with a circular chamber (1.10 x 2.30 m) consisting a re-entrant throat at one end and the other end was attached with a cone known as 'cyclone tip'. It has a hinged door with a collar to sit in the cone opening to make it air tight with three chamber bolts. At the centre of the hinged door is a smaller opening with open-shut arrangement for both firing the furnace and a quick glance at the inside burning process for the cyclone. The husk was introduced into a 10 cm dia. pipe connecting the cyclone tip and primary blower which delivered

6 m^3/min at 100 mm w.g. pressure. The secondary blower had a rated capacity of 10 m^3/min at 185 mm w.g. pressure. The inside wall of the circular chamber was lined with refractory bricks and fire-clay.

The husk was introduced into the cyclone chamber with the help of a fluted roller placed in the hopper and with the help of a stream of air. The re-entrant throat was attached to the other end of the cyclone chamber. The furnace was fired by paddy straw and then blowers were switched one after another. The feeding of husk was also started at the same time. The highest furnace efficiency of 78.5 per cent occurred at the feed rate of 125 kg/hr with an excess air of 53.4 per cent. The flue gas analysis showed the presence of CO_2 as 12.65 per cent, O_2 as 7.4 per cent and CO as 0.10 per cent.

Having determined the suitability of cyclone furnace a steam generator was designed and fabricated and attached to the cyclone furnace to test its performance. The boiler was designed to generate 200 kg steam per hour at 5 kg/cm^2 to fulfill the steam requirements for the parboiling of one m.t. of paddy. The exhaust of the boiler was coupled with a grain dryer (1.25 m.t. holding capacity). The highest combined furnace – boiler efficiency of 37.5 per cent occurred at the husk feed rate of 125 kg/hr and air flow rate of 12.74 m^3/min. The best over-all efficiency (76.45%) of the complete system (including drying system) was obtained at the husk feed rate of 125 kg/hr and air flow rate of 12.74 m^3/min. The furnace was also operated on firing groundnut shell and paddy straw successfully and efficiently.

The fabrication cost of cyclone furnace and steam generator was Rs. 3,000 and Rs. 5,500, respectively. The total operating cost of the cyclone furnace and steam generator was Rs. 6.27 per hour for steam generation and grain drying.

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