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INTERIM REPORT
PYROLYSIS OF RICE HUSKS IN INDONESIA

GOVERNMENT OF INDONESIA
AND
U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
PROJECT NO. 497 – 0268
"APPROPRIATE AND LOW COST TECHNOLOGY"

CONDUCTED BY
THE DEVELOPMENT TECHNOLOGY CENTER
INSTITUTE OF TECHNOLOGY BANDUNG

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INTRODUCTION

Third World Countries such as Indonesia face extraordinary problems in meeting the energy demands required for development. They are also confronted with high rates of unemployment, but have the mixed blessing of low wage levels. Therefore, a renewable energy system that could engage many people in its operation would be an especially welcome prospect. Since most Lesser Developed Countries lie in the tropics and already have economies largely based on agriculture and forestry, the potential for biomass as a renewable energy source is especially great ; particularly since it is very labor intensive. In Indonesia, a large supply of biomass is already available in the form of rice husks and rice straw that, to a very great extent, are currently wasted. These residues are not only scattered about in the fields, but they are also concentrated at rice mills, and therefore a significant fraction is already available conveniently as an energy source. Not only would the use of these residues significantly reduce Indonesian national fossil fuel demands, but it would also strongly alleviate the pressure on the forests to provide firewood for domestic and industrial purposes, and thereby curb the severe erosion, flooding, and river pollution problems currently experienced in Java due to these practises.

The main problem, however, with biomass as it is available now is that: at an industrial scale, most current energy conversion equipment is designed to operate an fossil fuels and, at a domestic scale, most if not all stoves are for wood or charcoal use and will not operate properly on these residues. Thus there is a need for a means for converting residues into synthetic coal, oil and gas which could be utilized in existing

equipment. Pyrolysis, especially low temperature pyrolysis, which favors char and oil production, offers a particularly promising means of conversion, since the char and oil products are storable and easily transportable; an especially attractive characteristic in developing countries.

Morever, recent U.S. experience with the steady-flow, vertical packed bed, partial oxidation pyrolysis process (1,2)[1] has demonstrated that this technology, updated from its earlier forms is a viable means for conversion of forestry and agricultural wastes into synthetic fuels. In addition, the basic simplicity of the process makes it suitable for applications in rural environments because of its few moving parts, low maintenance requirements, and general ruggedness. But the steady-flow, vertical, packed bed, partial oxidation pyrolytic convertors produced thus far have been built primarily in developed countries with a high level of automation and capital intensity and are subject to environmental constraints totally inappropriate to developing countries. However, recent studies (3,4,5) of the application of partial oxidation pyrolysis-in a suitably modified form-to Third World countries have indicated the technical-economic potential of the process, and these studies have led to hardware development programs in Ghana, Indonesia, Papua New Guinea and the Philippines.

This paper is concerned with one of these programs and represents a progress report which describes efforts under a joint American-Indonesian project to develop appropriate, economical pyrolysis technology and associated equipment so that rice husks can be effectively converted and used for rural/domestic energy purposes. The primary objective of the project is the development of a nominal one ton/day pyrolytic convertor optimized

[1] Numbers in Parenthesis denote literature cited in the REFERENCE section.

for Indonesian operation with rice husks. A secondary goal is the design of corresponding hardware which allows utilization of the char, oil and gas products of the conversion process. The implementation strategy involves locating the pyrolytic convertors at rice mills, of which there are about fifteen thousand on the island of Java alone. The charcoal would be used for domestic cooking, the oil utilized for domestic lighting and the gas used for drying the padi at the rice mill and powering the diesel engine that runs the mill.

The paper includes :

(1) a description of the basic design concept for the convertor, which has been continuously updated as the program has progressed.

(2) an extensive review of previous and current work, including a discussion of the equipment developed and problems encountered.

(3) an economic analysis of the system.

(4) an evaluation of program objectives and strategy in light of project experience to date.

(5) a description of future activities.

Upon review of this presentation, it is hoped that an understanding of:

(1) where the program is today

(2) where its future work will lie, and

(3) what the overall economic potential of the pyrolysis process is in Indonesia

will be clear to the reader.

THE BASIC PYROLYTIC CONVERTOR DESIGN CONCEPT

Throughout this program the design of the pyrolytic convertor has steadily evolved from a system initially suitable only for wood residues to a truly Indonesian design applicable for rice husks, and a detailed description of this development process is presented in a later section. However, basic to appreciating what has been done in the program is an understanding of the overall system design concept, and therefore this section is presented at the outset to provide the needed background information.

First, regarding the vertical, packed bed, partial oxidation process itself, the following discussion should provide an understanding of the basic principles involved. Thus, referring to Figure 1, it is seen that the system operates as follows :

Dry, pulverized feed, introduced at the top of the reactor, passes downward due to the force of gravity, through a pyrolysis zone. The pyrolysis gases produced are vented through the sides near the top of the reactor. Thus the counter-flowing, hot gases, generated in the lower bed, provide an exceptionally effective means to uniformly heat each downward flowing feed particle which in turn gradually is converted into char; thus releasing a quantity of pyrolysis gases and oil vapors. As the char descends further into the bed, it reaches the combustion zone where a relatively small amount of air is introduced. This air reacts with a small fraction of the char to produce hot carbon monoxide gas which transmits the heat generated to the feed and thus maintains the self-sustaining reaction. A careful balance between the downward flowing feed rate and the rate at which the char zone tends to grow upward keeps the char zone fixed in po-

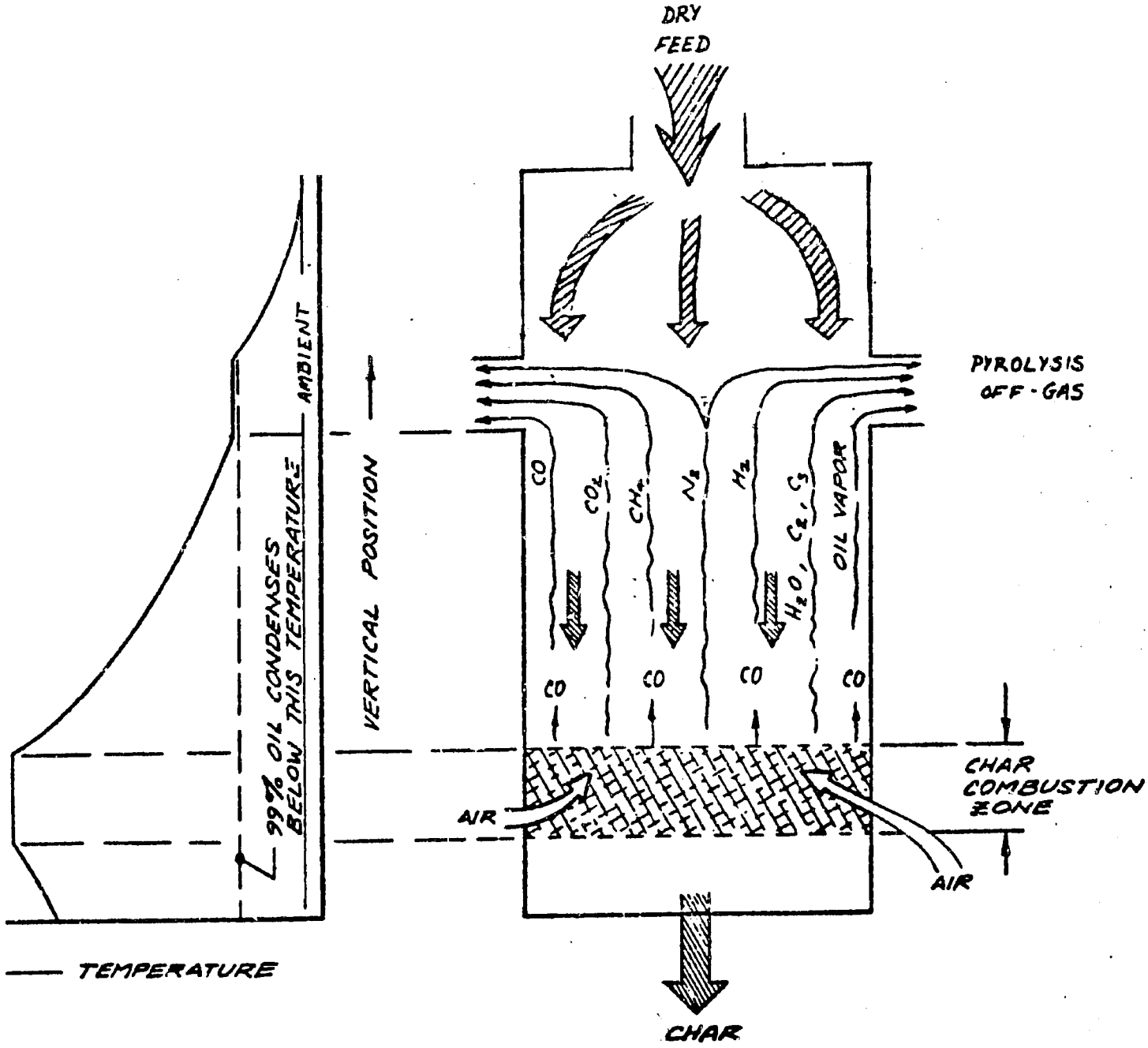


Figure 1

SCHEMATIC DIAGRAM OF STEADY FLOW, VERTICAL,
POROUS BED PARTIAL OXIDATION PYROLYSIS REACTOR

sition relative to the reactor. Upon leaving the hot zone, the char is removed from the convertor and cooled. The hot pyrolysis gases, and oil vapors (which exit from the reactor at a temperature greater than that where significant oil condensation occurs), pass through a condenser which removes the oily fraction with boiling points down to slightly above the dewpoint of the off-gas mixture which is typically 170-180°F. (This avoids the production of water which would dilute the oil and could present a serious disposal problem).

Dry feed is preferred because, if dehydration of the feed occurs in the bed, it can only be done so using the sensible heat of the gases produced, with the result that greater quantities of gas must be generated, a result counter to the objective of maximum char and oil production. On the other hand, if external drying of the (normally wet) feed is accomplished, the chemical energy of the gas can be utilized with the result that, by adjusting the gas production to the drying requirements, no energy is lost in the form of gas and maximum oil and char yields are realized.

Besides providing energy for feed drying, the gas can also be used to drive an internal combustion engine to power the various mechanical components necessary to operate the system (8) and to also provide power for external requirements. Thus while the gas is not seen as the principal product of the process, it is a valuable by-product that can be used very conveniently at or near the production site. The amount of gas produced can be regulated by adjusting the air-to-feed ratio, which in turn controls the char bed temperature. Hence, because the gas, char and oil yields can be readily varied, the process flexibility is another particularly attractive feature

of this design. Nominally, the process produces about 0.25 lb. charcoal, 0.15 - 0.2 lb., oil, 0.3-0.35 lb., gas, and 3 - 35 lb. water per pound of dry input feed.

This process has been developed in the U.S. to an advanced state using a capital intensive design approach. However to develop an Appropriate Technology pyrolytic convertor inevitably means the compromising of many design features, performance, and environmental constraints to gain economy, simplicity, reliability and maintainability. Thus there is little doubt that existing, more capital intensive convertors can provide higher performance than described here. But under the conditions for which they were developed, we believe the characteristics and performance of the designs discussed in this paper are sufficiently advanced to make them at least the basis for a first generation of economically practical conversion systems.

To illustrate the problems of developing an Appropriate Technology design; once the basic decision to use the partial oxidation pyrolysis process is made, several questions immediately have to be dealt with: i.e.

(1) How to make the process continuous so that oil and gas also can recovered without the use of expensive controls and input-output equipment?

(2) How to avoid the difficulties experienced in the U.S. with particulates in the off-gas which tend to foul the condenser?

(3) How to avoid corrosion problems using available materials?

(4) How to add the process air without blocking the internal flow and / or burning up the process air delivery system?

(5) How to separate out the oil aerosol and / or condense the oil vapor from the off-gas in a practical condenser?

(6) Using a manual technique, how to maintain proper materials flow within the convertor and avoid the bridging problems associated with conventional packed bed designs?

(7) How to maintain a fixed bed depth to insure a more uniform off-gas temperature; thus allowing proper condenser operation?

(8) How to develop a simple char output system that provides a uniform flow over the convertor cross section-as opposed to other systems that do not?

