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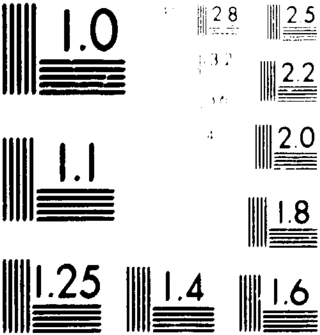

MICROCOPY RESOLUTION TEST CHART

RESTRICTED

12916

July 1983
English

Philippines.

ASSISTANCE TO ENERGY PRODUCTION FROM BIOMASS WASTE MATERIALS

DP/PHI/78/022

Technical report *

Prepared for the Government of the Philippines
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Mr. John W. Tatom
Consultant in Biomass Pyrolysis

1102

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INTRODUCTION

This document describes work accomplished during the period 1 February 1983 - 6 April 1983 under the subject program. As such, it includes: (1) a description of the new ERDC Prototype Pyrolysis System, (2) the Tripartite Meeting held on 16 March 1983 and preparations for it, (3) the Design of a new 200 Kg/hr Coconut Shell Pyrolysis Unit, and (4) Recommendations for Future Work. While the efforts described herein are basic to the completion of the project plan, this document does not include any contractually required outputs. In essence, however, the work reported corresponds to the job description of this consultant for the indicated period.

ERDC PROTOTYPE PYROLYSIS SYSTEM

During the period August 1982 through January 1983 the all purpose ERDC Prototype Pyrolysis Facility was constructed under the direction of ERDC engineers, and the pyrolysis system, fabricated in June and July 1982 by a Manila shop, was installed. Some preliminary checkout testing was also conducted in late January. The overall schedule was delayed several months by the weather and by a misshape in delivery of a key system component.

Shown in Figures 1 through 8 are views of the final pyrolysis system. The overall design (shown in Figure 1) is discussed in an earlier report (1)[1] in some detail, but for purposes of this document it can briefly be described as including:

(1) A drier, where the feed (or any other appropriate material) is dehydrated. The drier (composed of a drying bin, ducting, a gas burner and a blower), shown in Figures 2 and 3, is a batch continuous system, which is energized by combustion of the pyrolysis off-gas. It utilizes a cross flow/up-draft design, including recirculation of a large percentage of the hot air with ultimate venting at the top of the drier bed.

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(1)/ Numbers in parenthesis refer to literature cited in the REFERENCES section.

