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REPORT

OF THE

AID/USDA BIO-ENERGY WORKSHOP

April 17-18, 1980
Washington, D.C.

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Introduction:

The Bio-Energy workshop, sponsored by the Bio-Energy Team (Bioresources for Energy, PASA No. AG/DSB-5709-6-79) was held on April 17-18, 1980, in Meridian House, Washington, D.C. Meridian House provided a charming and beautiful environment and adequate facilities for the workshop.

Attendance consisted of 28 officials from 20 foreign countries, 12 representatives of bioenergy conversion contractors, 27 invited guests and speakers from the U.S., 11 representatives from AID and USDA, and 3 members of the International Institute of Education. As an unexpected dividend, 4 members of a delegation from mainland China attended the first day of the workshop. See Appendix 1 for a listing of attendees.

Preceding the workshop, the team had just entered into 11 contracts with national and international authorities to describe the state-of-the-art of various biomass conversion technologies. These experts would be available to attend and contribute to the workshop, and, in fact, lead the discussions. The workshop would also discharge the Team's obligation as stated in the PASA, to hold 2 such workshops.

The purpose of the workshop was threefold:

1. Discussion of the latest developments in biomass conversion technologies with emphasis on the application in LDCs including social, economic, and political aspects in addition to purely technical considerations.

2. Exchange of information between LDC officials and U.S. specialists.

3. Consultation with contractors for "state-of-the-art" papers to ensure complete coverage of technologies yet avoid unnecessary duplication and overlap.

Agenda:

In preparing the agenda (Appendix 2) for this workshop an attempt was made to avoid duplication of presentations that were going to be made in the Bio-Energy '80 Congress in Atlanta. This posed some difficulty as a final printed program for the Congress was not available until after the workshop had been held.

It was decided to devote the first day's workshop to technical matters and the second day to socio-economic aspects of bio-energy technologies. In order to accommodate the expressed interest of our foreign visitors, the workshop was split into 3 parallel sessions each day:

1st day - Combustion, gasification and Pyrolysis.
- Biogas (Biomethanation).
- Biomass production.

2nd day - Substitution of biomass for oil in industry.
- Substitution of biomass for oil in transportation.
- Bio-energy in rural development.

Each of these sessions was chaired by a knowledgeable person connected in some way to the AID/USDA Bio-Energy project, either as an AID or USDA employee or as a contractor for the project. In this manner it was hoped that the flow of information would be reciprocal and that useful personal contacts would develop. Reports for each of the workshop sessions, except for the one on bio-energy for rural development, can be found in Appendix 3.

Critique:

About half of the foreign visitors gave us the benefit of their evaluation of the Workshop, the Congress in Atlanta, and field tours. Only the comments on the workshop and relevant comments on the Congress are reported here.

In general the visitors were very pleased with the workshop. Objectives 1 and 2 (see introduction) were fully achieved and more. Most of the visitors said they learned more at the 2-day Workshop than at the 5-day Congress.

From both the visitors and American specialists we heard that Objective 2 was well achieved. This was obvious even to the casual observer. During their stay here, the visitors developed firm and warm relationships among themselves and with host country specialists. This success was due in no small measure because the Missions carefully selected high calibre people.

Objective 3 also was achieved. In a workshop of this kind it is very important that the visitors be asked to give a thumbnail sketch of the situation in their countries. In this case opportunity was given prior to the workshop.

Sense of Visitor Comments:

Although the subject was highly complicated and the visitors represented many, often opposing viewpoints, there were some threads running through the discussions and debriefings that deserve reporting.

1. Energy concerns are a recent development in many LDCs and often there is no firm foundation of understanding of the problem or potential solutions from which to approach these concerns.

2. There is a need for within-country energy needs and potential to provide a data base on which to build policy and programs. When making assessments, it would be well to have had some pilot scale experience with the technology being assessed before finalizing recommendations.

3. World Bank view is that the need and urgency for biomass energy is so great that one should proceed now with tree planting programs while refining the data base.

4. A recurring comment was, during this workshop and many others, that developed country technologies need to be adapted for LDCs by keeping them simple and scaling them down in terms of size and cost.

5. Better communication is needed between LDCs. A way to achieve this could be through use and promotion of regional exchange of ideas and experiences.

6. There still is too much separation between production, utilization, and conversion of biomass. There is a need to emphasize an integrated approach which also takes into account socio-economic aspects.

International Guests

PHILIPPINES

Ms. Annabelle S. Adriano
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PROGRAM

USAID/USDA Forest Service Workshop

On Bio-Energy in Developing Countries

April 17-18, 1980
Meridian House
Washington, D.C.

Thursday, April 17, 1980

	Plenary Session
9:00	Purpose of Workshop, Mr. H. Gus Wahlgren, USDA - Forest Service
9:10	Description of Agenda, Mr. J. J. Fritz, Office of Energy, A.I.D.
9:25	Practical Issues Facing Bio-Energy Development, Mr. Robert Nathans, EDI
9:45	A Data Management System, Mr. Charles Bliss, Mitre Corp.
10:10	Coffee Break
10:30	Three Concurrent Workshops
	— Group 1 - Combustion, Gasification and Pyrolysis
	— Group 2 - Biogas (Biomethanation)
	— Group 3 - Biomass Production
12:30	Lunch
2:00	Continuation of Workshops
4:00	Coffee Break
	Plenary Session
4:20	Summary Reports by Rapporteurs
5:15	Welcome Address - Mr. Alan Jacobs and others, A.I.D.
5:30 - 6:30	Social Hour at Meridian House

Friday, April 18, 1980

9:00	Three Concurrent Workshops
	Group 4 - Substitution of Biomass for Oil in Industry
	— Group 5 - Substitution of Biomass for Oil in the Transport and Petrochemical Sectors
	Group 6 - Bio-Energy for Rural Development
10:30	Coffee Break
11:00	Continuation of Workshops
1:00	Lunch
	Plenary Session
2:30	Summary of Reports by Rapporteurs
3:30	Coffee Break
4:00	Panel Discussion on the Economic Evaluation of Bio-energy Projects. Chairman - Mr. Russell de Lucia, META
5:00	Adjournment, Mr. H. Gus Wahlgren

GROUP 1

Combustion, Gasification and Pyrolysis

Chairperson, Mr. Charles Bliss, MITRE Corp.

10:30	Introduction, Chairperson
10:40	Combustion, Mr. Donald Pingrey, Nor'West Pacific Corp.
11:30	Gasification, Mr. Lyle Mudge, BNL, Mr. John Goss, UC Davis
12:30	Lunch
2:00	Pyrolysis, Mr. John Arnold, Mr. Anil Chatterjee, SRI
3:30	Session Summary, Chairperson

GROUP 2

Biogas (Biomethanation)

Chairperson, Mr. Rolf Skrinde, Olympic Associates

10:30	Introduction, Chairperson
11:00	Principles of Low Cost Design, Chairperson
11:30	Operating Characteristics, Chairperson
12:00	Research at Cornell University, Mr. Kabrick, Cornell
12:30	Lunch
2:00	Economics of Community Units in India, Mr. Vinod Mubayi, Brookhaven; Mr. Ramesh Bhatia, Harvard
3:00	Egyptian Progress, Dr. Mohamed Nabil Alaa El-Din, Institute of Soils and Water Research, Giza, Egypt
3:30	Session Summary, Chairperson

GROUP 3

Biomass Production

Chairperson, Mr. Peter Hoekstra, USDA - Forest Service

10:30	Introduction, Chairperson
10:40	World Demand and Potential Support of Woody Biomass for Energy, Mr. John Spears, IBRD
11:35	Agricultural Biomass for Energy, Mr. Allan Atchley, USDA-SEA
12:30	Lun[illegible]
2:00	[illegible]omising Fuelwood Species, Mr. Noel Vietmeyer, NAS
2:50	[illegible]of Intensive Harvesting of Trees on Long-term Productivity, [illegible]ol Wells, USDA-FS
3:40	[illegible]n Summary, Chairperson

GROUP 4

Substitution of Biomass for Oil in Industry

Chairperson, Mr. Donald Pingrey, Nor'West Pacific Corp.

9:00	Introduction, Chairperson
9:10	Feasibility of Technical Routes to Biomass Substitution, Mr. Charles Bliss, MITRE Corp.
9:40	Char/Oil Slurries for Power Generation, Mr. Anil Chatterjee, SRI
10:30	Coffee Break
11:00	Fuel Supply Handling Infrastructure Characteristics
12:00	Session Summary, Chairperson
1:00	Lunch

GROUP 5

Substitution of Biomass for Oil in the Transport and Petrochemical Sectors

Chairperson, Mr. Alan Poole, Office of Energy, A.I.D.

9:00	Introduction, Chairperson
9:15	Issues in Food/Fuel Trade-offs, Mr. William Ramsay, RFF
10:00	Economic Analysis of Ethanal from Sugar Cane in India, Mr. Ramesh Bhatia, Harvard
10:30	Coffee Break
11:00	Opportunities for Cost Reduction in Methanol and Ammonia Production, Mr. Tom Reed, SERI
11:30	Thermochemical Conversion to Gasoline, Diesel Fuel and Petrochemicals, Mr. Martin Neuworth, MITRE Corp.
12:00	Opportunities for Improvements in the Hydrolysis of Lignocellulose, Mr. John Zerbe, USDA-FS
12:30	Session Summary, Chairperson
1:00	Lunch

GROUP 6

Bioenergy for Rural Development

Chairperson, Mr. Peter Benedict, Near East Bureau, A.I.D.