The design that has evolved to this date to best deal with these questions is presented in Figure 2. The convertor shown can be described as a "batch continuous" system which operates externally in a batch mode, but internally in a continuous mode-so long as the feed level is maintained above the submerged off-gas port. It bears a definite similarity to its earliest predecessor built by Tatom and Stone (6), even though at least three A.T. development generations have preceded it.

The basic idea is to store the feed within the reactor itself and thus-so long as the system is periodically refilled to provide a continuous flow of feed through the working section of the convertor, and thereby produce a practically constant supply of off-gas to the condenser at a nearly fixed temperature, but yet avoid the expensive material handling equipment and controls needed for a continuous system. The submerged off-gas port not only allows the batch continuous operation, but it guarantees a fixed bed depth and provides an effective means for filtering the gas through use of the bed itself, which forms a filter cake around the off-gas port (however there is a substantial pressure drop through the bedusing the technique). Moreover, since there is no free surface through which the gases must pass, and no continual addition of feed, as in conventional continuous systems, the fine fraction of the feed has little op-

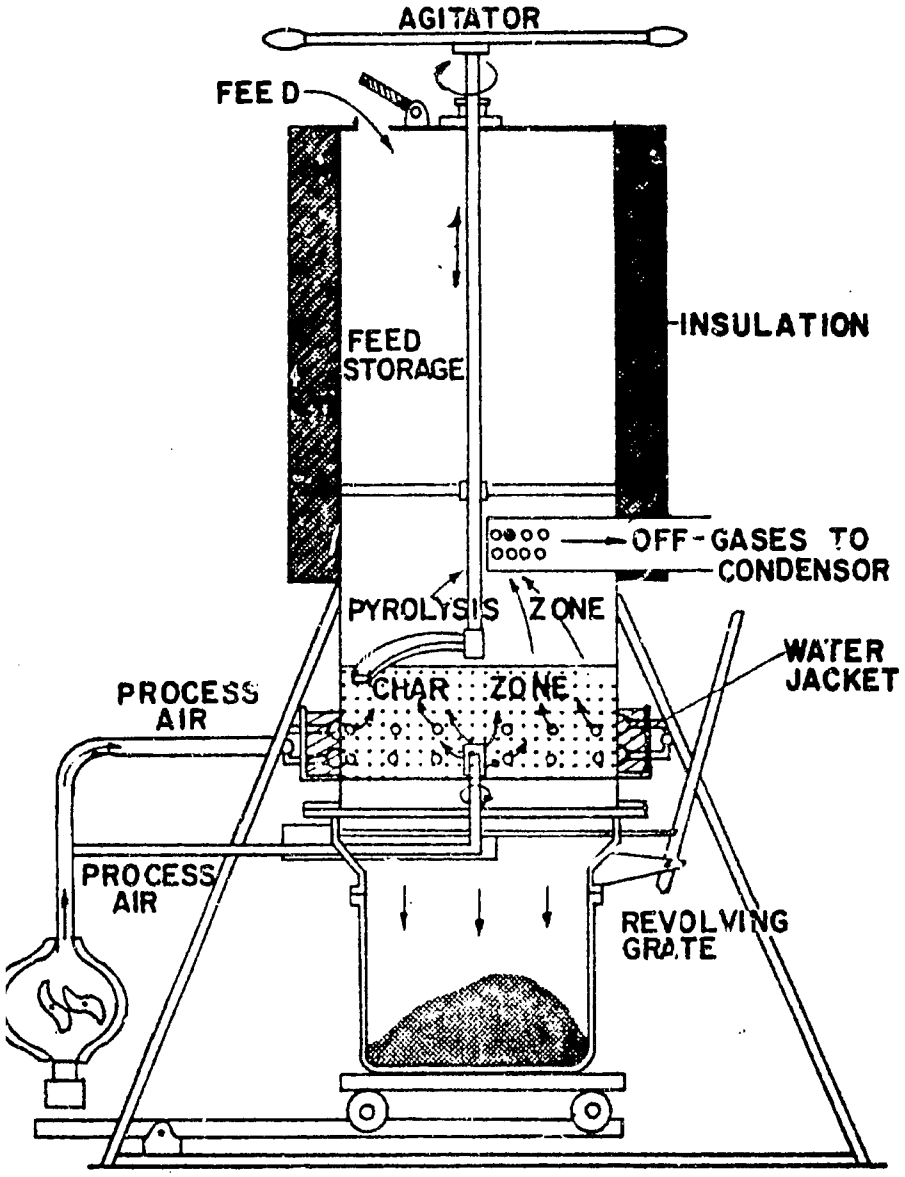


Figure 2. Appropriate Technology Pyrolysis Convertor

portunity to be carried away by the off-gas stream to subsequently clog the condenser.

Since the maintenance of a free-flowing condition within the feed / char inside the convertor is essential to successful system operation, every effort has been made to facilitate the flow. Thus the manually operated agitator, together with the conic shape of the convertor and the almost complete absence of any obstructions to the flow within the reactor effectively guarantee that the packed bed design will operate properly.

In early Indonesian units, the process air was introduced through the water jacketed convertor walls only. The resulting gases migrated to the entrance of the off-gas port which is located near the center of the convertor. Thus the flow was not vertical and hence the feed generally passed diagonally through the gases. An advantage to this arrangement is that the convertor walls are not exposed over a wide area to the hot off-gases. A disadvantage is that the depth of the bed may be relatively small, the degree of carbonization is considerably less near the center than at the walls and thus occasional penetrations of uncharred feed can occur, even at relatively low process rates and especially if sufficient agitation is not employed.

An important improvement, recently added to the wall process air introduction technique involves the use of a centrally mounted, water cooled, process air port to provide a more uniform air distribution, with more even charring of the husks; a condition allowing a greater feed throughput.[1] A jam-proof, slotted, movable top surface, rotary "star" grate-as opposed to the older sliding, perforated grate with a movable lower

[1] The basis of this improvement arise from a comment (7) by Dr. John Powell, Kumasi, Ghana, regarding a similar modification he made to the Ghana convertor to increase throughput.

surface design (8)-has been developed to complement the central air introduction. Compared with the older fixed top surface design, the movable top surface rotary grate stimulates a much more uniform material flow in the lower bed because of the large degree of bed agitation created during grate operation. This in turn eliminates the need for the lower bed agitator blade, which allows shortening the agitator shaft; a modification that avoids overheating problems. The blade itself is crescent shaped rather than flat and cuts rather than forces its way through the feed. All together these improvements, which are also indicated in Figure 2:

(1) substantially increase feed process rates.

(2) generate more uniformly carbonized charcoal and increased oil yields.

(3) significantly reduce the torque required to turn the agitator.

Their combined effect is to overcome the early shortcomings of the original Indonesian design (8) and to bring the feed throughputs up to the design rate, and the char and oil yields to near their nominal values.

The condenser/demister system chosen, and shown in Figure 3, is basically a compromise between performance and complexity, since to effectively remove all the fine aerosol oil mist in the off-gas leaving the convertor and to condense out the remainder without collecting an excessive amount of water requires a much more sophisticated system than believed practical for the application intended in Indonesia. Thus the condenser/demister design chosen involves no moving parts and is entirely cooled by natural convection. The off-gas-oil mixture from the convertor enters the unit and expands through a series of holes in the inside pipe. The resulting jets impinge on the inside surface of the outer natural convection cooled jacket, thus producing good local heat transfer and a high degree of turbulence and mixing as the resulting wall jets expand, collide, roll up, and are reintrained into the impinging jet flows. Thus a single fuild particle

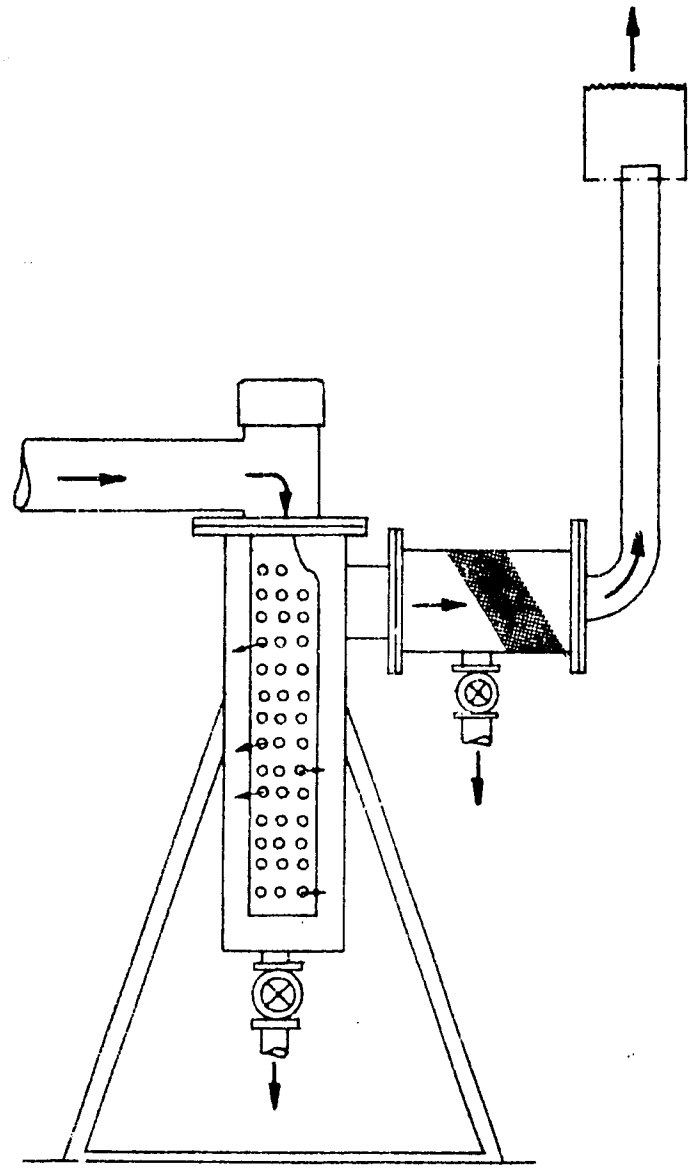


Figure 3. Pyrolysis Oil Condenser

in its complex path through the condenser, is effectivelly cooled and has many opportunities to collide with other particles to form larger particles or droplets and/or be collected on the outer condenser walls. The demister is of conventional design and uses available fiber to provide a matrix through which the condenser off-gases pass. Vegetable fiber "ijuk" from a species of palm tree has been successfully used for this purpose. The overall system takes maximum benefit of the effectiveness of the submerged off-gas filter technique, and with weekly maintenance operates free of the clogging problems that have plagued other condenser designs. Thus while its performance can no doubt be improved through further optimization, current oil recovery levels are acceptable, but not outstanding.

Regarding corrosion; while it is well known that the hot pyrolytic oils are acidic and thus could seriously threaten the condenser, it has been found that the tar in the oil in most cases tends to cover the exposed metal surfaces with an almost enamel-like coating that effectively protects them from excessive oxidation. However some problems with corrosion of the outer condenser shell have been encountered due to the scrubbing action of the impinging jets on its inner surface; a condition which tends to continuously expose the metal to the corrosive oil. Protection of this surface by use of locally available epoxy paint is currently being tried.

Moreover, while a metal matrix in the demister such as from lathe turnings is destroyed in a matter of days, the lifetime of ijuk appears to be indefinite.

Another area where corrosion must be confronted is in the water cooling system. However by use of automotive radiator rust inhibitors and / or by the introduction of water soluble oils, oxidation of the exposed surfaces can be practically eliminated.

PROGRAM DESCRIPTION

In the course of the project to date, two reactors have been constructed. The first, called the Technology Development Unit (TDU) was designed primarily for research and development and for crew training, and is currently located at the Lembang facility of the Development Technology Center. The second reactor was built to run in an operating rice mill and utilizes the best available technology, proven in long term operation. Photographs of these two units are shown in Figures 4 and 5. It should be understood that the development of these convertors, especially the former, has been an evolutionary process in which numerous modifications to the design have been made. Therefore, the configurations have changed continuously and it is not practical to describe all the technical variations evaluated. Hence only the more significant studies are discussed here.

Besides the reactor development work, a vigorous effort has also been made to devise means and equipment for utilizing the products of pyrolysis. Therefore, also presented here are descriptions of:

(1) the charcoal briqueting system developed, together with properties of the briquets.

(2) an off-gas burner for crop drying applications, and tests of diesel engine operation on the off-gas, including off-gas clean up equipment developed, together with properties of the off-gas.