Figure 1

Overall View of ERDC Prototype Pyrolysis Facility

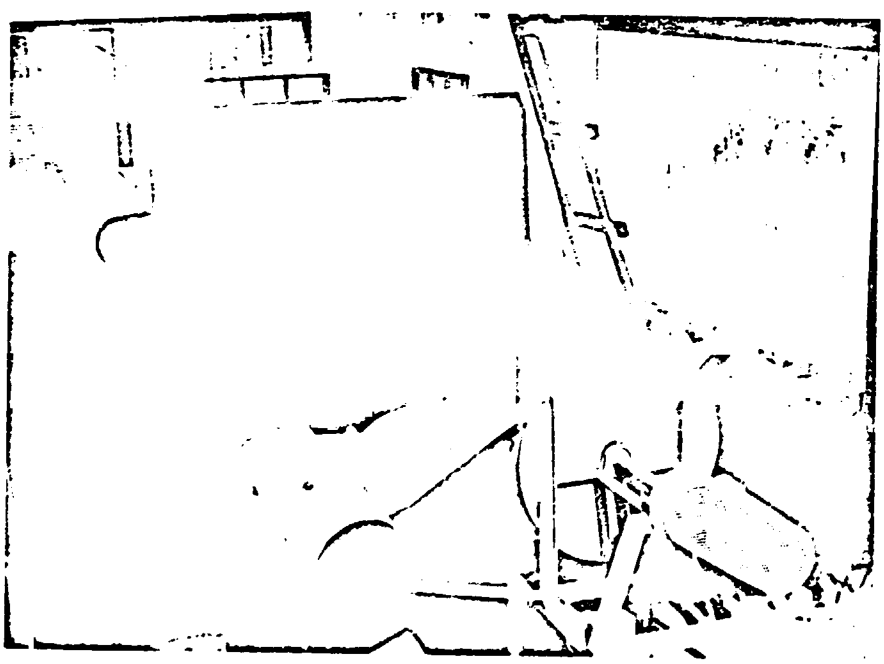

Figure 2

Top, Side View of Feed Drier System

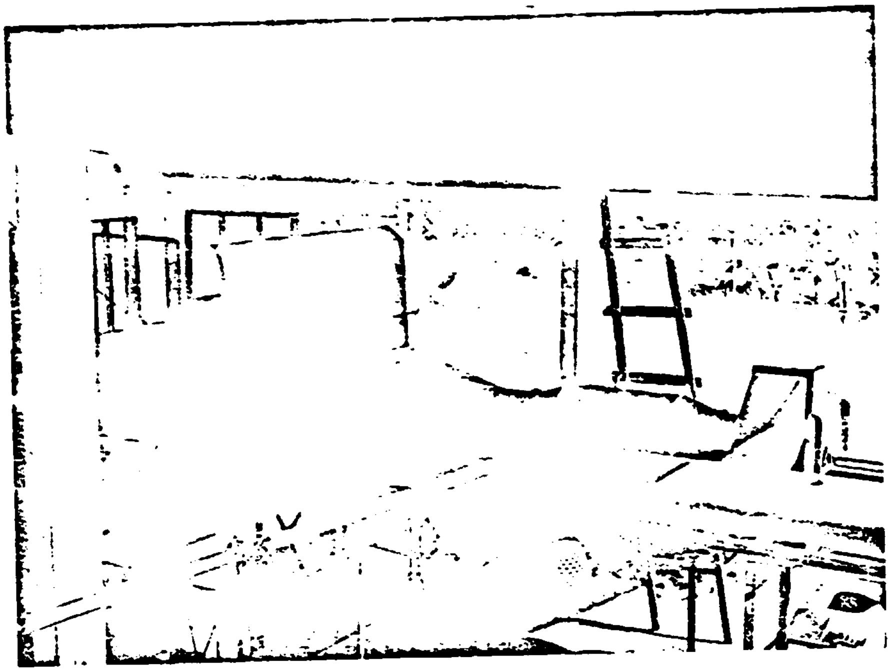

Figure 3

Top, Rear View of Feed Drier System

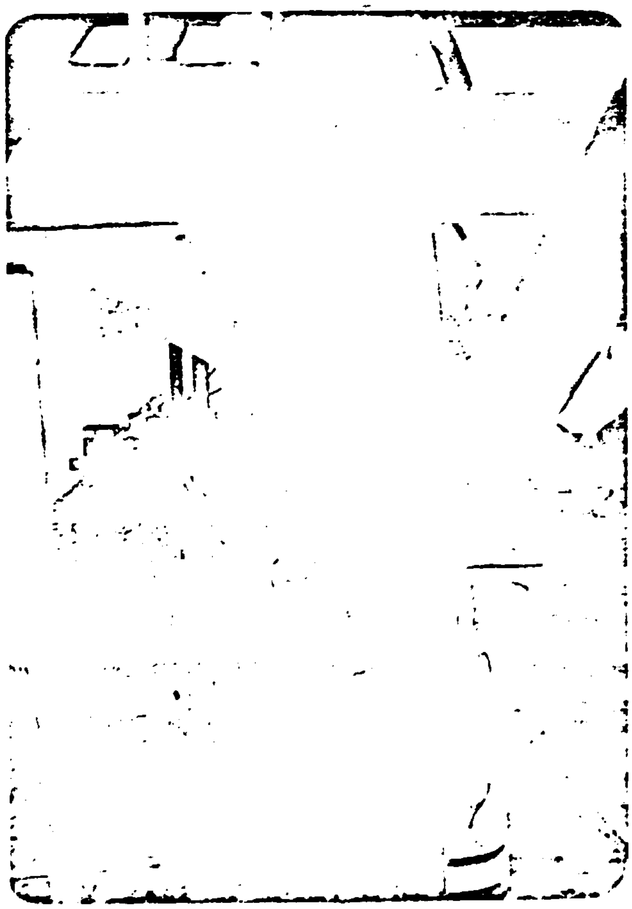

Figure 4

Airlock-Screw Conveyor System

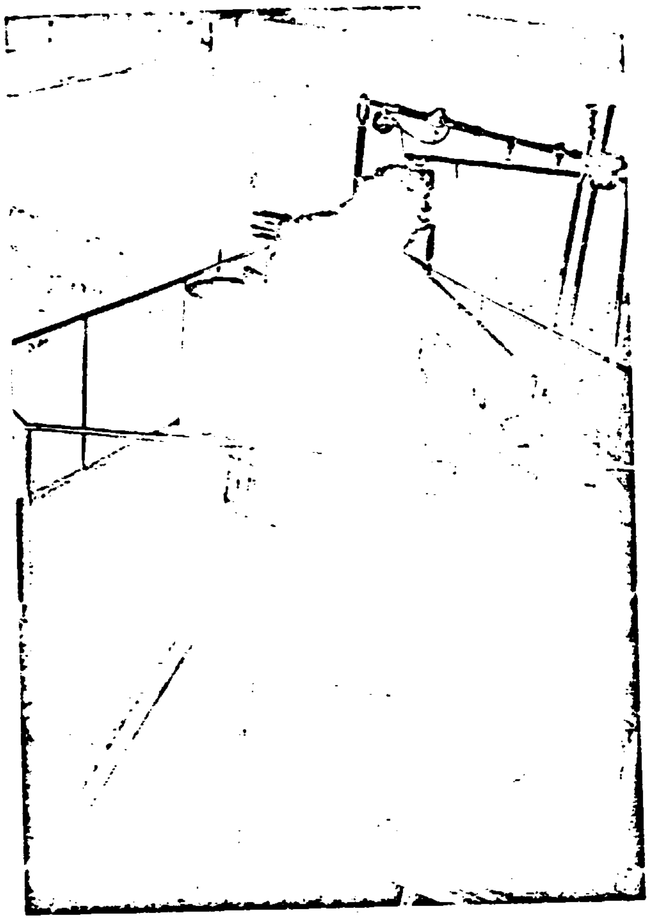

Figure 5

Top Rear View Pyrolytic Convertor

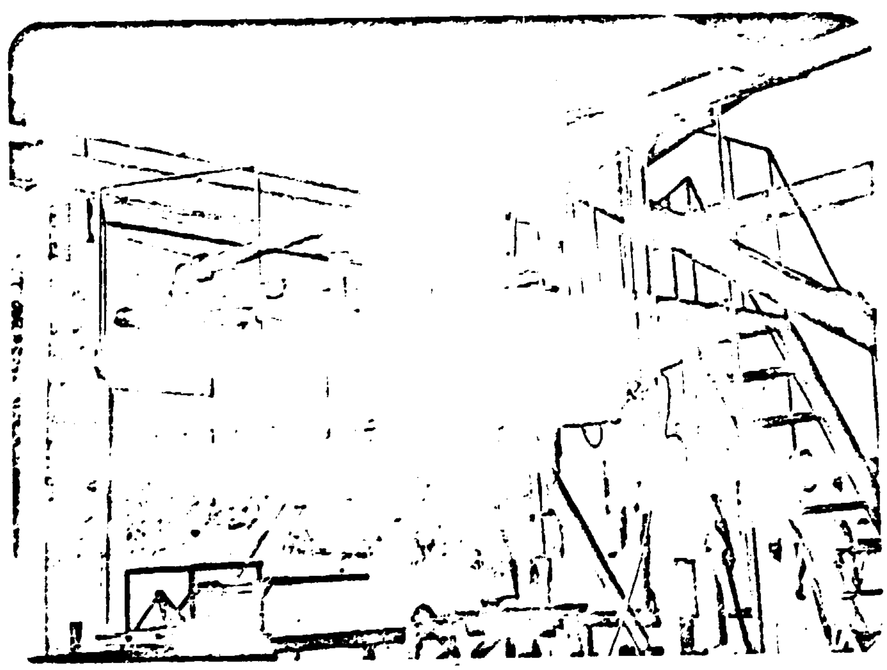

Figure 6

Lower Rear View of Pyrolytic Convertor
including Dual Jet Condensers