9:00	Introduction, Chairperson
9:10	Biomass and Village Energy Systems, Mr. George Self, A.I.D.
9:30	Overview of Factors, Resource Availability, Environmental Impact and Measures, Mr. Russell de Lucia, META
10:00	Factors Influencing the Implementation of Household Biodigesters, Mr. Vinod Mubayi, Brookhaven
10:30	Coffee Break
11:00	Factors Influencing Decisions on Fuel Use in Small Rural Industries and the Deployment of Efficient Cooking Stoves, Mr. John Arnold,
11:40	Trade-offs Between Alternative Sources for Decentralized Power Generation, Mr. Peter Rogers, META
12:20	Session Summary, Chairperson
1:00	Lunch

REPORT OF THE GROUP 1 SESSION ON COMBUSTION, GASIFICATION AND PYROLYSIS

by Charles Bliss, The MITRE CORPORATION

Group I covered the subjects on biomass combustion, biomass gasification, and biomass pyrolysis. These are different technologies for biomass conversion, but they have in common the fact that some oxygen must be used and the conversion, products can compete in the same markets. Combustion requires the most oxygen (as air), sufficient to produce carbon dioxide and water vapor from the combustible content. Gasification limits the amount of oxygen to produce mixtures of combustible carbon monoxide and hydrogen. Pyrolysis uses a minimum of oxygen, to the extent that the needed heat to decompose the biomass is supplied by the combustion of part of the biomass.

The two basic products of biomass conversion by the three technologies are direct heat or a high pressure steam for use in processing (for example, vegetable oil extraction or electricity generation). Gasification produces a fuel gas that may be transportable for combustion in another location, at a lower cost than the transport of the wood itself. The fuel gas is also suited for electricity generation from an internal combustion engine, for which the wood itself is not suited. Low nitrogen content fuel gas can be used as a raw material for chemical production, e.g., methanol or ammonia. Pyrolysis produces a solid product, charcoal, suited to combustion industrially or domestically (cooking), and a liquid fuel oil which through further processing may be a chemical raw material. Low heating value gas is also produced; the proportion varies with the pyrolysis conditions.

The processes are all technically developed. The problems of utilization vary and include the proper training of local personnel in the operation and maintenance procedures, and the appropriate methods of design and local fabrication in the case of small gasifiers. In brief, the execution of projects using these technologies, assistance in evaluating alternatives and adequate training of personnel appear to be the real needs.

A sampling of the countries represented by the participants in the session showed that biomass is actively being considered in the energy supply sector. Noteworthy activity is occurring in the Philippines, and specific interest to use biomass to reduce industrial fuel oil consumption exists in Guyana.

Illustrated presentations were given on the three topics of the session. They were essentially oriented to available equipment and current experimental work. Donald Pingrey (Nor'west Pacific Corporation) presented the combustion topic and showed diagrams of large and small steam generation equipment for wood fuels which are currently in use. John Goss (University of California at Davis) discussed current activities

in small scale gasification with emphasis on mobile equipment that can travel to locations of concentrations of agricultural waste. Lyle Mudge (Battelle Northwest Laboratories) discussed current work on large-scale wood gasification and described the large pilot plant operated by his organization.

After the lunch break, John Tatom (consultant) presented the subject of pyrolysis and a discussion of the solid and liquid/oil products which can be produced. Anil Chatterjee (SRI) presented the subject of the preparation of char-oil fuels from wood pyrolysis to enable combustion of wood derived fuels in liquid form.

As a general comment and observation, a voluminous amount of material was presented. In retrospect, the developing country participants could have been helped by receiving a handout of the significant illustrations projected on the screen.

REPORT OF GROUP 2 SESSION ON ANAEROBIC FERMENTATION OF BIOMASS

By

Kurt H. Vause, Project Engineer
Olympic Associates Co.
Seattle, Washington 98109

DISCUSSION GROUP SUMMARY REPORT - ANAEROBIC FERMENTATION OF BIOMASS

This workshop group dealt with anaerobic fermentation of biomass materials to combustible gas (biogas) and liquid slurry (sludge). The session was chaired by Dr. Rolf T. Skrinde of Olympic Associates Co., Seattle, Washington, U.S.A., and was attended by members of the international community shown in the attached table.

Dr. Skrinde opened the session with a brief description of the principles and history of anaerobic fermentation technology. In anaerobic fermentation of biomass, complex organic matter is degraded by microorganisms to methane (CH_4) and carbon dioxide (CO_2) gases, and simpler residual organic compounds, while nutrients such as nitrogen are conserved. In developing countries, available biomass usually consists of animal and human wastes, although agricultural residues are sometimes used.

The natural process of anaerobic fermentation yields a medium BTU gas which can replace conventional non-renewable fuel supplies, and also a liquid slurry with significant fertilizer value which can be used in a variety of ways. The fundamentals of this process have been known for many years and have led to widespread utilization of anaerobic digestion technology for pollution control purposes, but with increased emphasis on energy from renewable resources, biomass fermentation has been given increased attention with regard to energy production.

The objectives of the workshop, as Dr. Skrinde emphasized, were to exchange information on the use of anaerobic fermentation for energy production in developing countries, identify feasible conversion systems which are simple and of low cost, and serve as an introduction to future interactions between the participants. Eight topical areas were thus identified by Dr. Skrinde as being pertinent to the objectives of the workshop, those being:

1. Low-cost designs of biogas plants, using local materials
2. Low-cost gas storage methods
3. Low-cost operation and maintenance procedures
4. Low-cost operational control of biogas plants
5. How to achieve safe operation
6. How to train operators of biogas plants
7. How to achieve integrated biogas systems
8. How to encourage biogas programs

Due to time constraints, some of these areas could not be discussed at length in the workshop. Shown below then is a summary of the information presented by various individuals, much of which resulted from lively and active discussions between group participants.

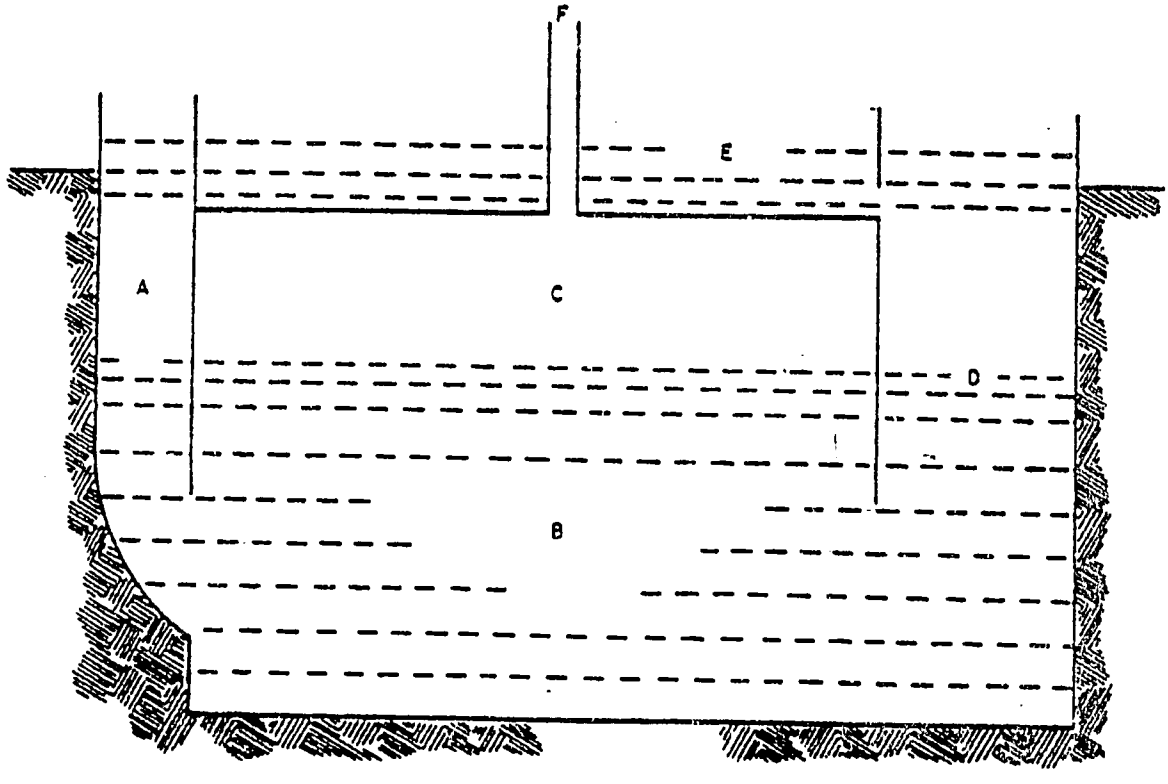
The first presentation given was made by two members of the Chinese delegation to the symposium, Prof. Chen Ru-Chen and Mr. Li Nian-guo. Prof. Chen is head of the Biomass Division of Guangzhou Institute of Energy Conversion, while Mr. Li is head of the Information Division of the Institute. Since 1958, Prof. Chen explained, China has conducted research on anaerobic fermentation and has developed three

biogas plant designs. In the period since 1972, China has embarked on an implementation program and has installed 7 million units throughout the country. As a result, biogas has become an important energy source in China.

Typically, biogas plants in China are 4 to $10m^3$ capacity, the larger size being used in the colder northern regions of the country. All operate at ambient temperatures, with conversion efficiencies on the order of 15 to 20% (i.e., conversion efficiency of biomass materials—human and animal wastes, and agricultural residues—to energy by direct combustion of the gas). The gas produced provides about two-thirds of a family's fuel requirements at a capital cost of U.S. $30-50 (excluding labor costs).