(3) tests directed toward development of oil utilization equipment, together with a discussion of the properties of the oil.

Development Technology Unit

This convertor was commissioned in May 1979. The reactor itself cost US $ 776 (485,000 Rp.). The access platform, storage shed, diesel engine, blowers and other associated equipment cost an estimated additonal US $ 2054 (1,28 million Rp.).

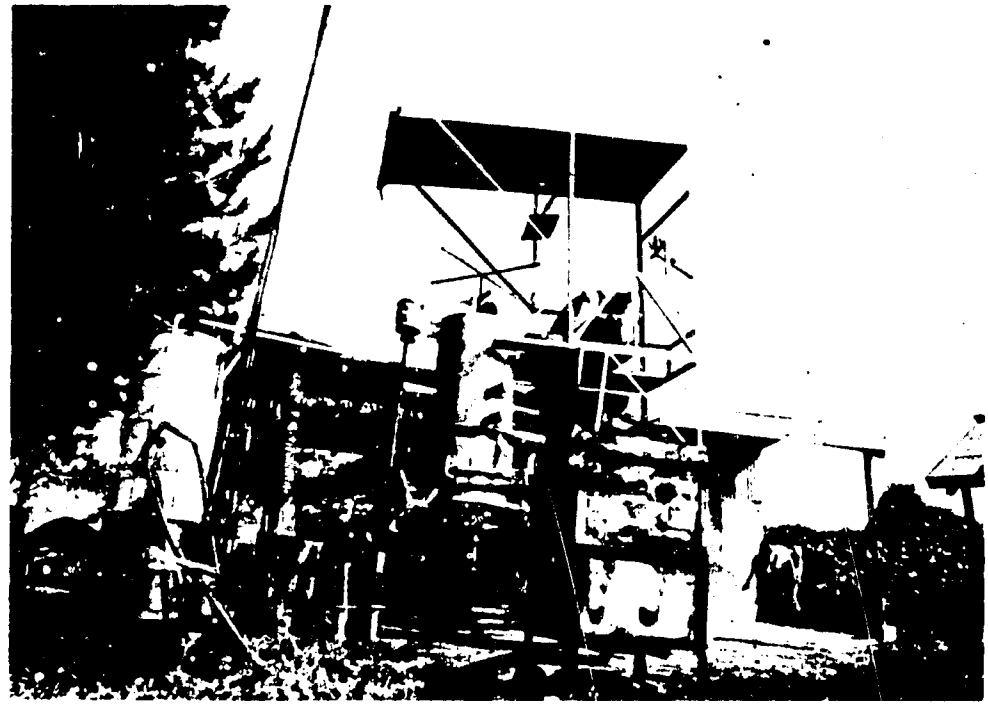


Figure 4

Lembang Convertor

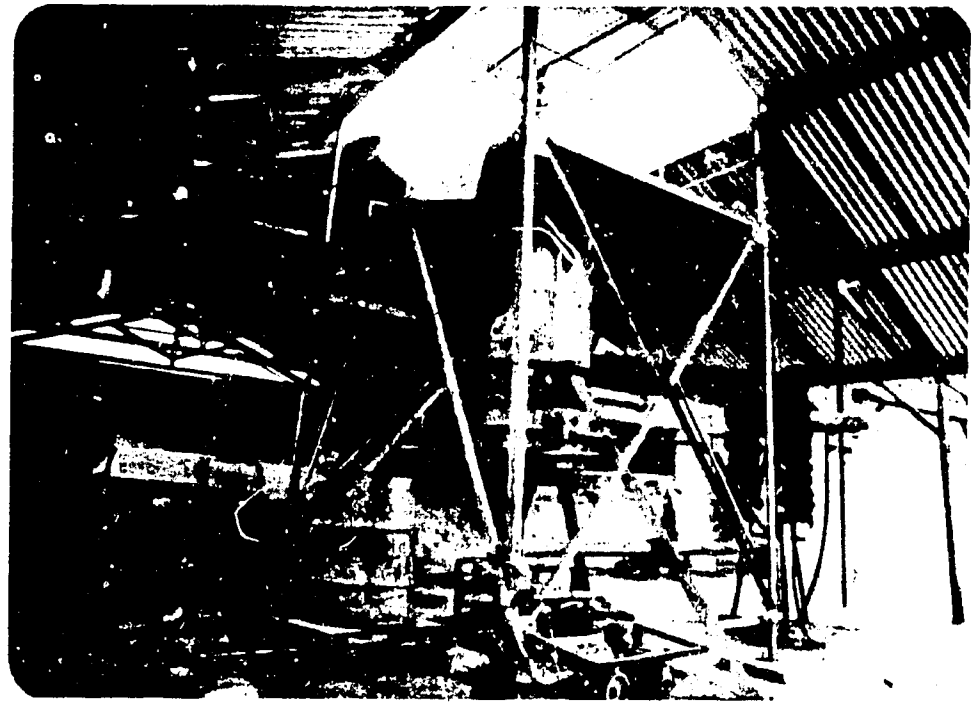


Figure 5

Ciranjang Convertor

While many technical improvements have been made using this system, its original principal purpose was to investigate alternative means of process air introduction and off-gas removal, with the object of avoiding as many obstacles to the materials flow within the convertor as possible. Process air configurations investigated were a pebble bed system used in the original convertor (6) and the Ghana and Philippines (9) systems and a flush mounted, water jacketed technique, wherely the air is introduced directly through the convertor walls. The primary objections to the pebble bed design were the very large fraction of the convertor cross section blocked by this component and the tendency of the design to cause the formation of hot spots resulting from cracks or channels created in the shear layer between the central, core flow and that above the pebble bed. In addition, a flush mounted off-gas system having four ports, manifolded together, and the simpler, internally mounted probe system used in the Ghana design were tested. It was hoped that succes using the four flush mounted ports would allow removal of the internal probe which does present some obstruction to the flow. However, from the start it was also recognized that the resulting internal gas flow patterns might leave a relatively uncharred core in the convertor center, since the shortest path for the gases would be along the convertor walls.

System Description. The convertor stands 2.35 meters tall, has a base diameter of 0.84 meters and a top diameter of 0.70 meters. It is built of mild steel, typically two to three millimeters thick. Instrumentation includes a process air orifice, and dial thermometers for measuring bed, convertor off gas and condenser off-gas temperature. In operation the rice husks are added at the top and charcoal removed at the bottom through the grate. Process air is introduced near the bottom of the system and the resulting gases passes upward to exit through the off-gas system and then enter the condenser/

demister which removes the oil-tar fraction.

System Operation. The system is started by first introducing charcoal from the previous day's operation up to the level of the top layer of air holes. Burning charcoal briquetes are then put into the convertor and are subsequently smothered by the feed which fills up the storage section. The process air is then introduced at about 10 to 20 percent of the full steady-state flow rate and is slowly increased. After several hours the temperature of the off-gas begins to rise rapidly and limited actuation of the grate is initiated. Gradually the process air rate is increased and the removal of charcoal accelerated until the desired operating condition is reached.

Perhaps the two most important indices of system performance are the convertor and the condenser off-gas temperatures. If proper control of these two is maintained and correct interpretation of variations in these temperatures is made, the system operation can be relatively routine. To illustrate: the average convertor off-gas temperature is not only important so far as oil production is concerned, but rapid increases in it may indicate the formation of cavities in the bed, while decreases may suggest that char is being removed too rapidly. Likewise the condenser off-gas temperature must be maintained above the dewpoint of the mixture to avoid water condensation, but not so high as to reduce the oil yields. For rice husks with a moisture content of about 14 percent, an ash content of 20 percent, and at a bed depth of about 0.30 meters, the desired convertor off-gas temperature lies between 120°C and 140°C while the condenser off-gas temperature is around 85°C.

Once the desired conditions have been reached and the planned process rate established, the system can be operated in a steady-state mode. This may take four or five hours from a cold start, or two to three in a run where hot char from the previous days operation is in the convertor.

During the steady mode operation, feed is added about every 30 minutes, the char grate opened for a few seconds 30 to 40 times each hour and the char drums emptied every hour. To prevent burning, the char is stored in sealed barrels while it cools. The oil is periodically gathered from the condenser and demister. Typically the condenser recovers about three quarters of the total oil while the demister recovers the remainder.

Except for a total of three or four minutes each hour when feed is added and / or the char drums changed, the system operates continuously. During these filling/emptying periods the air supply is shut off and operations halt. However, the thermal capacity of the system is sufficient to insure that only minor changes in temperature occur during these periods. The result-so far as char production and oil production are concerned-is that the operation is effectively constant. However, because the off-gas flow too is interrupted, measures must be taken either to store a short supply of the gas or to restart the gas utilization system-using a single convertor. With several convertors, manifolded together such as in Ghana, the operations can be staggered with no interruptions in off-gas production.

Since by its nature the system involves a minimum of instrumentation, it is vital that maximum use of every other indicator be made. For example, abrupt changes in capstan torque can suggest cavity formation and indicate the need for more agitation. Likewise, the average torque is a measure of bed depth and-during start up-of the degree that charring of the bed has occured. The color of the char also is a measure of convertor performance. Hence uncharred material suggests too rapid a throughput, while greyish white char indicates the process rate is too low. Even the characteristics of the boiling in the water jacket can provide useful information regarding the internal condition of the reactor. Excessive, or film boiling at specific points indicates hot spots, most likely due to the presence of cavi-

ties in the bed and suggests the need for more agitation of the bed.

Initial Test Results. Since the combination of direct introduction of process air through the convertor walls and the flush mounted off-gas system is so attractive, in that it minimizes internal resistance to flow, it was investigated first. Thus a series of tests were conducted to see if this combination would operate satisfactorily and with good performance. While the water jacketed process air system worked extremely well, there was no problem in materials handling, the convertor off-gas temperature was in the desired range, and good char yields were achieved, it was found that gas production was excessive. While the oil was clean, the yields were low, the maximum throughput was less than half that for which the system is designed, the air-to-feed ratio ran well in excess of unity, the gas heating value was disappointing and excessive heating of the uncooled walls above the water jacket occurred. It was thus concluded that the short circuiting of the off-gas flow that had been feared, did indeed occur, and while some pyrolysis was present, a significant amount of gasification took place near the convertor walls. Therefore since greater throughputs and oil yields were desired, it was decided to abandon this configuration and to test the sub - merged off-gas port in combination with the water jacketed process air system.

This led to a second, more promising test series. At first, the bed depth was operated at 0.50 meters, which in the Ghana program, using five to seven percent moisture hardwood feed, had been satisfactory. But it was found that while improved process rates were obtained, much lower air-to-feed ratios were achieved, and gas production was moderate, the convertor off-gas temperature was too low and oil recovery was still disappointing. The low oil yields were attributed to the low off-gas temperature obtained, with the presumption that significant oil condensation occured in the bed.

Since the current philosophy is to try to avoid the need for a mechanical drier and to use the husks as they are produced, the feed moisture content typically runs at about 14 percent of the wet weight. Thus this relatively high moisture fraction, together with the high silica content (20 percent) of the husks was believed responsible for the low off-gas temperature and oil yields, since in tests with wet feed reported in (2) similar disappointing oil yields had occured. Therefore a series of tests at a bed depth of only 0.23 maters was conducted-in an effort to raise the off-gas temperature. The results of these tests are presented in Table 1. Study of the results reveals that the char yields are well in excess of those expected from the data correlations in (1) and (2) at the air to-feed-ratios used. This is believed due to oil condensation in the bed because of the high feed moisture content. On the other hand, recovered oil yields are very low. However, the table shows that the trends of increasing oil yield and decreasing char yield with increasing air-to-feed are similar to those reported in (1) and (2). The consistency of the data, with one exception, is encouraging.

Initial Test Results
Table 1

Test No	Air/Feed (kg / kg, dry ash free)	Feed Process rate (kg/hr)	Average Convertor off-gas Temp. (°C)	Average Condensor off-gas Temp. (°C)	Char yields (kg/kg, dry ash free)	Recovered oil yields (kg / kg, dry ash free)
1.	0.633	64	121	93	0.247	.033
2.	0.732	47	150	93	0.218	.045
3.	0.596	50	132	85	0.255	.028
4.	0.63	47	135	82	0.251	.025

While the recovered oil yields were quite low, it was observed that significant quantities of oil were lost in the off-gas stream, apparently due to inadequate condenser/demister performance, and thus with proper optimization of this system it was concluded that oil yields at least equivalent to those reported from Ghana (8) could be realized, if the feed moisture content were brought down to the desired five to seven percent.