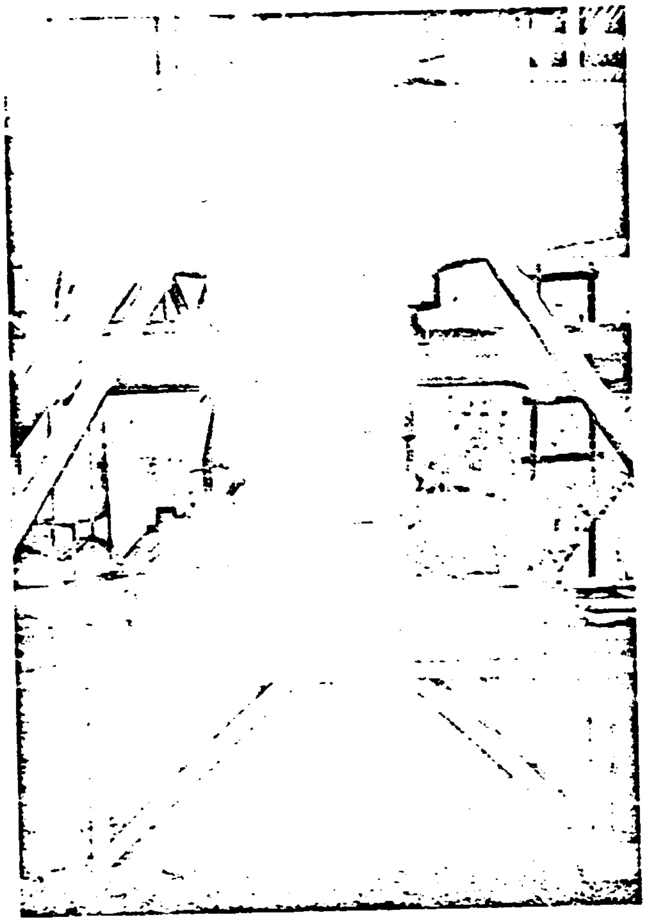

Figure 7

Char Removal System

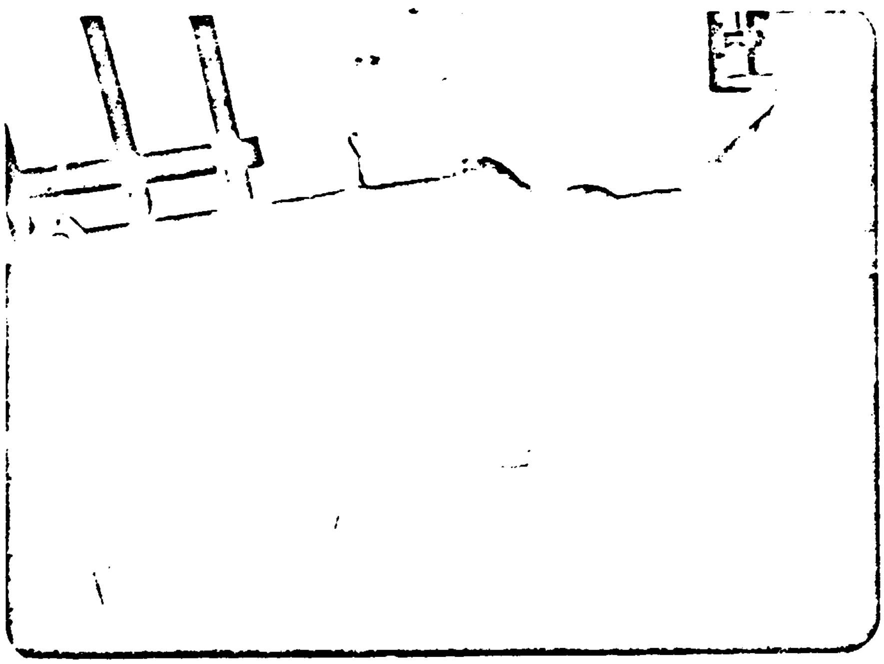

Figure 8

Off-Gas Burner

(2) An airlock and screw conveyor system which transports the feed from the drier into the pyrolytic convertor. This system, operated on demand by a level control switch within the pyrolysis reactor is shown in Figure 4.

(3) The pyrolytic convertor (see Figures 5 and 6) which utilizes a moving bed, partial oxidation design and is nominally rated at 100 kg/hr. throughput. A major component of this unit is the slowly rotating "Airgitator" through which process air is delivered to the lower region of the bed and by means of which the bed is continuously stirred. Another vital sub-system is the timer-solenoid controlled, pneumatic operated "Star Grate", which periodically opens and closes; thus allowing the charcoal to fall from the unit into receiving drums located under the convertor (see Figure 7). These drums are replaced as they are filled using an elevator system and a simple trolley to move the hot drums out of the way.