Total gas production in Chinese biogas plants averages 0.15 vol/vol/day, or about $0.5m^3$ gas/kg solid added when operated at a residence time of 60 days. The gas produced is usually between 60-70% CH_4, the higher concentration of CH_4 found when using night soil. Although a trace amount of H_2S is present, no provisions are made to remove this contaminant. This has not been a problem for the Chinese however, Prof. Chen reports, since several biogas plants have operated for periods of 5 to 6 years without corrosion problems with biogas combustion equipment.

Of the three types of biogas plants developed in China, the most common type of plant is one which partially resembles a sealed septic tank. Referred to as the water pressure digester, this plant consists



A — INTAKE CHAMBER
B — DIGESTER
C — GAS STORAGE
D — OUTLET CHAMBER
E — LIQUID PRESSURE COMPARTMENT
F — GAS PIPE

Fig. 1. Water Pressure Biogas Plant Schematic (China)

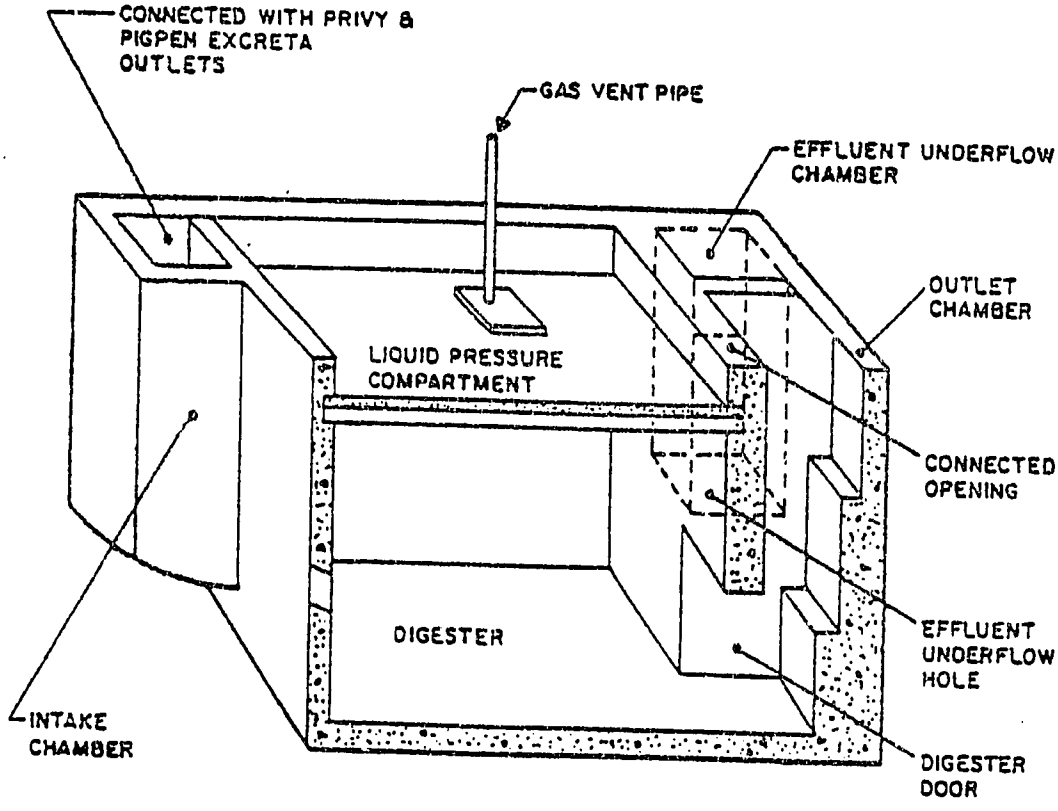


Fig. 2. Water Pressure Biogas Plant Section (China)

of a sealed, rigid wall tank with an effluent chamber designed to act as a pressure regulator (Figures 1 and 2). As biogas is produced and collects within the digester, slurry is displaced into the vertical effluent chamber because of the pressure which builds up inside the sealed tank. When the head differential between the liquid levels in digester and effluent chamber exceeds a given amount (1.0-1.5 m of slurry) any excess gas would be released. When gas is withdrawn from the sealed tank, the internal pressure is reduced and slurry in the effluent chamber flows back into the main compartment. In this design then, careful attention is made to seal the main tank to prevent gas leakage. The inside of the roof of water pressure designs are given 5 layers of plaster, three of which consist of clear cement, the others of cement sand mortar. The tank is built with locally available materials such as coal slags, lime kiln drags, etc.

Biogas from these family sized units is used primarily for cooking and lighting purposes, and sometimes is used to run internal combustion or diesel engines. With diesel engines, biogas can be used as the primary fuel source (75-85%), with only 15-25% diesel fuel needed. Some engines can be designed to run on biogas only. One m^3 gas produces about 1.4 KWH of electricity if a biogas fueled diesel engine is used with a generator.

The second design is similar to the first in that the digester consists of a sealed rigid-wall tank, however gas storage is provided in a

separate unit consisting of a bag made of PVC film of .24mm thickness. Prof. Chen described the installation of one such plant, referred to as the biogas power plant, a 90KW pilot project. The plant utilizes 28 individual digesters with a total capacity of 1300m^3, with night soil at 2% Total Solids (TS) being the only biomass material used. Gas production averages .3 vol/vol/day. The gas holding bag operates with a maximum internal pressure of 3cm water, and has a life expectancy of about 2 years.

The third type of digester design utilized in China is very much like the one developed in India over the past 25 years. It consists of a rigid wall digester with a floating cover, usually made of steel, which captures the gas and floats on the slurry. A more detailed description of such a design was provided by a member of the Indian delegation to the symposium, and is discussed below.

The advantages and disadvantages of the three types of digester designs were discussed by Prof. Chen, and included the following:

	Advantages	Disadvantages
Water Pressure	1. No moving parts 2. Uses cheap, locally available materials	1. Low gas production 2. Not good design for large system 3. Some gas leakage
Fixed Cover Digester W/Gas Bag Storage	1. Good for large systems 2. Can be fit into community systems easily	1. Not suitable for individual or family use 2. Gas pressure in bag is low. Must use suction equipment or vacuum to extract gas from bag, but a gas engine performs this in the intake system
Floating Cover Digester	1. Convenience 2. Consistent gas pressure for end uses of gas 3. Can feed slurry high in % TS	1. Hard to build inexpensive floating cover 2. Corrosion of steel

Following Prof. Chen's discussion of the Chinese experience, Mr. G. L. Patankar of the Khadi Village Industries Commission, Bombay, India, discussed the Indian floating cover digester design. The design, as illustrated in Figure 3, was developed in the 1950's in India and in the last few years has been utilized more extensively than in the past. To date, approximately 70,000 plants have been constructed as a result of an active government program to promote the widespread use of biogas energy systems.

Construction of the floating cover digester consists of a deep (up to 16' in depth) brick, mortar and plaster digester covered by a steel gas holder which rides up and down on a center guide in response to gas production within the digester. Influent and effluent slurry tanks are built of similar materials as well. Inside the digester, a center partition made of brick and mortar is installed to prevent short circuiting and compartmentalize the digester. Plants of this size range from 100 to 330 cu. ft. (3-8.5m^3) and typically cost on the order of U.S.$200.

To charge the digester, feedstock material (usually cow dung) is mixed with water in the influent slurry tank, then flows to the bottom of the first compartment of the digester through an asbestos cement pipe. The slurry tank is designed to remove grit or other inert material before charging the digester, thus obviating the need to clean out the digester on a frequent basis. In this manner, clean out is necessary only every two or three years. Once charged, the digester contents