In numerous subsequent tests involving several thousand kilograms of husks, the basic system performance was verified, with average ash-free char yields of 24.1 percent and average oil yields of 3.7 percent realized-both on a dry ash free input feed basis. However, the average throughput was only about 44 kg/hr of husks-although, on occasion, process rates up to 65 kg/hr were recorded. Since the unit is designed to process 100 kg/hr, this lower than expected average rate was of special concern, since the overall system economics (as discussed later) are strongly influenced by system throughput. It was initially thought that with an improved process air supply, the throughput would easily reach the design value. However, experience taught otherwise, and it was found that even at very high air-to-feed ratios, above a certain process rate, uncharred husks began to penetrate the char layer-primarily near the convertor center-and pass into the char drum. This suggested that better distribution of the process air was necessary; in particular, a supply of air near the reactor center needed to be provided.

Besides the limited process rates, several minor problems were encountered with the reactor operation. These problems, together with their solutions are listed below:

(1) Over an extended test period, rusting of the exposed water jacket surfaces occured. This was resolved by addition of a water soluble oil additive.

(2) Buckleling of both the moving and fixed grate surfaces occurred after a number of tests. This problem was overcome by the use of a heavier gage metal and a redesign of the grate itself.

(3) The torque initially required to turn the agitator was greater than a man could generate. This situation was corrected by a more careful design of the agitator blades and a reduction in the number-by judicious choice of their location on the shaft.

Recent Test Results. As mentioned previously, in an effort to increase the feed process rate and to generally improve convertor operation, a major modification to the lower grate section of the TDU has been made recently. The primary changes were the addition of a centrally mounted, water cooled, process air port, the introduction of a rotary "star" grate with a movable top surface, and the shortening of the agitator. These additions are shown in Figure 6. Recent tests of the improved system indicate that without doubt, these improvements have together had a greater effect on convertor performance than any of the changes made so far. However, since these modifications have been made so recently, there has been little time to develop on extended set of test data, and at this time only the following statements can be made i.e.

* First and most important, the rice husks throughput has now been raised, in repeatible tests, up to 1[illegible] kg/hr, which is well above the design value of 100 kg/hr. Of particular interest is the fact that as this limit is reached, the charcoal gradually changes from a rich black color to a general brown, uncharred condition, as opposed previously to an over charred, grey color of the char near the walls together with an uncharred core when the maximum process rate was reached. This clearly indicates that the desired condition of a near uniform process air introduction has been achieved. At this process rate, the system economics are very favorable, as the later analysis demonstrates.

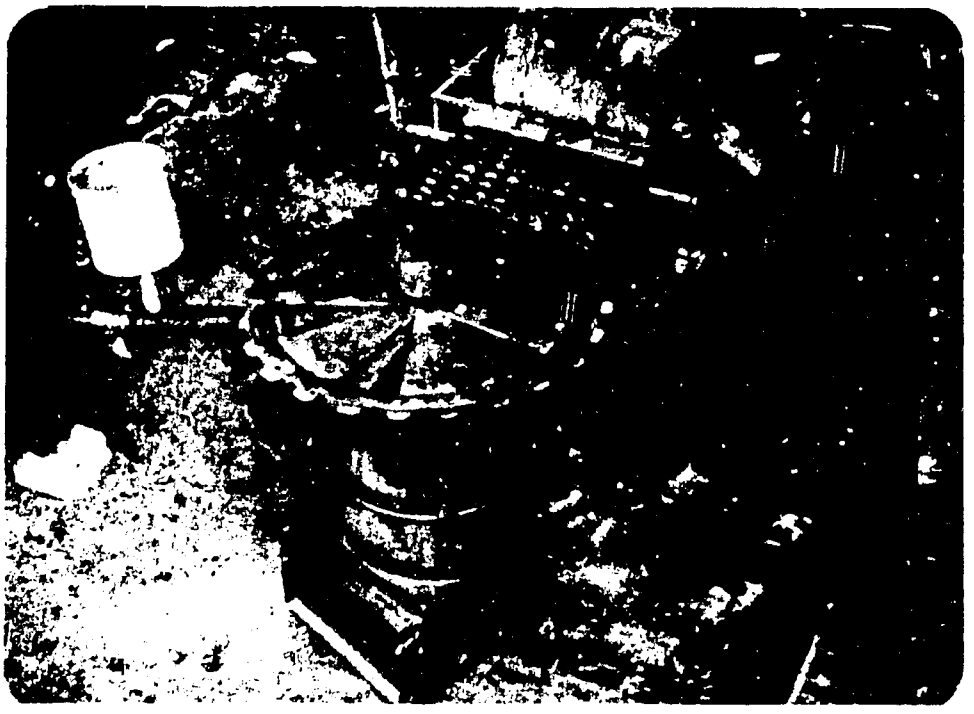


Figure 6

Star Grate, Central Process Air System

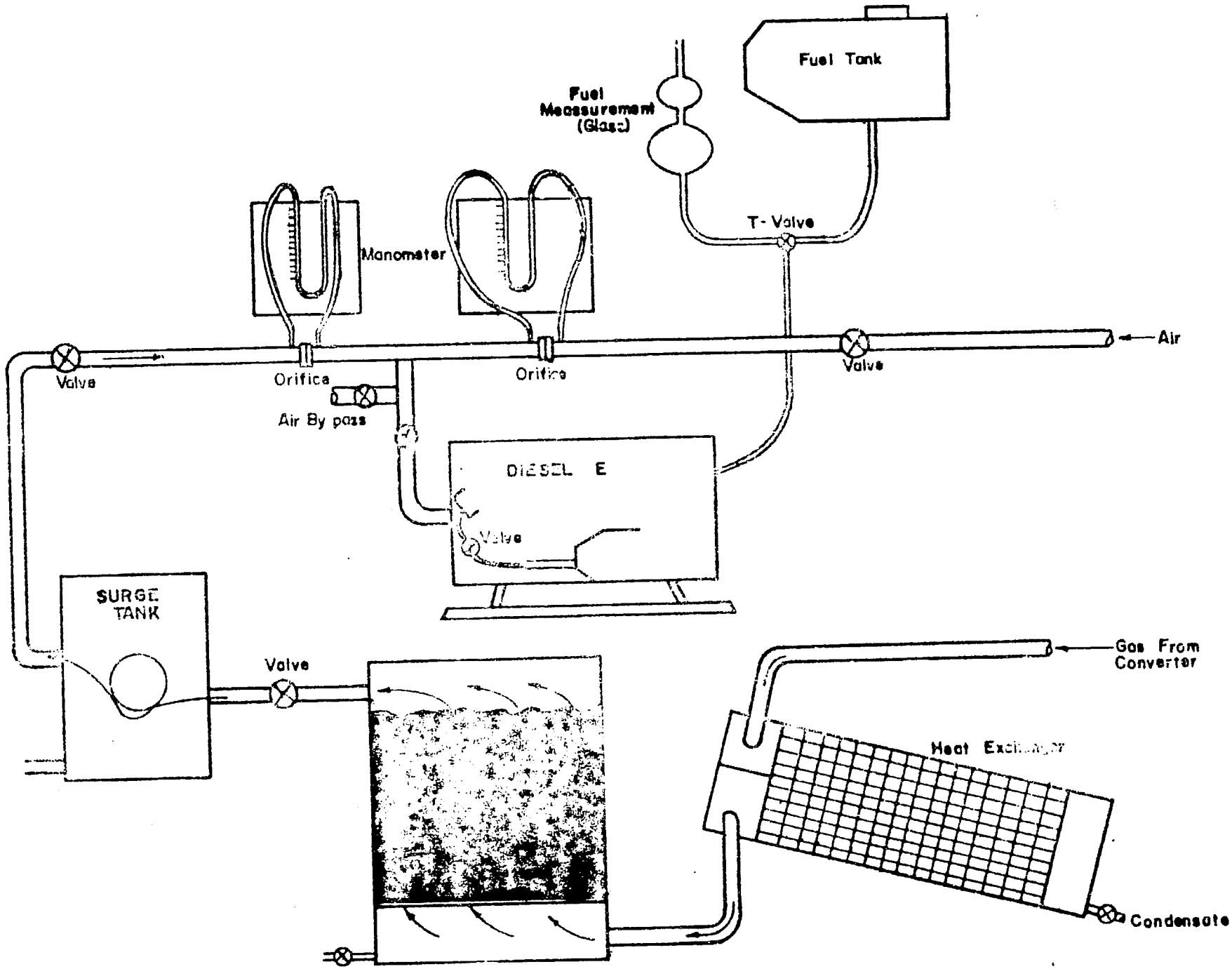


Figure 15.

Off-Gas Cooler Filter Schematic for Diesel Engine Operation

* Second, the oil yields have now been almost tripled over previous results and are now nearly ten percent. This also represents a major performance improvement that turns the oil from a by-product status back into one of the major outputs of the convertor, although the yields are still 35 percent below the hoped for values. This result has been accomplished through better operating techniques and because of the lateral uniformity of the bed temperature field produced by the improved process air introduction technique.

* Third, the water cooled, central process air introduction system has suffered absolutely no damage due to the increased heat release and high temperatures of the adjacent charcoal.

* Fourth, the new grate has demonstrated significant operational advantages over the earlier design, has reduced bridging problems, and has suffered no damage or warping whatsoever in its operation, although minor problems with locking up of the linkage mechanism that rotates the grate have indicated that more care in its fabrication is necessary.

* Fifth, the reduced torque required to operate the shortened, single bladed agitator has substantially increased crew acceptance and encourages them to not abandon the neccesary stirring activities, which previously represented a major physical exertion, and all to often were left unattended.

Ciranjang Convertor System

This reactor is currently operating at the Sukasari rice mill in Ciranjang which is a one and one half hour ride from Bandung on the road to Jakarta and serves as a field test system to complement the Lembang facility. This convertor was installed in October 1979 at a cost of US $ 4084 (2.54 million Rp.) including the access platform briqueting plant, storage shed, diesel engine, blowers and other associated equipment. It was orginally designed to take advantage of the TDU experience and technical improvements

developed to that date and has now been upgraded to include the improved process air, grate and stirrer described previously. Thus it has a heavy duty grate with a movable upper surface, a better char removal system, an internally mounted probe off-gas system, a larger access platform etc. The primary purpose of its installation so early in the program was to get a maximum amount of real world program experience as quickly as possible even at the expense of some inefficiencies due to working in the field. This was because of the opinion that many operational problems, not recognized in a controled test situation, would probably arise and, in turn, result in the need for modifications in equipment and/or procedure that could be embarrasing if recognized too late in the program. To date this unit has been well worth the extra expense and work associated with its operation.

So far, the performance data from this unit indicates that the char and oil yields are very close to those with the TDU. Therefore since its operation and performance are so similar to that of the TDU, there is little reason to further describe this program except to note that apparently since the feed moisture content is slightly lower in Ciranjang, the oil yields have been incrementally better than those in Lembang.

Charcoal Briqueting

Since the rice husk charcoal, as produced, is a coarse powder, it must be briqueted before it can be successfully used for cooking, because in its initial form it is not suitable for char brazier or stove use. Therefore some method for briqueting it must be devised. A simple approach is to use an agglomeration technique, rather than mechanical pressure, to form these briquets. In so doing, both energy and capital are minimized but at the cost of a reduced briquet quality. The technique devised as part of the project is to:

(1) load a rotary, 55 gallon oil drum ("ball mill") with the charcoal and

several pipes or stones and then to rotate the mill until the charcoal is finely powdered. This takes approximately 15 to 20 minutes.

(2) Unload the pipes and/or stones, add a mixture of cooked starch, and water, to act as a binder, to the powdered charcoal and then turn the drums for 15 or 20 more minutes. The resulting tumbling action together with the binder tends to cause the charcoal to form into balls.

(3) Unload the resulting "fireballs", which range in diameter between one and two inches, place them in the sun and allow them to dry for several days.

Figures 7 through 10 illustrate part of the sequence described above.

Initially, cooked waste cassava pulp from a local starch mill, in a ratio of 2.5 parts charcoal, one part cooked waste cassava pulp, and 3.5 parts water, was used successfully as a binder, and the briquets formed burned cleanly and without odor or smoke. However, since the waste cassava pulp is not available everywhere, a binder using cooked, pure starch (which is for sale in almost every market) and mixed in the ratio of 20 parts charcoal, one part starch, and 20 parts water has also been success fully tested. The results are again good quality charcoal briquets, although in both cases their density is not quite as great as would be desired.

The production of the fireballs has been accomplished by means of an electric motor driven laboratory prototype shown in Figure 11 and by a manually operated system shown in Figure 12. To date, the laboratory prototype has generated sustained production rates of 21 kg/hr of briquets, which is less than half that required to match charcoal production from a reactor operating at its design capacity. However, improvements in the laboratory operating procedure, using a single unit already demostrated should increase production to the point that two mills of the size shown will easily keep pace with a single reactor. Production of briquets from the manually operated

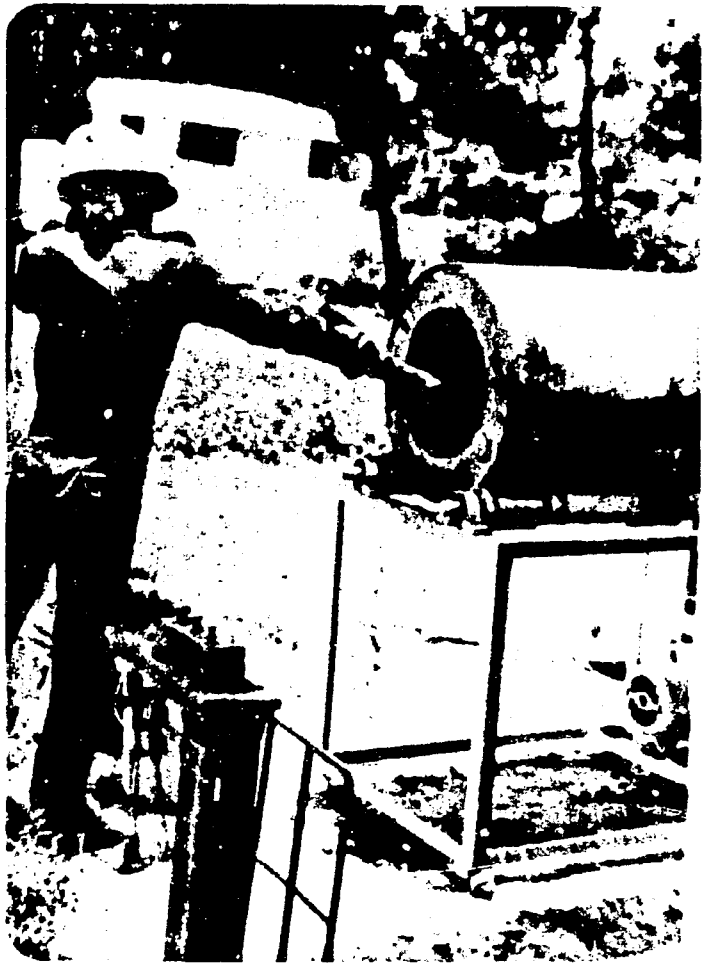


Figure 8

Fire Balls formed in the Mill

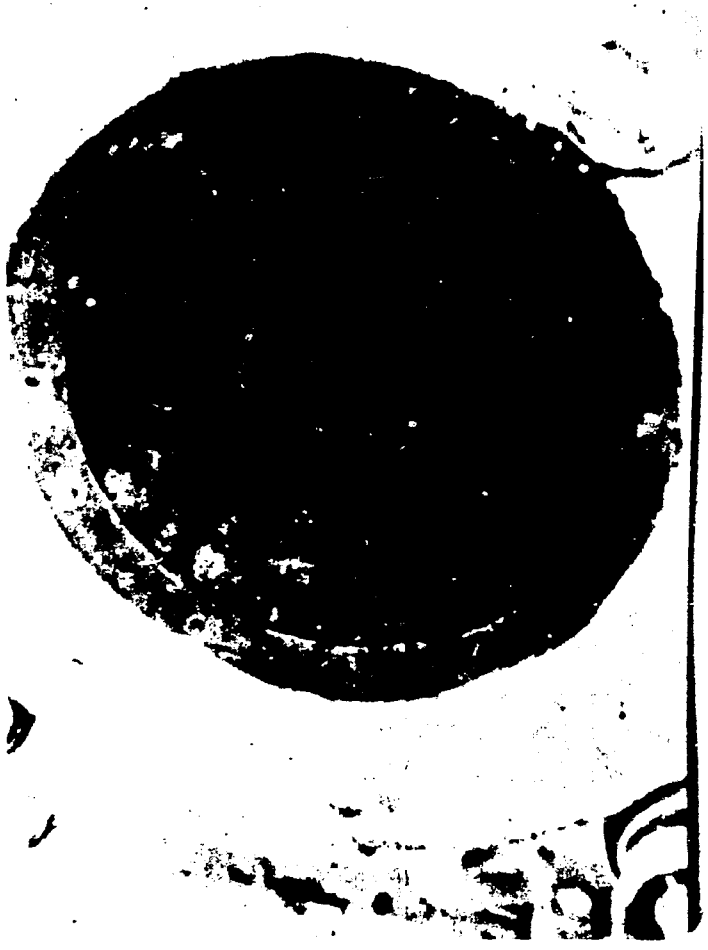


Figure 7

Loading the Briqueting Mill

Figure 9

Unloading the Fire Balls

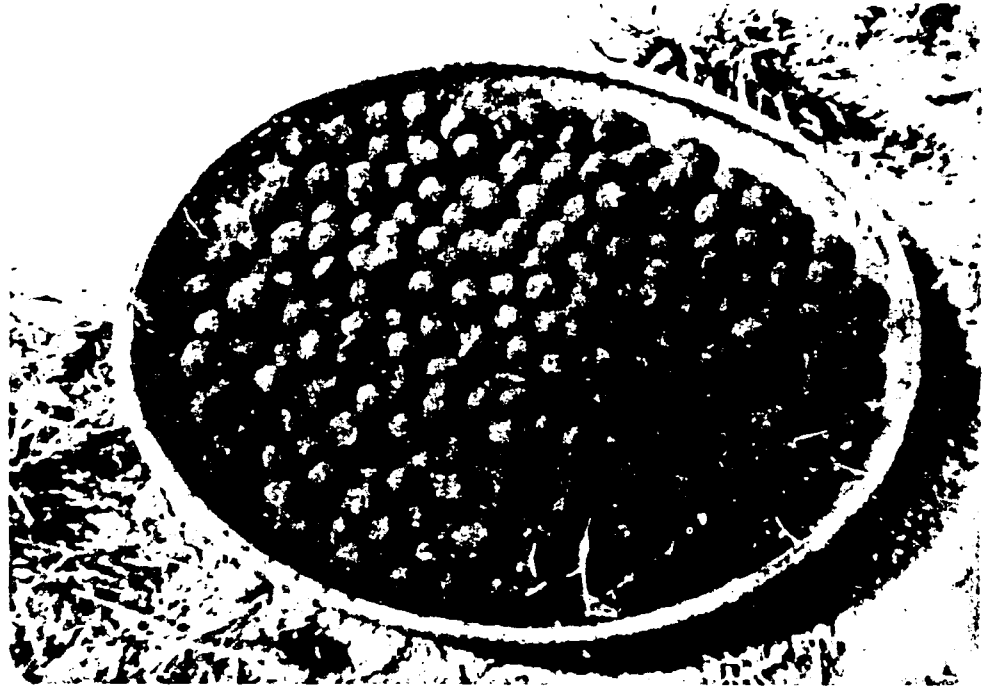


Figure 10

Sun Drying the Fire Balls

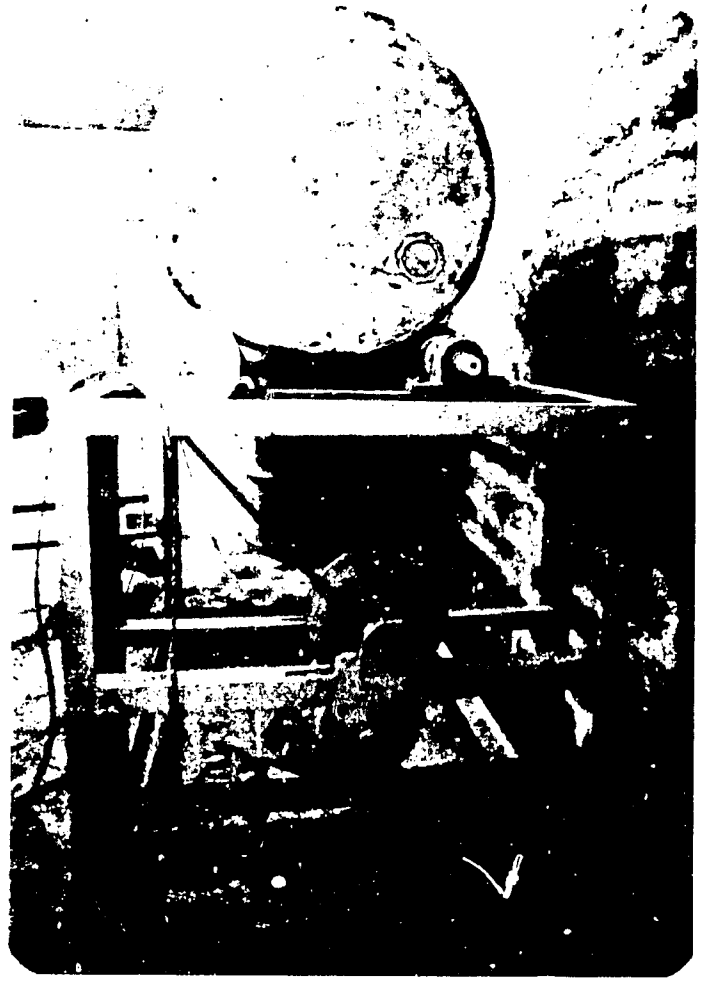


Figure 11

Mechanized Briquet Mill

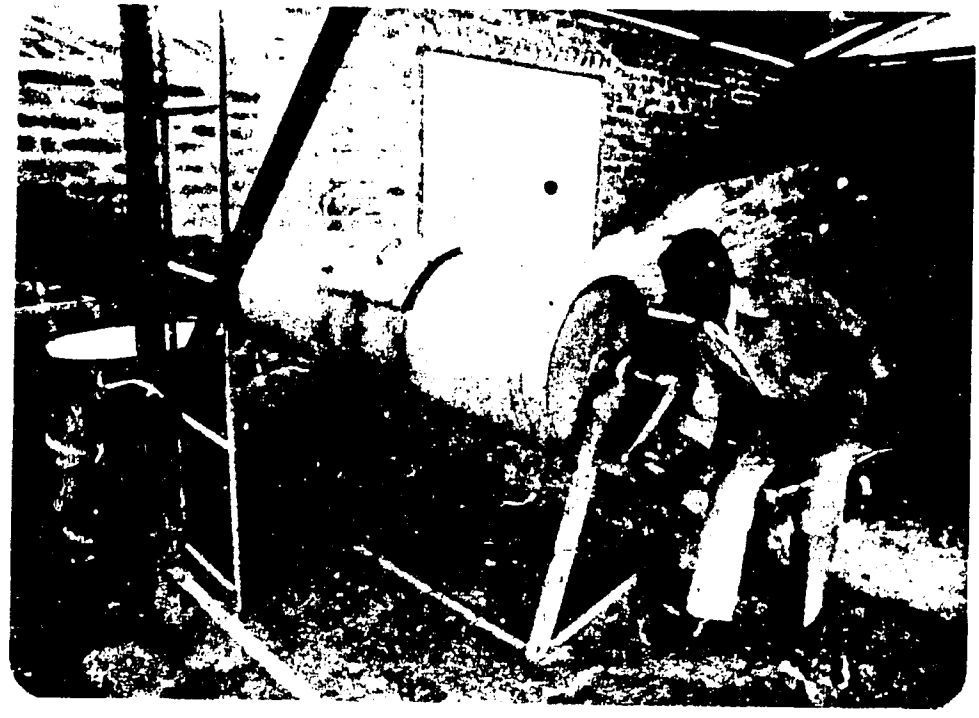


Figure 12

Hand Operated Briquet Mill

unit has not lived up to initial expectations because the large torque required to turn the loaded system makes it difficult for a single man to operate it. Hence, redesign and down-scaling of this component is currently being made.