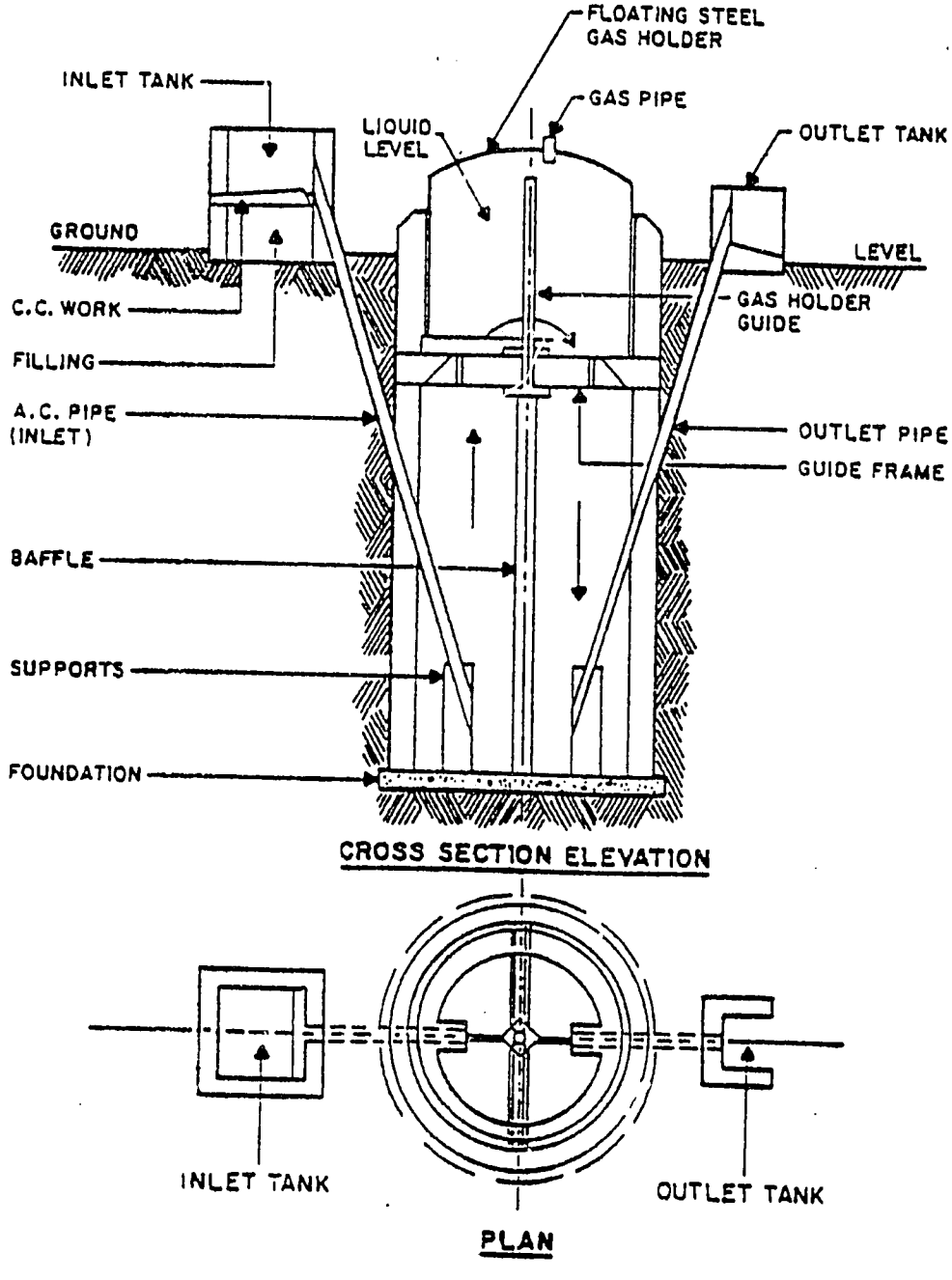


Fig. 3. Standard Indian Design Biogas Plant With Floating Steel Gas Holder

flow up through the first compartment, over the center partition, and then into the second compartment, from which the effluent is discharged. In some cases, this effluent is filtered to remove the remaining solids and the liquid portion recycled to be used as make-up water for the feed slurry. However, because the digester is charged every day, adequate fresh water supplies are needed to prevent against build-up of dissolved constituents in the slurry water.

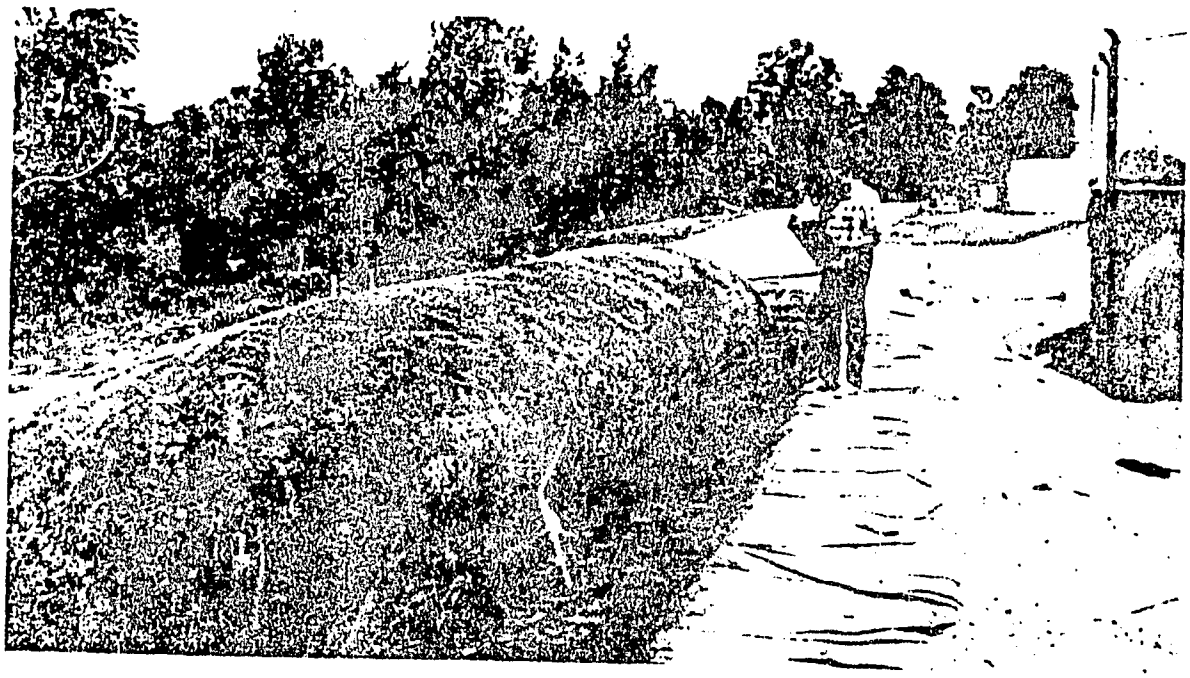
In the Indian design, influent slurry is usually charged at 9% TS, and effluent slurry discharged at about 7% TS, thus reflecting a 20-25% reduction in solids. Operating at a detention time of between 50-60 days, gas production totals about 6 cu. ft. per lb. of solids added, with the gas produced consisting of approximately 55% CH_4 and 45% CO_2. Gas pressure within the digester is kept fairly constant at 3" water pressure. At 3" water pressure, the gas can conveniently be stored for use in cooking, the primary end use for biogas in India, since existing gas stoves require gas pressure of 3 inches water column to function properly.

The government in India has embarked on a national program to develop the use of this technology in rural areas by providing direct subsidies to villagers and farmers of about 20% of the cost of such a plant, and providing loans through the national bank for the remaining 80% of the total cost. Research and development is also underway to improve on the present design and develop new techniques to use biogas. Mr. Patankar mentioned several new developments in these area, including

improved burner design; development of gas lamps to burn biogas using kerosene lamps; mantles, using 7HP horizontal displacement engines to burn a mixture of 80% biogas and 20% air; new horizontal biogas plant designs for regions of high groundwater table or shallow rock strata; and incorporation of covers placed over the floating steel gas holder to act as solar collectors for heating of the influent slurry water.

Following Mr. Patankar's discussion of the Indian experience, Mr. Randolph M. Kabrick of Cornell University, Ithaca, New York, U.S.A., gave a presentation concerning low-cost anaerobic biogas plant designs being researched in the United States. Mr. Kabrick pointed out that in the U.S. the trend in agricultural practices has been to consolidate operations into more centralized structures, thus resulting in the establishment of farms with large numbers of livestock in rural areas. As a result, large quantities of animal and agricultural wastes are produced on the farm, requiring larger facilities to handle the residues than smaller sized family units of the designs shown above.

At Cornell then, researchers have developed a low-cost anaerobic fermentation facility design, that being plug-flow digesters located in excavated lagoons or pits. The design, shown in Figure 4, consists of an excavated pit over which a bag made of ethylene propylene diener monomer is installed to cover the pit and store gas as it is produced. Insulation consisting of foam glass and fiberglass is provided along digester walls, and an internal piping grid is provided to heat the digester contents. Head space is minimized to prevent heat loss, and



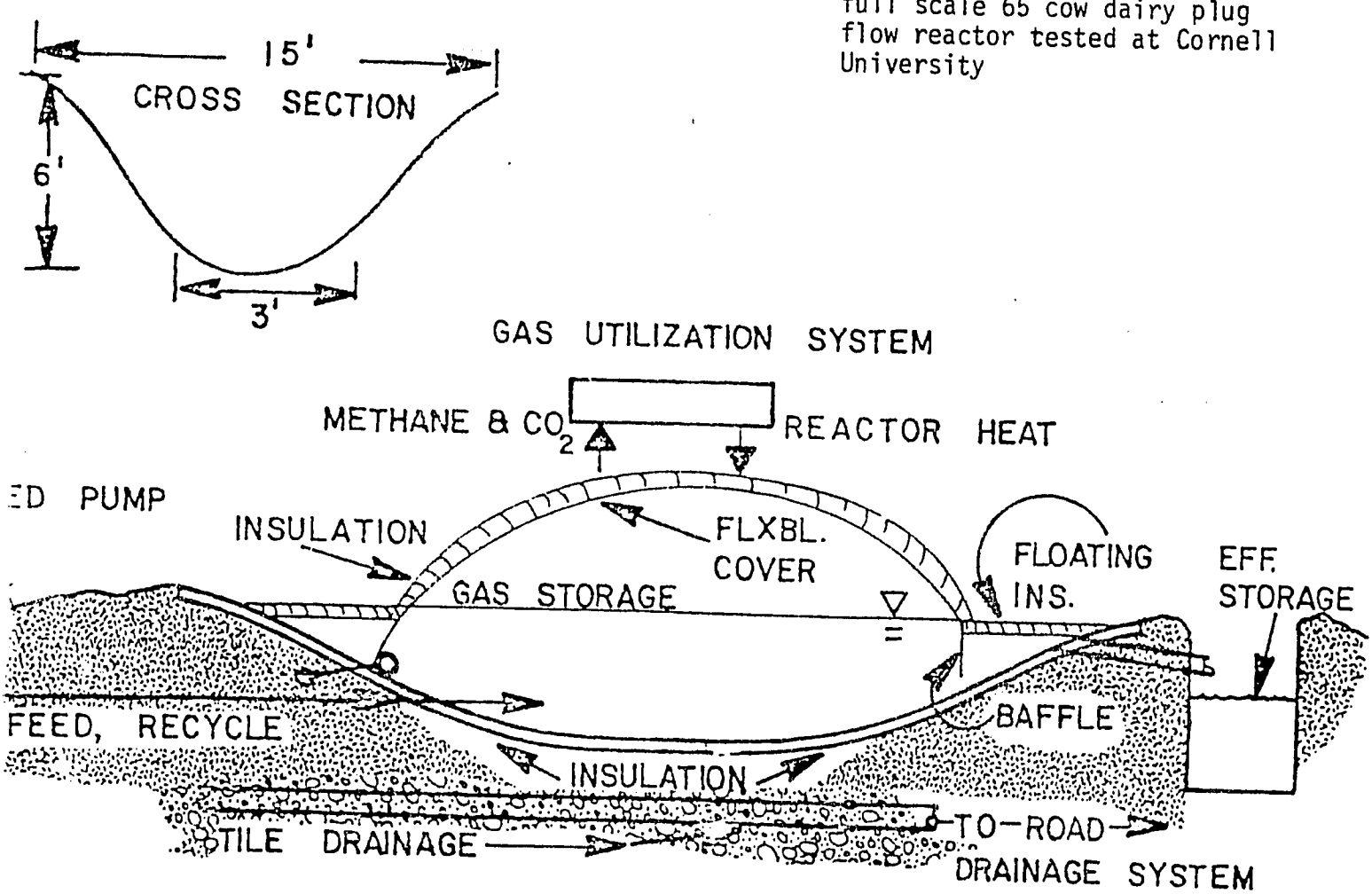


Fig. 4. Schematic and photograph of full scale 65 cow dairy plug flow reactor tested at Cornell University

the bag is fully supported by the gas pressure (4 inches water pressure maximum) developed within the digester. Total cost, including labor, materials and construction for such a unit is estimated to be $20,000 for a $60m^3$ digester, the size required for a 100 cow dairy operation. Of this total, the major portion is due to insulation and cover costs.

Operation of the plug-flow bag digester is similar to that of the other designs discussed above, with the exception that the slurry is pumped into the digester rather than being added manually or by gravity flow. Also, the raw feedstock, consisting of cow manure and urine, is at 13% TS and thus requires no dilution prior to charging.

Gas production at the Cornell digester is higher than that which would be expected to occur in similar installations in developing countries since the feedstock used comes from animals which are fed a rich diet. At 35^oC and 15 day residence time, and at 25^oC with 30 day residence time, gas production amounts to 2.5 vol/vol/day with gas consisting of 65% CH_4 and 35% CO_2 as compared to 0.15 to 0.3 vol/vol/day found in applications elsewhere. For medium sized and larger farms, Mr. Kabrick noted that a more favorable energy balance might be achieved if separate gas storage facilities were provided for the gas, perhaps consisting of medium pressure (approximately 200 psi) compression storage tanks on-site, since most heat loss occurs through the cover of the digester.

Following Mr. Kabrick's discussion, Dr. Sompongse Chantavorarap of the National Energy Administration of Thailand gave a presentation concerning the Thai experience with anaerobic fermentation technology.

Dr. Chantavorarap first discussed the need to develop data concerning fuel needs of a country's population prior to developing detailed designs to be implemented on a wide scale within the particular country. For example, in Thailand, per capita energy needs have been calculated to be about 1000 Kcal/day for cooking; thus, approximately 1 m^3 of biogas is required per day for cooking for a family of 4-6. Thus, typical designs developed for family use are in the range of 1.5 m^3 to slightly larger capacity to provide sufficient gas production to meet a family's particular energy demand.

In Thailand then, a typical design is one in which a 1.5 m^3 cement water jar is constructed above ground to serve as the digester, with separate gas storage provided in a concrete tank with floating cover design similar to that of the Indian design shown in Figure 3. Cost of the concrete digester water jar is U.S.$15. Digesters are charged daily through a small elevated pipe located on one side of the water jar, and effluent discharged from a similar pipe on the opposite side of the jar. On the top of the water jar, a water seal is provided to protect against any gas leakage or intrusion. Several individual 1.5m^3 water jars can be installed in parallel to increase digestion capacity, with each feeding to one central or a series of gas storage units with floating covers.

Following these discussions on technical aspects of anaerobic fermentation technology, the remainder of the workshop session focused on economic, social and political aspects surrounding the use of these technologies in developing countries. First, Dr. R. Bhatia of the

Institute of Economic Growth, Delhi, India and visiting professor at Harvard University, Cambridge, Massachusetts, U.S.A., discussed the India experience in implementing biogas technology throughout that country. Government programs instituted in the last decade in India involving direct subsidies and loans were initially directed toward development of individual, family-size digesters. These programs were only moderately successful in promoting wide-spread adoption of the digester units however, because other conventional fuels were readily available. As a result, government programs were shifted to include emphasis on the development of community digester plants, with the expectation that the social and individual or private benefits would be more favorable under this structure.

Even with community based digesters, adoption of the technology has not proven to be as successful as hoped for, Dr. Bhatia explained. In a case study of such a community system, Dr. Bhatia found community cooperation to be lacking, primarily as a result of attitudes from various members of the villages that there was unfair distribution of the benefits, or that benefits were not commensurate with the amount of r[illegible]es contributed by individuals. Furthermore, Dr. Bhatia noted that villagers' perceptions of the benefits from digester systems presented difficulties in that all did not value the products (gas and slurry) equally, nor were their willingness and ability to pay for such products equal. Despite such difficulties, Dr. Bhatia found that as alternative uses for the biogas were developed in place of its use as a cooking fuel or for rural electrification purposes, such as for

irrigation pumping, that the benefit/cost ratio for such systems improved.

Following Dr. Bhatia's discussion, Dr. V. Mubayi of the Brookhaven National Laboratory, Upton, New York, U.S.A., presented the final address of the session, a discussion of other issues surrounding implementation of community digester systems. Issues which need to be addressed, according to Dr. Mubayi, include: achievement of and mechanisms behind cooperation between individuals comprising a community based system; determination of viable end uses of the products of community rather than individual digesters; desirability of implementing such technology for purposes of decentralized power generation; necessary organizational forms to implement community systems in different geographical, economic and political settings; and effects of unequal ownership of resources within the community on development of community-based systems. Other concerns to be addressed, according to Dr. Mubayi, include: technical questions concerning efficiency of biogas plants and specific equipment, and appropriate roles for governments to take in promoting adoption of such technology throughout developing nations.

The session was concluded with summary remarks by Dr. Skrinde, who re-emphasized that viable biogas technologies must be both simple and low-cost in order to become implementable in developing countries. Following these final comments, the group adjourned.

REPORT OF GROUP 3 ON BIOMASS PRODUCTION

By Kjell Christophersen

The workshop was informative and interesting, with lively discussion. It nicely dovetailed the presentations given earlier in the morning, particularly the need to distinguish between the concepts of viability and implementability. In a most generalized sense, the presentations were focused on viability and the discussion on implementability.

John Spears, World Bank, opened the presentations with a very informative and useful expose of overall world needs in biomass for energy. The statistics point to the severity of the problem. Even when considering technological advancement and increased utilization of alternative energy sources, such as solar, wind, tides, and others will still be far short of meeting the projected wood biomass required by the year 2000. The World Bank estimates that by that year, 50 million ha will have to be planted worldwide. Only 20% of that requirement is being met.

In response to this severe biomass for energy problem, the World Bank and numerous other donors have substantially increased their commitment to forestry. However, the situation is likely to get worse before it improves. This happens when people are turning to alternative energy sources such as agricultural waste and dung without regard for or understanding of the consequences of changing the energy source before it is too late. As fuelwood becomes increasingly scarce, and people switch to the alternatives, food production is foregone because of losses in nutrients and soil productivity.

Spears' talk triggered considerable discussion. His major point, that there is a great discrepancy between present consumption of wood biomass and projected consumption, was driven home despite some disagreement over the validity of the FAO statistics used in the analysis. The group agreed that consumption studies need to be continued and refined whereas other kinds of studies are less important. We are well aware of the problems and need more on-the-ground activities.

The second presentation was by Alan Atchley, USDA-SEA. He outlind the merits and limitations of his agency's development of a computerized data bank that will have the capability of matching a range of tree and plant species with habitat and climatic conditions to establish ecological parameters in project design. The utility of this kind of information is potentially great since it could help us from continually reinventing the wheel of deciding which species to plant under what conditions. There was some discussion about the ecological ramifications of monoculture plantations in the Tropics.

The third speaker, Mr. Trehan from the MITRE Corp discussed a study they have been doing on tree energy farming for electricity on marginal lands in the Dominican Republic. Their conclusion was that this is economically

feasibile vis a vis the alternatives. Some discussion followed regarding how to convince the farmers to become involved in tree farming for energy. Because of longer rotations or time between original investment and returns, there is greater risk, as well as indebtedness, which are difficult to accept in countries where credit is poorly developed.

The concept of marginal land warrants additional discussion. A "solution" to the biomass for energy problem always seems to be to grow the plants or trees on marginal land, or that which is otherwise not used for anything else. In overpopulated countries that is simply not the case. "Marginal" land is utilized more often for food rather than wood production with low yields. Moreover, the term marginal is usually based on biological criteria, or the land's ability to support biomass production. Economic "marginability" is equally, perhaps more important, particularly in a locational context. Biologically marginal land near population centers may be economically more valuable for biomass production than rich land that is located far away.

The fourth speaker, Mr. Noel Vietmeyer of NAS discussed some promising fuelwood species that have gained considerable attention lately. On top of the list is the Leucaena, a fast growing species that serves a multitude of purposes.

The NAS will also come out with a book on firewood species and trees for energy production which should nicely complement Mr. Atchley's data base.