While the overall product utilization strategy involves distributing the fireballs only in the neighborhood of the rice mill production site and thus exposing them to minimal handling, there is still some question as to the general structural ruggedness that the briquets must possess. Therefore, in a series of tests which represent an extreme condition to which they would be exposed, the briquets were droped two meters on solid concrete to investigate their impact strength, which was felt to be the property of primary concern. As part of the tests the degree of drying was also varied to see if there is an optimum drying time so far as handling properties are concerned. The results of these tests are tabulated in Table 2 and presented graphically in Figure 13. From the tests, it appears that after 4 days drying, the number of broken briquets is minimal and the drying is esentially complete. Therefore, after four days it appears that the briquets can be most easily transported and with a minimal breakage. However, it should be noted that after the briquets have dried for several months, they become very brittle and suffer badly from impact. Therefore, every effort must be made to get the briquets into the hands of the ultimate user as quickly as possible after they have been produced. This should not represent a serious problem, however, since the distribution of the briquets would normally be only over a few kilometers. But it does loudly proclaim that the briquets themselves should not be stockpiled and if storage is necessary it should be done using the bulk charcoal only.

exposed metal surfaces with tar droplets that may remain in the stream. This then is the real technical challenge of this phase of the project and work to improve the gas clean up techniques is continuing. In addition, considerable study of the dry off-gas composition has been made and typical elemental gas breakdowns are shown in Table 3. The heating value of the dry gas should be in the range of 170 to 180 Btu/ft^3, with the compostions indicated.

In an early series of tests, a 6 hp Yanmar diesel engine, driving a 3 kw generator and utilizing a very simple carburetion and gas clean-up system, demostrated a sustained 30 percent fuel reduction, when operated in combination with the pyrolytic convertor off-gases. While this is far short of the hoped for 85 percent reduction reported in the literature, it still represented a good start, especially since there was clearly a great quantity of water vapor present in the gas.

In a current series of tests in which improved gas carburetion and gas clean up/drier systems are used, further efforts to reduce diesel fuel consumption are being made. The new system includes a natural convection cooled, two pass, fin tube condenser designed with convenient access to the tubes for easy cleaning. The system, together with a packed bed using the rice husks as the filter media, is designed to essentially remove all the aqueous material in the off-gas and to filter out any submicron particles remaining. To complement the new clean-up system an upgraded engine carburetor/fuel control system, based on suggestions (10) by Mr. C.V Pederick of Western Australia, who is a pioneer in producer gas engine operation, is also being evaluated. This overall system is shown during early tests in Figure 16 and shown schematically in Figure 17.

Table 3

Dry Pyrolysis Gas Composition

Sample Number	Percent Volume Compostion				
	H_2	N_2	CO	CH_4	CO_2
1	9.74	59.91	18.55	3.06	8.74
2	10.42	56.46	23.61	3.04	6.47
3	10.78	59.92	21.72	2.4	5.16
4	10.7	56.01	22.54	3.33	7.39

Note: It should be recognized that typically there are one half pound of water per pound of dry gas produced. Therefore the above results do not apply to the gas leaving the condenser, but only to the dry gas.

Perliminary testing indicates that the engine operates smoothly on the off-gas, the use of which reduces the diesel fuel consumption by more than 60 percent. The new cooler-filter system works much better than the original, reduces the gas to nearly ambient temperature, and removes practically all the water. However, there still is a residual amount of tar, in an aerosol form, that is suspended in the gas and which must be removed to avoid long term engine damage. Currently a second packed bed filter using a mixture of charcoal and lime as the filter media is being evaluated for this purpose. It is hoped that the lime will chemically neutralize the oil with the result that the corresponding liquid-to-solid phase change will make the filtration easier. Then working together, the charcoal and the fine silica particles present in the new filter in combination with the second stage rice husk filter will remove the resulting solid particles.

Table 2

Fire Ball Weight Loss and Drop Test Survival

Time (Days)	Total Ball Weight (grams)	Number of Balls		Percent Survival	Percent Initial Weight
		Broken	Survive		
0	553.1	20	0	0	100
1	424.9	20	0	0	76.8
2	377.8	13	7	35	68.3
3.	337.9	2	18	90	61.1
4	318.5	0	20	100	57.6
5	315.8	0	20	100	57.1
6	311.6	0	20	100	56.3
7	302.5	0	20	100	54.7

Notes : (1) Drying time was 5 hours/day

(2) Fire Ball composition = 20 parts charcoal, 1 part starch
20 parts water

(3) The drop distance was 2 meters on a concrete slab

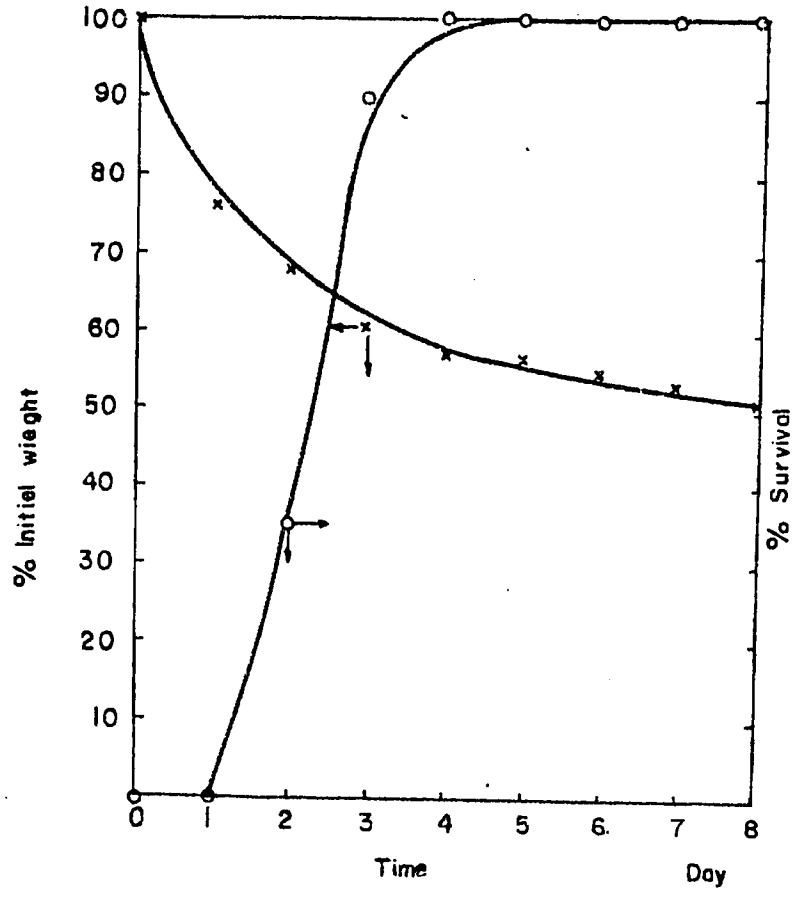


Figure 13

Fire BAll Weight Loss and Drop Test Survival

Therefore it appears that with reasonable care, there should be little, if any problem, in the transport of these briquets for moderate distances.

Because of the high (20 percent) silica content of the oven dry husks and the resulting concentration of this element in the charcoal, only about 50 percent of the char is actually carbon. Therefore the heating value is correspondingly reduced. Calorimeter tests of the briquets indicate an average heating value of about 6770 Btu/lb (3762 cal/gm) as opposed to a heating value of 5697 Btu/lb (3165 cal/gm) for the 14 percent moisture husks. Thus the charcoal has only about a 19 percent higher heating value than the husks. However, it must be remembered that the briqueted charcoal is a much, much more conveniently useable, smokefree, socially acceptable fuel than husks alone. Moreover, the fireballs have a bulk specific gravity of 0.32 or a bulk density of about 20 lb/ft^3. Therefore compared with the husks, which have a bulk density of only about 8 lb/ft^3 (0.13 gm/cm^3), they are much more convenient to transport. On a volume basis, the briquets have a bulk "energy density" of about 135,000 Btu/ft^3 (1204 cal/cm^3) as compared with rice husks with a bulk energy density of only 46,000 Btu/ft^3 (411 cal/cm^3). Therefore, overall they are a much more desirable fuel than the husks alone. Moreover, the opportunity to utilize the oil and gas associated with the charcoal production would not be present if the husks were burned directly.

While there is little doubt that higher density briquets-produced for example, by a high pressure mechanical press-would be desirable, there is some question as to the practicality of so doing, both in terms of the energy required, and the production levels attainable. However, since the answer to this question is unclear, not only are efforts continuing to improve the agglomeration technique, but the application of a modified Cinva ram is also being studied, with the idea of producing larger, stove size briquets, if possible.

Because the heat of combustion from the fireballs is only half that from charcoal, a question has been raised whether the combustion temperature

of the fireballs would be high enough to properly cook food. It can be theoretically argued, assuming radiation to be the dominant heat transfer mechanism, that the average radiating absolute temperature of the fireballs ($\bar{T}_{fb}$) is equal to that of the charcoal ($\bar{T}_c$) divided by the fourth root of two,

i.e. $\bar{T}_{fb} = \dfrac{\bar{T}_c}{[2]^{.25}} = \dfrac{\bar{T}_c}{1.19}$. In that case, since the known combustion temperature of the charcoal is approximately 950°K (~ 675°C), one would expect the fireballs to produce an average surface temperature of about 800°K (~ 525°C) which is more than sufficient to cook any Indonesian food (or any food anywhere else, for that matter).

To verify this conclusion simple tests of the temperature of the burning charcoal and the burning fireballs were made as a function of time. In the tests, one half kg samples were burned in a standard "Anglo" clay stove or brazier and the temperature measured using a thermocouple. The results of these tests are presented in Figure 14. It might be noted that in the figure time zero has been taken as that point when the briquets actually started burning, and thus the data does not include the period when the kerosene starter was still ignited. While the data shows some fluctuations in the temperature history, in both cases, a characteristic similarity between the two sets of data is present in that both show a rapid rise to a maximum and then a gradual fall off with time. Graphical integration of the two curves results in values of :

$\bar{T}_c$ = 962°K (or 689° C)

and

$\bar{T}_{fb}$ = 789° K (or 516° C)

The ratio of the measured absolute temperatures is 1.22 or about 3.5 per cent above that expected. Considering the roughness of the test, this is believed to be a surprisingly good confirmation of the expected results.

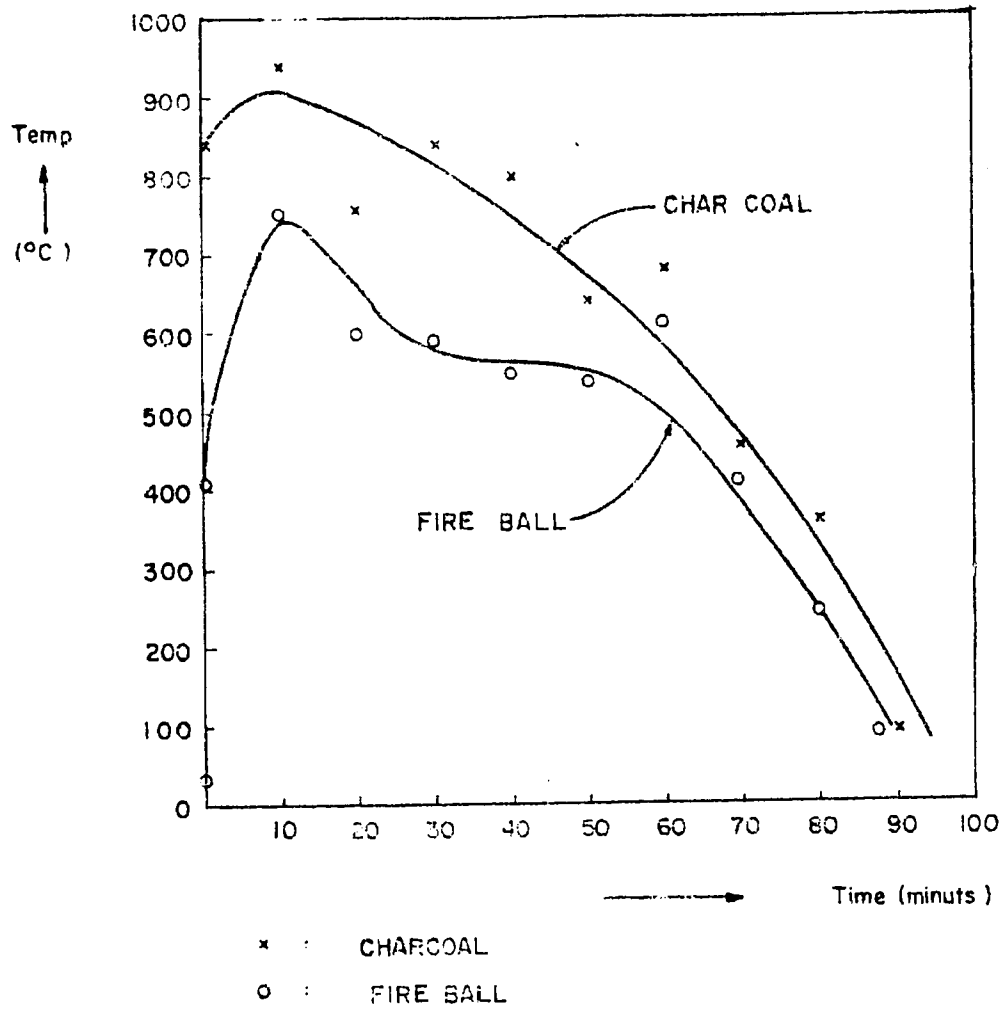


Figure 14. Combustion Temperature Histories for Charcoal, Fire Balls.