Carroll Wells, USDA-FS the last speaker discussed the extent to which soil productivity is declining as harvesting is intensified. The shorter the rotation, the greater the problem.

The group's discussion of what to recommend for the plenary session was a bit disjointed. However, if there was a common denominator from all the comments, it was probably Community Forestry. The community, or the local people will have to be involved in the project, from its design through its implementation if it is to be successful.

REPORT OF GROUP 4 ON SUBSTITUTION OF BIOMASS FOR OIL IN INDUSTRY

By Donald Pingrey
Nor'West Pacific Corporation

Matters discussed in this session include:

(a) Biomass application as fuel for steam generation

(b) Char/oil slurries for power generation

(c) Review of known alternatives to residue industrial oil consumption.

(d) Guyana Bauxite Production as a case study in looking into macro technological implications of using biomass as substitute for oil in industry.

A. Biomass as fuel for steam generation

The topic of the discussion was concerned with the problem of converting oil or gas fired steam generators into units that utilize biomass as fuel. The following are factors or items important to be considered.

(i) Tube spacing:

With oil, there is practically no problem caused by solid particles entrained in the flue gas. That is not the case with biomass

-erosion
-impingement
-deposition

of solid particles requires that gas velocity should be less than or equal to 50 feet per second.

(ii) Combustion volume:

Solid fuel requires larger combustion volume, this is mainly due to the moisture content of fuel (biomass fuel); high moisture content requires longer resistence time.

(iii) Fuel supply and preparation includes:

-storage
-forming and sizing
-land area for forming

(iv) Some handy rules of thumb:

* 5.0 lb. biomass is equivalent to 1 kW hour (@ 50% moisture content).

* 2.2 to 2.8 lb. of steam is generated by 1 lb. of biomass (@ 50% moisture content).

* For biomass, combustion volume will be 1 cu. ft. per 20,000 Btu of heat generation; compared with oil (or gas) 1 cu. ft. is required for every 50-80 thousands Bty per cu. ft. of heat generation.

(v) Environmental control requirements: smoke and particulate emissions.

B. Char/Oil slurries for power generation

The basic consideration for suggesting the use of char/oil slurries are:

- it is possible to reduce/suppress oil consumption

- char can be very easily produced and a well-known technology

- heating value, sulfur content, and ash content of char has values that are suitable for preparing char/oil slurries for fuel.

The discussion included the following:

- preparation of char from wood

    - retort (external heating)

    - introduction of insufficient air

    - multiple hearth

- comparison of composition and heating value of wood, char and oil, namely: carbon content, ash content, moisture content, sulfur content and heating values.

- economic analysis, which indicates that the use of char oil slurries would cut down fuel cost

- technical problems envisaged:

    - stability of suspension

    - plugging

    - ash deposit

    - pumping

- burners

- process control

- proper particle size: -150 + 200 mesh; finer particles require more energy for grinding/pulverizing

C. Review of known or possible alternatives to residue industrial oil consumption

(i) Heat:

1. Burn coal

2. Burn coal/oil mixtures

3. Burn wood (or other biomass)

4. Burn char

5. Burn char/oil mixture; the oil could be petroleum or oil from wood pyrolysis

6. Gasify wood and burn gas

(ii) Raw Material

Gasify wood (other biomass) with oxygen and steam as combustion agent to produce syn-gas for methanol or ammonia production.

D. Problems and possibilities of using biomass as energy source in bauxite production - Guyana case

Basically, there are three major processes in bauxite production, where energy supply is of major consideration:

- power generation

- calcinizing

- aluminum production.

Presently, fuel cost runs at 34% of income which is U.S. $20MM.

(i) Power generation

The particular problem under consideration is steam generation; converting the existing steam boiler so that biomass fuel can be used.

(ii) Calcining

The fuel utilized must be dry, and process temperature is high. In this case, biomass does not seem to be proper; oil and coal mixture would be possible.

(iii) Aluminum

Using fluid bed calciner, the proper form of fuel would be gas; oxygen fixed gasifier may be a possiblility if biomass is to be used as energy source.

In facing the energy problem, the company has taken steps so that within a short time their energy problem can be overcome:

(1) experimenting with pilot scale fluid bed calcination unit (Lurgi), which could reduce fuel consumption down to 40% of current consumption.

(2) taking stringent measures in power plant operation.

(3) recycling of dust emitted from the calciner; this will recover up to 30% of losses of product currently experienced, and therefore, more efficient energy use.

The following emerged during the discussion following the presentation about the Guyana bauxite plant:

(1) In using biomass as major energy source proper measures must be taken concerning forest farming and management practices; these include:

- labor/employment opportunities

- institutional set up; who is involved in providing the biomass or who must handle that activity, relation to the company.

(2) lead time necessary to exploit biomass for steam generation purposes; it requires a basic minimum period of preparation of not less than two years.

(3) comparison of mechanical vs. labor intensive way of wood harvesting; it was pointed out that in the Philippines, mechanized harvesting is more expensive, labor intensive harvesting costs about 25% of the mechanized way, based on labor cost of about U.S. $3 per day.

(4) household energy need; in Guyana the following are widely used:

- kerosene

- LPG

- electric stoves

With increasing oil prices, many people will face energy problems. It was pointed out, that in such situations, electric energy would be the best solution; this will overcome logistics problem that would be faced if biomass is used directly or converted into fuel forms that need material handling and transportation.

(5) Dual production scheme in exploting forest is considered to be more profitable: timber and biomass.

REPORT OF GROUP 5 ON SUBSTITUTION OF BIOMASS FOR OIL IN THE TRANSPORT AND PETRO CHEMICAL SECTORS

By William G. Padolina

This group dealt with the issues involved in the substitution for oil in the transport and petro chemical sectors. It was pointed out that in the developing countries the fuel needs are concentrated in the transportation sectors. Likewise it was emphasized that for purposes of the discussion non-sugar and starch derived fuels were to be discussed just to dramatize the alternatives available to us now even if our fuels are derived largely from sugar and starch. It was felt that such an approach would give us flexibility in responding to the fuel crisis.

Mr. Ramsey in his discussion of the "Issues in Food/Fuels Trade Offs" discussed some issues related to the competition between food and fuel in the allocation of resources. It was recognized that the issue has been emotional and that the clash of these two giant imperatives indeed deserves food and fuel needs is really artificial. A view whereby there is a symbiosis between food and energy needs must be worked out. The discussions highlighted the need for a closer examination of the food and fuel question.

Dr. Ramesh Bathia then discussed a case study entitled "Issues in the Economic Analysis of Bioenergy Project - A Case Study of Ethanol from Sugar Cane in India." His analysis showed that the prospects did not look too good at this point. Ethanol could not compete with subsidized kerosene. Likewise the question of diversion of sugar from export for the local production of alcohol is a major consideration. However there are certain tradeoffs because such diversion will reduce dependence on the international sugar market and the production of ethanol will reduce dependence in naptha. This will insure certainty in the availability of fuel.

Tom Reed presented the case for the production of methanol and ammonia. He discussed the current state-of-the-art as well as efforts to design smaller plants using biomass. The advantages and disadvantages of methanol as a transport fuel were discussed and compared with ethanol. The issue remained unresolved but would indeed be a question for future study especially in the context of fuel needs of the developing countries.

Martin Neuworth then discussed the high technology process of converting methanol to gasoline by the Mobil process. The technical aspects of the process were presented. The question of the need to convert methanol to gasoline was discussed in the light of the fact that methanol *per se* is suitable as fuel.

John Zerbe presented the developments in the technology for the conversion of lignocellulosic wastes to alcohol. He pointed out that acid hydrolysis of wood to sugars is a technology that is now in use. There are snags in the enzymatic conversion of wood to sugars. An economic assessment and the process alternatives for lignocellulosic as new material for fuel alcohol was discussed.

REPORT OF GROUP 6 - ON BIOENERGY FOR RURAL DEVELOPMENT

By George Self
Near East Bureau, AID

The purpose of this session as to discuss the potential and problems associated with the utilization of biomass resources for rural energy applications. Salient points that emerged were:

1. Rural biomass resources are scarce and therefore must be optimally allocated.

2. Technology for application of biomass for energy in rural areas is not well developed and will require comprehensive analysis.

3. Issues regarding socal acceptability, realistic need assessments, equitable resource distribution and community participation in decision making need to be thought out prior to project implementation.

4. Local government support and implementation capabilities need to be assessed and enhanced prior to project realization.

A. Introduction - Mr. Peter Benedict.

B. Biomass and Village Energy Systems - Dr. George Self and Mr. Russell de Lucia.

Three types of projects should be considered, 1) conservation, 2) shift to more efficient energy sources, and 3) increased energy.

In designing energy projects:

1. Energy needs must be defined, eg., type of energy, heat, light, fertilizers, mechanized. . . .

2. Resource availability must be defined.

3. Feasibility of various conversion technologies must be investigated.

4. Household energy balance should be determined, eg., biomass resource competition, food, soil conditioners, construction materials.

Project feasibility, such as bio-gas unit, must include examination of system effects and adjustments related to the required loss of feedstock.

C. Trade-offs Between Alternate Energy Sources - Dr. Peter Rogers.

Favorable alternatives for technology decision making:

Low capital investment
Low operating costs

Easy maintenance
Reliable and robust technology
Portability
Multi-fuel capacity
Multi-use
Local available fuel
Local manufacture
Off-the-shelf technology
Small power output/high efficiency
Socially acceptable

D. Factors Influencing Implementation of Biogas Units - Mr. Vinod Mubayi.

1. Capital cost - especially if fuel is free.

2. Efficiency.

3. Equity-distribution.

4. Ownership of feedstock.

Three levels of discussion

1. Level of national policy - energy substitution - equity.

2. Needs of local community supply based on need.

3. Individual project based on socio-economic analysis.

E. Improved Rural Stones - Mr. John Arnold.

1. Need for merger of laboratory work and field study.

2. Need to understand present cooking technology and incorporate those needs into improved stove technology.

3. Acceptance of improved stones is a function of perceived fuel scarcity. There must be a perceived functional improvement if it is to be adapted to large numbers.

F. Steam Operated Liquid Piston Pump for Rural Application - Mr. S. Jayaraman.

A biomass fired steam operated pump has been developed by the Central Power Research Institute of Bangalore, India in response for the need of water for irrigation using agricultural residues as fuel. It operates on steam expansion and condensation principle employing a mechanism to induce suction through steam condensation. Efforts are under way to increase output capacity and decrease fuel consumption.

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STEAM OPERATED LIQUID PISTON PUMP (SOLP)

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ABSTRACT

In rural areas, major consumption of energy is towards agricultural water pumping. In view of shortage of conventional energy, alternative renewable sources and pumping devices must be considered. Use of windmills is known. The use of biomass as an indirect utilisation of solar energy is also of value. The biomass-burning SOLP pump developed by CPRI has low capital cost and is simple and reliable for operation in rural areas. It operates on the steam expansion and condensation principle. It employs a special mechanism to induce suction through steam condensation and thus ensures cyclicity of operation. Efforts are progressing to increase output capacity and decrease fuel consumption, thereby increasing efficiency.

INTRODUCTION

Analyses made by CPRI on the energy utilisation pattern in rural areas reveal that agricultural water pumping is one of the main areas. Where electric pump sets are used, they are operated for about 4 to 5 hours in a day, power for which is provided by extending 11 KV or LT lines. Extending lines involves capital expenditure and distribution losses are also present. Further, some field measurements indicate that the pumps operate at an average efficiency of 14% or so. From published agricultural statistics, it is found that the total potential of minor irrigation through wells and tanks in our country is about 39 million hectares, out of which 19 million hectares have irrigation facilities. Water pumping is essentially a device to supplement the muscle power of a farmer. The present level of pump sets (electric pumps) installed is approximately 3 million and these account for pumping facilities for about 3 to 4 million hectares of land. 14% of electricity generated in the country is consumed in the operation of these 3 million pump sets. It is, therefore, necessary to increasingly tap alternative, renewable sources of energy and develop suitable pumping devices. Apart from wind energy, the use of biomass, which is the most efficient form of absorption of solar energy by nature, is a dependable alternative. While agricultural wastes form one source, the raising of quick-growing trees in a portion of the land with a view to generating its own supply of biomass (energy source) would constitute a self-sustaining cycle.

The SOLP pump developed by CPRI and operating on biomass, operates on the steam expansion and condensation principle. The concept of using steam expansion for pumping out and its subsequent condensation for producing suction is not new. But the mechanisms attempted hitherto to make such a pump operate smoothly and cyclically have been plagued by many difficulties. For example, in sizeable units, the delivery flow may be unsteady owing to jerky pumping. Condensation may be ineffective or incomplete, resulting in occasional and spasmodic suction or even a totally blocked condition. Steam generation may overtake the suction process and throw the operation into disorder. In these circumstances, with any semblance of cyclic operation absent, the overall time may be prolonged and the pump may yield meagre output. Perhaps this is the reason for dubbing this pump as a not very useful device.

Best Available Document

With the present spurt in energy studies, interest in this type of pump has revived and quite a few institutions and scientists are understood to be engaged in this investigation. Attempts are known to be made to use intermediate liquids of low boiling point, with the ultimate aim of using solar energy. These systems, though good, may pose a lot of operating problems with the conditions existing in rural areas. Hence, CPRI's approach has been to use the water itself as the working fluid.

Through intensive study and experimentation, CPRI has developed the SOLP pump to the level of a big-size outdoor prototype giving an output of about 700 litres per hour over a head of 7 metres (22 feet), consuming approximately 8 Kg of fuel per hour. The speciality of the pump is that it incorporates the following features:

a) inclusion of a simple and effective internal fountain mechanism which is actuated automatically and is also self-replenishing, eliminating the need for external cooling tanks or special mechanisms.

b) Provision of suction line at the top of the cylinder while delivery line emerges from the bottom. This inverted configuration ensures proper operation of the pump.

c) automatic replenishment of water in the boiler compartment during every suction stroke and the boiler itself designed for optimum quantity of water for generating steam.

d) "pumping" and "suction" occurring cyclically and the process being automatic.

e) the duty of the operator being only to feed the fuel (biomass) to the stove.

f) the output of the pump being far more than what a man can pump with his own muscle power.

MECHANICAL FEATURES

The pump (Fig.1) consists of an M.S. Cylinder (ERW pipe) of internal dia 0.450m and height 1.250m with a flat boiler box (Fig.2) projecting at the top to one side. The boiler has a tray-like depression to hold water for continuously generating steam. The steam pressure acts into the cylinder through an internal window cut-out where the box joins the cylinder, instead of through the usual connecting pipe. An oven is placed so as to surround the boiler and fuel is burned underneath (like in any conventional stove in rural areas).

Inside the cylinder, at the bottom, is fixed another, smaller, cylinder with two spouts at diametrically opposite points piercing through the main cylinder. This forms the fountain generating mechanism for cooling. The central tube which pierces through the top plate of the fountain has a shower cone fitted at the top and while its open bottom end reaches down leaving a small clearance. The fountain chamber has no communication with the main cylinder except through the many tiny holes on the shower cone.

A delivery pipe line emerges from the bottom end of the main cylinder and is fitted with a non-return valve V1. The suction pipe line, which has a foot-valve V2, rises from the well and, after a sloping segment, takes a horizontal, diametrical course across the cylinder top and opens into the boiler at the other end. It is important that the sharp downward bend of the horizontal portion commences as close to the cylinder as possible (d in Fig.1) as, otherwise, suction will be hampered. The suction pipe is half embeded at the cylinder top. Its embedded semi-cylinderical underside has a few parallel lines of holes, each line having 3mm dia holes 20mm apart, with each line 30mm distant from its neighbour. 6 or 7 such lines of holes may be formed in this way. These holes provide a top spray during suction flow.

The entire unit is a closed system and is sensitive to leakage. All constituent

parts are welded leak-proof and separately tested at every stage of construction. All pipe connections are made leak-proof by sealing joints with araldite. Reliable quality non-return valves are recommended to avoid reverse leakages. The cylinder is fitted with a centre-zero pressure gauge, which provides vital clue to conditions prevailing at every instant during the operation of the pump. Design of each of the constituent is also very important.

OPERATING PROCEDURE

The empty pump is filled with water in two steps. Firstly, the fountain chamber is filled upto spout level and the spouts are then plugged tight. The chamber now contains water with a quantity of air trapped above. The main cylinder is then filled through the top spout, until cylinder, boiler suction pipe, etc., are all full and a corresponding level is found in the delivery pipe. The filling spout is then tightly shut and the pump is now ready for operation. The oven is placed in position and a fire is lighted on the hearth below and maintained.

After about 10 minutes of warm-up time, during which the pressure reading gradually mounts, the delivery flow starts. Steam formed locally within the boiler expands and, acting through the 'window', forces the cylinder water out, resulting in delivery flow. The suction valve remains shut on account of positive pressure in the system. The trapped air in the fountain chamber closely follows the system pressure, and its volume adjusts, the water taking corresponding different levels under different conditions (Fig.1), leaving or entering, as required, through the shower cone's perforations.

Pumping proceeds steadily and the cylinder water level descends. When about 100 litres of water have been pumped out (in about 3 minutes), the water level just exposes the top of the fountain chamber to the steam above. The steam heats up, by conduction, the trapped air which, expanding, forces the chamber water out into the main cylinder in the form of a fountain. This fountain chills the steam, the cylinder pressure drops progressively below atmospheric and the delivery valve closes, stopping the flow. The time duration from the start of delivery flow to its stoppage is called 'delivery time'.

The fountain causes an escalating action and the dropping pressure serves to draw more and more water into the fountain, chilling the steam further. When pressure drops sufficiently low (suction threshold, determined by the suction head), the suction valve opens and suction flow commences. The suction flow, while traversing the horizontal pipe, simultaneously throws a top spray through the underside holes. The top spray quenches the steam still further and produces an intensely low pressure. This establishes a powerful suction flow mainly directed into the boiler (the spray is a minor perpendicular flow now) and overflows into the cylinder, (Fig.2) thus refilling it. The suction valve thereupon closes. The pump has thus been restored to its initial condition. The suction flow, on its way, has also replenished the boiler for the next cycle. The time duration from the start of pressure drop (stoppage of delivery flow) to the end of suction flow may be termed 'suction time'.

At the juncture of closing of suction valve, the system pressure would be slightly higher than the threshold pressure (negative). Thus for delivery to restart, this negative pressure has first to be overcome and then the requisite positive pumping pressure developed. The time duration from stoppage of suction flow to the start of next delivery is termed the 'waiting time'. During this pressure build-up the fountain chamber too regains its lost volume of water in the previous suction process. By the time the delivery pressure is attained, the chamber would have got filled to its old level. It is thus seen that the fountain chamber too gets replenished automatically. The above sequence of operations repeats cycle after cycle.

PERFORMANCE

The prototype depicted in Fig.1 has shown the following performance features:

Suction head = 4.55 m (15 ft. 2 in)
Delivery head = 1.35 m (4 ft. 6 in)

Total head = 5.90 m (19 ft. 8 in)
Warm-up time = 8 min. 15 secs.