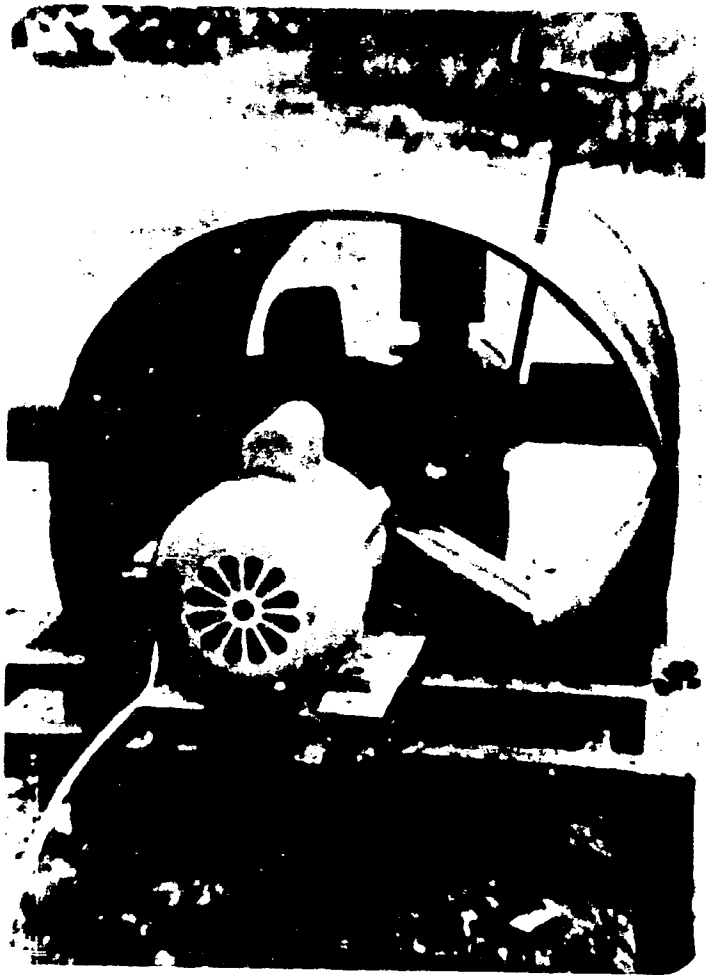
A final remark regarding the start up process; it has been found that the fire balls, because of their composition, shape, and the absence of any corners or crevices, are often difficult to ignite. This is true of most briquets and is nothing unique to these. It has been found, however that if the fire balls are laid on top of a few ordinary pieces of charcoal, which can be ignited easily, the mixture quickly is afire and demonstrates all the smokeless properties of burning charcoal.

Finally, it might be noted that when completely implemented, the above charcoal production system, on the island of Java alone, has the capability of producing about 1.5 million tons of charcoal briquets each year. This would entirely satisfy the cooking needs of at least ten million people, or more than eleven percent of the island's population. Therefore it should be apparent that the potential contribution of the rice husk charcoal as a domestic energy source is quite substantial. In combination with the development of improved stoves, this contribution could be several times greater.

Off-Gas Burner System

Since the gas represents a valuable energy source for drying of the padi, and because mechanical drying is becoming increasingly attractive and/or necessary in many areas of Indonesia where multiple yearly crop production, especially using miracle rice, requires milling during the rainy season, a simple burner operating on this fuel has been built and tested. This system closely resenbles that originally devised by Tatom and Wellborn for wood waste drying in support of the Ghana pyrolysis program (8) and is shown in Figure 15. While the burner is occasionally hard to light, once it gets hot, it operates smoothly and produces a continuous source of clean energy free of any pollutants. Whether this burner system is used as a direct heat source or in combination with a heat exchanger, it provides a simple, proven, inexpensive means for drying padi or any other agricultural product. It is estimated that its use could typically reduce the current padi mechanical drying costs by more than 600 Rp./ton.

(A)



(B)

Figure 15

Front and Back View of Off-Gas Burner for Crop Drying Applications

Preliminary Diesel Engine Tests on Pyrolysis Off-gas

While the original program objectives did not include the use of the off-gas to operate an engine, in the course of the project it has become increasingly apparent that the gas could be used to fuel a small engine, such as that powering the rice mill. It is also evident that the heat rejected from the engine could be utilized, together with the unused gas for padi drying. Since the total diesel fuel consumption of the almost 30,000 rice mills in Indonesia represents of the order of 40 million gallons annually, which at current world oil prices has a value of about US $ 35 million (21.8 billion rupiah), the resultant potential savings are impressive, in terms of increased national foreign exchange earnings. At a local scale, the savings are not so significant because of the current, very heavy government subsidy on diesel prices. However, average annual fuel savings of about US $ 450 (281.000 Rp.) per mill could still be expected at even today's extremely low price of US $ 0.36/gal (60 Rp./liter). Since the future likelihood for increased fuel costs in Indonesia is great, it is evident that a program to develop the off-gas as a diesel engine fuel source should be persued vigorously.

It so happens that there is a great body of technical experience in the operation of diesel and/or spark ignition engines on "producer type" gases. However, most successful wood fueled producer gas generators for engine applications have involved "downdraft" rather than "updraft" designs, since they tend to produce much less tar and oil in the off-gas. Thus the off-gases utilized in most previous studies have been much cleaner than those available from our pyrolytic convertor which more closely resembles an updraft gasifier. The result is that there is an urgent need to carefully clean up the off-gases and to remove the water vapor present prior to its entry into the engine carburetor in order to prevent power loss and/or fouling of

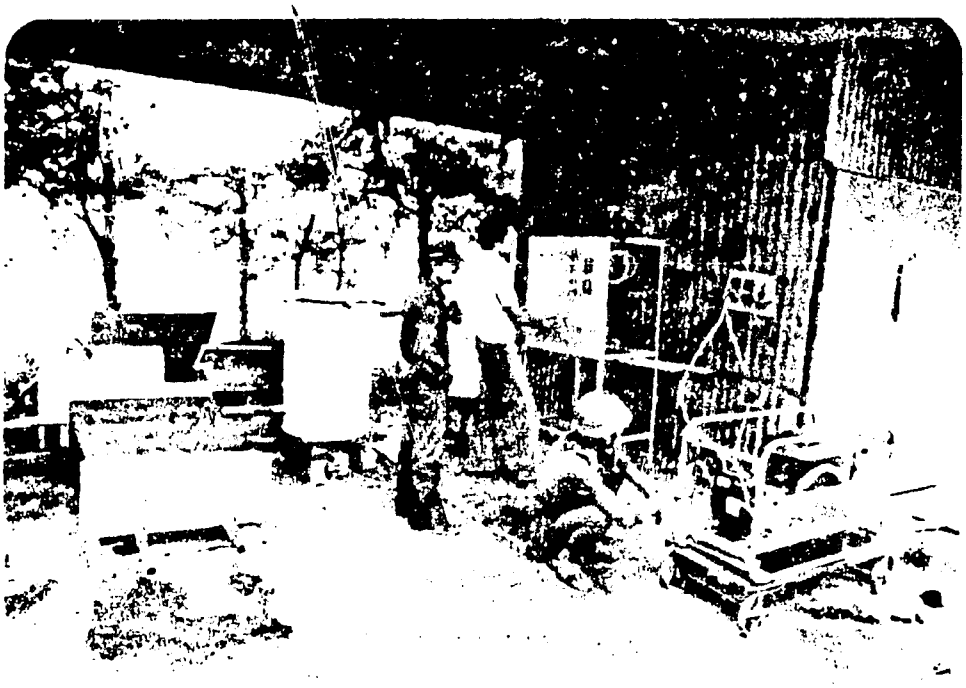


Figure 17

Yanmar Diesel Operating on Pyrolysis Off-Gas.

Therefore, while not completely successful, the latest tests represent a significant step forward and with improved procedure and filltration, it is believed that continuous, safe replacement of 80 to 90 percent of the diesel consumption is within sight.

Finally, it might be noted that the experience with the gas around the test facility has demonstrated its clean burning, convenient operation in even the simplest burners. This suggests that not only could it be used for engine operation and for drying, but also as an industrial fuel for firing brick or pottery kilns or boilers and to some extent for domestic uses, at least in and around the rice mill. Therefore, further study of these alternative applications should be made in future work.

Oil Utilization Studies

Since oil represents one of the important products of pyrolytic conversion, which in previous programs using a packed bed reactor with wood waste and peanut shells (1 , 2) has been shown to be an excelent industrial fuel and to be produced in quantities of up to 15 percent of the dry, ash-free weight of the feed, it is natural to look to this liquid as a major reason for pyrolysis. This is especially true because the technical literature (11) is filled with accounts of laboratory rice husk pyrolysis experiments that have yielded very substantial oil fractions. Consequently, based on the assumption that the oil yields would be very substantial, considerable study of the properties of the pyrolytic oils has been made in several laboratory investigations. Characteristics such as density, heating value, flash point water content, and viscosity, have been determined in several experiments, the results of which are summarized in Table 4. To serve as a reference, the corresponding properties of more familiar liquids such as diesel oil and kerosene are also tabulated. Study of the table indicates that the oil has several

physical properties that are similar to those of kerosene. However, its viscosity and density are considerably higher, yet its heating value lower than diesel and kerosene. Also largely because of the presence of a consider able quantity of water its distillation properties, which are shown in Figure 18, are also quite different. Finally, it is observed that while kerosene and diesel are basically neutral, the pyrolytic oils are mildly acidic, even at room temperature.

Table 4

Properties of Various Liquids Compared with Pyrolytic Oil

	Kerosene	Diesel Oil	Pyrolysis Oil
Surface tension (dyne/cm)	37.60	42.04	38.55
Dynamic viscosity (centipoise)	~ 3.3	~ 4	15.3
Kinematic viscosity (centistoke)	2.52	2.96	13.73
Flash point (^{o}C)	46.3	64.5	56.5
Pour point (^{o}C)	< - 4	< - 4	5.3
Water content (%)	--	--	10 - 20
Density (26.6 ^{o}C) (gm/cc)	~ 0.75	~ 0.75	1.11
pH	7	7	~ 5
Distillation Properties			
Initial boiling point (^{o}C)	108	140	98
10 percent distilled (^{o}C)	160	230	98
50 percent distilled (^{o}C)	220	294	236
End point (^{o}C)	278	358	252
Heating value (Kcal/gm)	~ 10	~ 10	~ 6

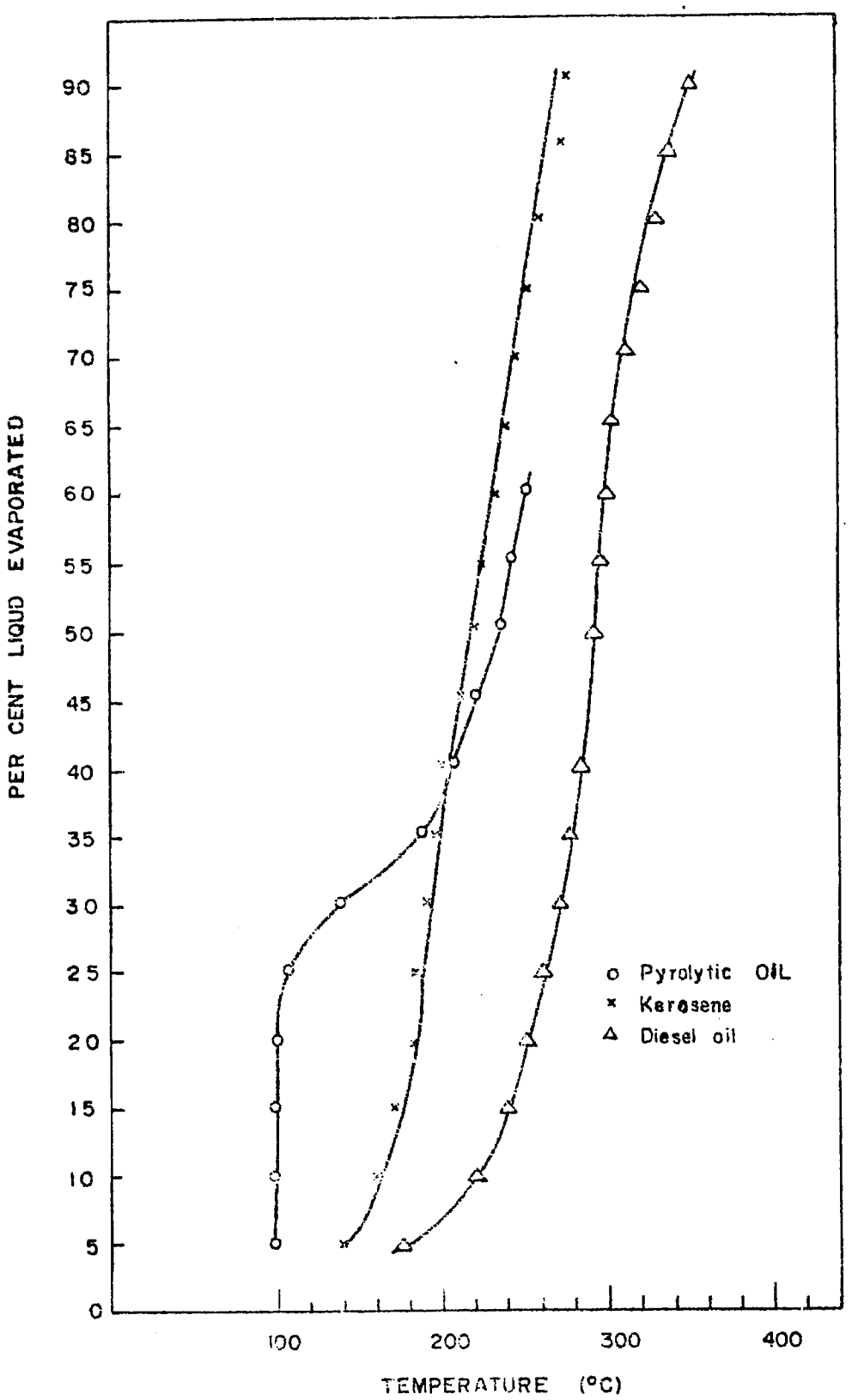


Figure 10. Distillation Curves for Pyrolysis Oil, Kerosene and Diesel

The presence of considerable quantities of creosols in the oil has been reported in the literature elsewhere (8). This suggests that besides their value as a fuel, they may have an important application as a wood preservative; a fact which is of special interest in Indonesia since termites regularly do terrible damage to homes and buildings. Therefore in a preliminary feasibility study, treated wood specimens were placed in a termite hill to see the reaction of these insects to the oils. The specimens were left in the ground for 10 months and upon removal it was observed that no damage to the treated specimens had occurred.

While it is recognized that these tests are in no way comprehensive, they do strongly suggest that the oils may have a valuable potential as a wood preservative and that further work in this area is warranted.

Originally, the pyrolytic oils were primarily conceived as potential kerosene substitutes for domestic uses, with the implicit assumption that the as produced oil would wick similarly to kerosene and/or that modifications to existing kerosene lamps and stoves could be made so that the oil could be utilized easily.

In practise, however, it has been found, in a series of unsatisfying experiments, that:

(1) the wicking action of the oils with a variety of porous materials is very poor and the oil will rise-due to capilarity-only a few millimeters; far less than necessary in practical lamp designs.

(2) even though dilute mixtures of the oil-with, for example ethanol-do have a weak wicking action that will operate a basic lamp (using a very thick cotton wick) for a few minutes, eventually the wick becomes clogged and coated with carbonized tar and carbon particles which result from both the breakdown of the oil due to the flame heat and the presence of carbon particles suspended in the unfiltered oil. In any event, the flame eventually goes out.

Thus clearly, the domestic lighting applications originally intended for the oils are simply inappropriate to its physical properties. It might be noted that the possibility of this occurrence was recognized in (4), but it was assumed that some means could be found to overcome the problems mentioned.

Besides this disappointment, the oil production-as previously discussed-has been lower than expected; primarily, we believe, due to the lack of a really dry feed, i.e. five percent moisture, as opposed to the 13 - 15 percent moisture husks typically available at a rice mill. Clearly the husks could be dried, using the off-gas, to the desired value, but that would involve the requirement for an extra, expensive drier for the husks alone. Moreover the padi itself could theoretically be dehydrated down to this percentage moisture but only at the expense of greatly diminished value of the rice together with increased storage and handling problems (it becomes brittle and breaks) and of difficulties in cooking.

Thus clearly, a question arises as to the possibility of developing another, more practical oil utilization strategy, rather than continuing down the original path which now appears of doubtful wisdom. Two possibilities are apparent; i.e. either use of the oil as:

(1) a coal tar replacement, for which the market is very large and would support, it is believed, a price of at least 80 Rp./liter.

(2) as a bunker oil replacement, which is not so attractive since bunker oil currently retails for 45 Rp./liter and therefore the oil would have a corresponding value of only about 25 Rp./liter.

ECONOMIC ANALYSIS

There are many factors which make a complete economic analysis difficult, especially in Indonesia where fossil fuels are heavily subsidized. Thus the question of whether to use the fair value of the products or their current market price must be answered. Moreover, it should be recognized that because the complete system still has only limited real world operating experience, many of the numbers in the analysis contain approximations to some degree. However, since two prototype system have now been built and operated, the required capital investment and manpower requirements are fairly well known. In addition, the value of the charcoal has now been established in contacts with retailers in Ciranjang. It is only in the estimation of the oil and gas value where some uncertainties are present.

Therefore in the following two brief analyses, which attempt to bracket the economic performance of the system, pessimistic and optimistic scenarios are assumed and the economic returns computed.

Pessimistic outlook

Rice mill operates 150 days/year; unit processes one ton husks per day; oil (dry, ash-free) yields are 9 percent; char (dry, ash-free) yields are 20 percent; oil used as bunker oil substitute at 25 Rp./liter, (U.S.$0.04/liter), char briquets,as produced (including ash), are worth 30 Rp./kg (U.S. $ 43.85/ton), gas replaces 80 percent of diesel oil (currently valued at 60 Rp./liter) used to run 12 hp (20 percent efficient) rice mill engine but has no other value; starch costs 100 Rp./kg wholesale;four men run system and are each paid 1,000 Rp./day (U.S. $ 1.61); total system cost is 2.5 million Rp. (U.S. $ 4019) and depreciates completely in 10 years; government loan money is available at 12 percent interest with 10 years payback; annual maintenance runs at 10 percent of system cost; annual overhead runs at 20 percent of labor cost. Therefore the following is obtained :

Income	millions of Rupiah	US. Dollars
Charcoal briquets	1.786	2871
Oil	.181	291
Gas	.245	393
Total	2.212	3555

Operating Costs	millions of Rupiah	US. Dollars
Capital & Depreciation	.442	711
Labor	.600	965
Maintenance	.250	402
Overhead	.120	193
Starch	.258	415
Total	1.670	2686
Net Profit	.542	871
ROI	21.7 %	-

Optimistic Outlook

Same assumptions as above, except mill operates 200 days per year, oil is used as coal oil substitute worth 80 Rp./liter (U.S. $ .129), gas is also used to dry padi down from 20% to 14% moisture at a savings of 600 Rp./ton padi.

Income	Millions of Rupiah	U.S. Dollars
Charcoal briquets	2.381	3828
Oil	.772	1241
Gas diesel	.327	526
drying	.360	579
	3.840	6174

Operating Costs	Millions of Rupiah	U.S. Dollars
Capital and Depreciation	.442	711
Labor	.800	1286
Maintenance	.250	402
Overhead	.160	257
Starch	.344	553
	1.996	3209

Net Profit	=	1.844	2965
ROI	=	73.8 %	

Therefore, regardless of the assumptions, the return on investment is attractive, and hence the installation of a pyrolytic conversion system is a highly viable economic proposition.

A final point concerns the importance to the whole concept of a source of capital available at the assumed interest rates: while money is officially available through government loans under the conditions assumed, there frequently is difficulty in actually obtaining the funds. Therefore of

critical importance to the success of this program is the increased availability of loan money to finance those installations. This will necessarily involve the active participation of the Indonesian government to insure that the money is properly and fairly distributed. It should be emphasized that if these funds are not made available, there is little likelihood that the pyrolysis system can have the immediate needed impact on the Indonesian fossil energy demand envisaged at the project outset.

INTERIM CONCLUSIONS

After a careful review of the original objectives of the program, of the technical progress to date, and of the economics of alternative approaches, it appears that a revision in the original products utilization strategy should be made. Thus it seems far more practical at this point to:

(1) focus primarily on the char utilization for domestic purposes and the gas utilization at the rice mill as a fuel to power the diesel engines and/or, where appropriate, as a heat source to dry the padi, but only down to 14 percent.

(2) consider the oil as of secondary importance and not expend further efforts in trying to upgrade oil production through drying of the husk, although improvements in condenser/demister performance should be sought. Emphasis should be given to use of the oils as wood preservatives or as industrial bunker fuels.

When all things are considered therefore, it is believed that this revised strategy will have equally as positive an impact on fossil and wood energy consumption in Indonesia as the original plan, be economically attractive and yet will be much more readily achievable and certainly more realistic in terms of the technology demanded.

In addition, because of this revised strategy and due to other factors, it now appears that the level of mechanization of the overall pyrolysis system should perhaps be ultimately raised above the present basic,manually operated level. This arises for several reasons, i.e.:

(1) Once emphasis is placed on rice mill diesel engine operation, the need for a (near) continuous gas supply is evident. This suggests that some means to reduce the frequency of interruption of the gas-due to filling and emptying operations-be developed. This could be accomplished by

using manually operated screw feeders connected to large air tight husk and char storage containers, perhaps sufficient for two to four hours operation and similar to that used in the Philippines (9).

(2) The availability of mechanical power on site also offers the tempting opportunity for automating the agitator drive, which in turn-because of recent technical developments (2) - further suggests that an inte - gration of the agitator and the process air introduction system be made. The resulting "AIRGITATOR" (2) would completely replace the present water jacketed process air introduction system and at the same time, because of the its stirring action, guarantee a smooth materials flow-free of bridges or cavities-in the reactor. Because of the effort demanded in turning it, operating the agitator represents the only truly difficult job on the pyrolytic converter and moreover does not really represent good utilization of human energy. Due to the work required, the agitator is frequently unattended or improperly operated with the result that cavities in the bed arise. Therefore, while the action considered could replace at least one man, the job eliminated is very unattractive, and the economic advantage in reduced labor costs, even with the expense of the mechanical drive and additional hardware, appear to be significant.

(3) To maintain briquet production levels compatible with the reactor, there may be a need to automate the drive system, since the effort required to operate it manually may be greater than one man can provide.

It must be understood that the above ideas should not be implemented too quickly, because there is still much to learn about the basic pyrolysis technology and the resources for this work are limited and cannot be spread too thin. However, it would be expected in the not too distant future that these or similar technical improvements will be waranted, because the advantages they offer will greatly off set the extra costs involved.

FUTURE WORK

Considering the ideas and facts presented previously the following activities will be vigorously pursued to the end of the current program:

(1) Intensive efforts will be made to continue to upgrade the convertor throughput.

(2) Work to improve briquet production techniques to better match charcoal generation will be done, and a higher quality briquet will be sought.

(3) The program to perfect diesel and spark ignition engine operation on the pyrolysis off-gases will continued.

(4) Alternative uses for the oils will be investigated.

(5) Preliminary design work to further mechanize the system will be begun, with initial emphasis placed on improved feed input and char removal.

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