A) Average Cycle Pattern:

Delivery time = 2 min. 30 secs.
Waiting time = 3 min. 58 secs.

Suction time = 1 min. 30 secs.
Cycle time = 7 min. 58 secs.

Output volume = 100 litres
Delivery pressure = + 3 psig. (17.7 psia)

Suction volume = 100 litres
Suction threshold = -45 cm of Hg (gauge) (5.7 psia)

Lowest suction pressure = -70 cm of Hg gauge (1 psia)

Weight of fuel = 8 Kg. per hour
Type of fuel : Strips of wood
Calorific value : 3710 cal/gm.

Average output per hour = 640 litres.

B) Formulae :

For simplicity of formulae, mixed units are used.

1) Output power $\doteq \frac{Q.H}{9,00,000}$ HP $\doteq \frac{Q.H}{1200}$ watts.

2) Input power $\doteq \frac{14.W.C}{9,000}$ HP $\doteq \frac{7}{6} \times W.C.$ watts.

3) Efficiency $\doteq \frac{Q.H}{14.W.C}$ %

wherein,

Q -- Output, litres per hour

H -- Total head, feet

W -- Weight of fuel consumed, Kg. per hour

C -- Calorific value, Cals/gm.

C) Calculation :

Output $= \frac{640 \times 19.75}{1200} \doteq 10$ watts.

Input $= \frac{7}{6} \times 8 \times 3710 \doteq 34,600$ watts.

Efficiency $\doteq$ 0.03%

D) Cost = Rs.900/- (approximately)

COMMENTS

The efficiency figure may appear disappointingly low. However, it is not uncommon for pumps of this type to register such low values of efficiency with scope for enhancement with improved designs. The formula for efficiency indicates maximisation of Q, i.e., per-hour output and reduced fuel consumption, W. Q is limited by cycle time which is now around 8 minutes. Its break-up indicates a fairly long waiting time, during which period the pump is resting. Attempts are under way to reduce it by suitable alterations in the design. Fuel consumption could also be brought down by efficient burning and better ovens are being

developed. Preliminary studies for improved ovens are very encouraging and indicate that there is scope to reduce fuel consumption by nearly 70%. However, the work is in progress.

CONCLUSION

1) Even the present stage of development of SOLP pump in CPRI warrants its application to agricultural lands. As indicated, only a small percentage of land has been provided with pumping facilities at present. Further, the capital investment involved to extend electricity to the agricultural sector is quite substantial. As against this, the capital cost of SOLP pump is very low.

2) SOLP pump runs on fuel which a farmer can easily generate himself as it is a renewable source. It can also be operated on biogas.

3) The operation of SOLP pump provides mechanical advantage to a farmer, as it can pump more quantity of water compared to that by muscle power or animal power.

4) The operation of the pump is simple so that a farmer can work it himself. The pump has no moving parts and no special maintenance is involved except cleaning of the valves occasionally. Only the initial filling need be done manually. If the stopping is done just after a suction (by removing the fire), the pump remains filled and ready for restarting whenever required.

5) Further work to improve the output and efficiency is essential.

NOT TO SCALE

SOLP PUMP

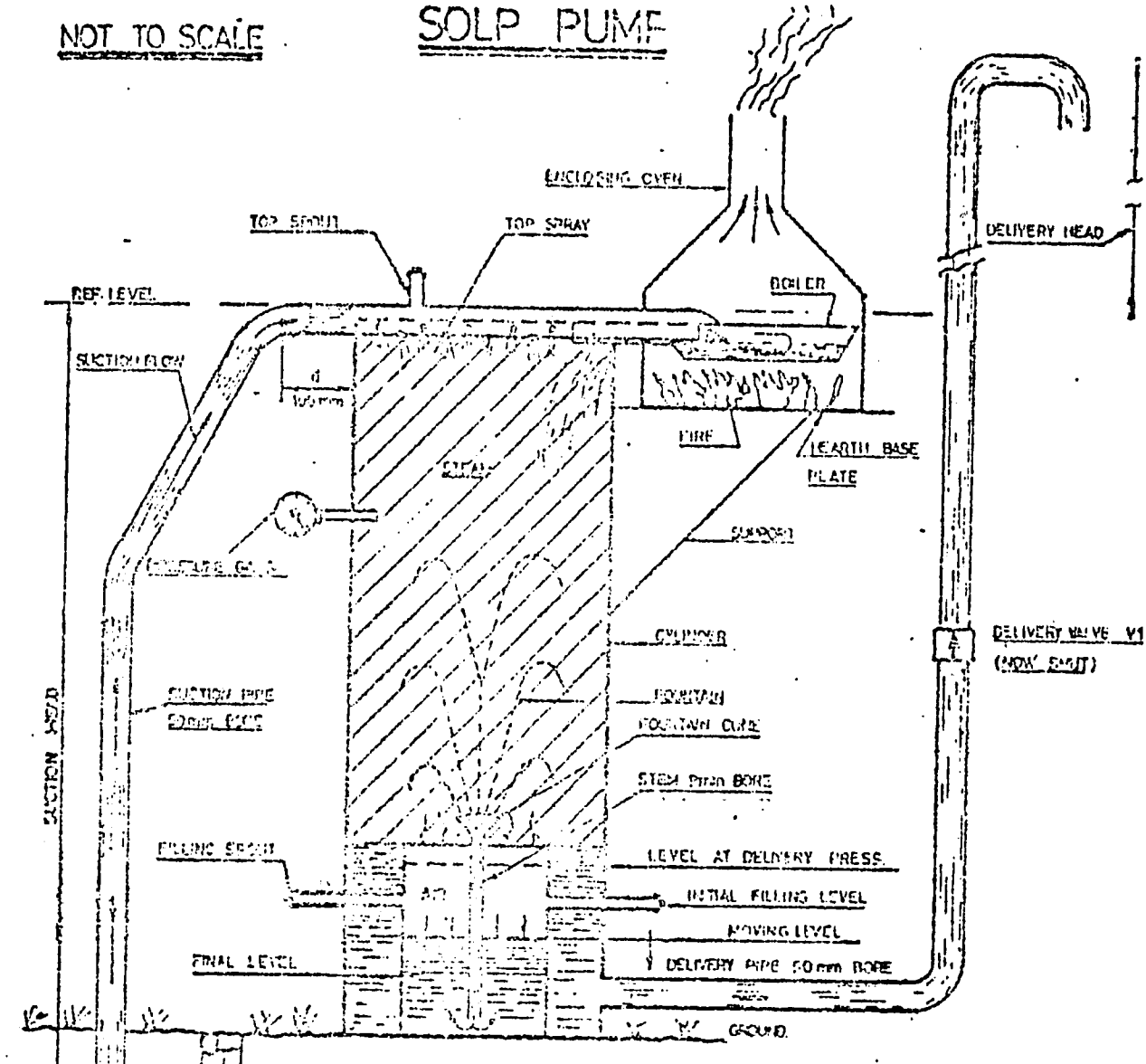

FIG 1: SECTIONAL ELEVATION OF SOLP PUMP
(Condition at commencement of suction flow)

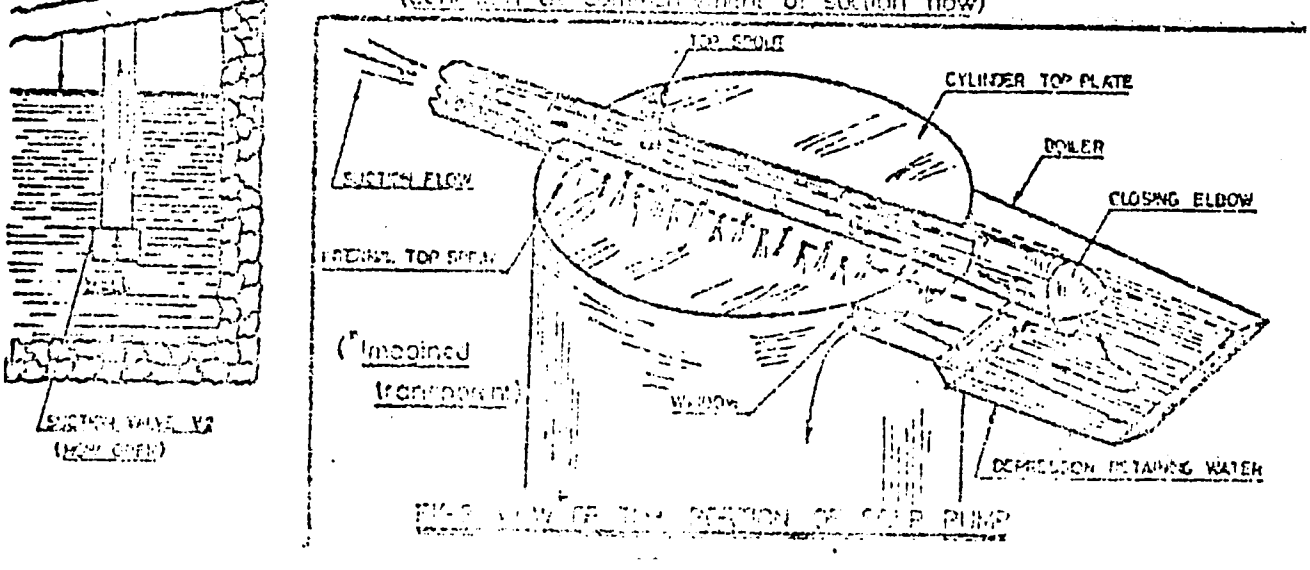

FIG 2: VIEW OF THE DEPRESSION OF SOLP PUMP