(4) The dual "Jet Condensers", which recover the higher temperature fraction of the pyrolysis tar and oil from the off-gas. This component, also shown in Figure 6, is designed to operate at a condenser exit temperature of about 190-200°F, which is slightly above the dewpoint of the off-gas. This avoids collection of an undue amount

of water in the oil/tar product.

(5) The off-gas burner, which is really part of the drier, but is worthy of note because it could be used in alternative applications. This component which utilizes a vortex combustion technique is essential to the system because it provides a simple means for incinerating the wet, low quality off-gas leaving the condenser. It is shown in Figure 8.

Considering the several subcomponents of overall the system together with its controls, it is to the credit of the ERDC project personnel that it was in proper working order upon arrival of the consultant on 1 February 1983. However, several interconnecting problems, not recognized earlier and mainly in the system manufacture, have required considerable attention, and delayed the routine operation of the system until late in this consultancy. The problems encountered include:

(1) An error in the "Star Grate" manufacture, with too great a clearance between the top moving surface and the lower fixed surface. Thus, the grate frequently would rot fully open. Corrective actions, together with modified operating procedures ultimately overcome these problems but occasional jamming of the grate still occurs, and it is

believed that ultimately it will have to be returned to the manufacturer for proper repair.

(2) Poor tolerances in the manufacture of the airlock, which therefore does not properly isolate the drier from the convertor system and, at larger process rates, is the source of smoke which may either enter the drier or be exhausted directly into the air, neither of which are desirable alternatives. Again, it is believed that this component will ultimately have to be returned to the manufacturer for remedial action.

(3) Inconsistencies in the manufacture of the slowly rotating drums located at the bottom of the drier. The result was that very large quantities of material would sift through at the ends, thus overloading the feed screw and upsetting the desired uniform downward flow within the drier necessary for proper dehydration. Corrective actions at ERDC have largely overcome this shortcoming but much time was lost in identifying the problem.

(4) Problems in bed "blow out" of the vented warm moist air as it exits from the top of the drier. While operator techniques have been developed to minimize this occurrence, it is not clear at this writing whether some kind of mechanical agitation system or perhaps an alternate venting/

heat exchanger unit may be necessary. Since this drier is of a relatively new design, it is not surprising that some problems in its operation have occurred, and this was anticipated in (1).

(5) The unavailability of a hammermill to crush coconut shells to a size compatible with the material handling system. This forced a resort to manual loading of the convertor with broken coconut shells, and while this procedure demonstrated the successful operation of the "Airgitator" and the grate with this material, it was not practical for any extended test periods. Therefore, the primary feedstock utilized during this reporting period was rice husks which, though bulky and thus with a tendency to form cavities within the drier, are readily available.

Because of the problems mentioned above and the time consumed in their solution, the primary focus of the testing completed so far with the pyrolysis system has been simply to achieve a trouble free operation at the maximum throughput possible. Thus, as of this date, there have been no engineering performance tests in which the inputs and outputs of the system were evaluated in detail. While data on feed input and char production have been produced, there has been no analysis of the oil and gas yields. This latter work should come later when the proper instrumentation is available, and after several minor modifications to the unit (e.g. the installation of insulation on the pyrolysis off-gas ducts) have been completed.

In regard to the results of the testing accomplished so far, the system has been operated at a range of throughputs varying from about 70 kg/hr. up to 100 kg/hr. The latter throughput is to a large extent restrained by the excessive smoke leaking from the airlock. With proper operation of this component, it is believed that the convertor capacity can be substantially increased. For the tests conducted, typically the char yields ran at about 40 to 45 percent, considering the 20 percent silica content of the rice husks. The char is uniformly carbonized in the convertor and has demonstrated that it burns with an (almost) smokeless flame. While no analysis of the pyrolytic oil has been made, it has been shown to readily burn in open air. Likewise, the gas has demonstrated that it burns cleanly in the combustor, although there appears to be some problem with this component because the flame tends to extend downstream of the four mixing arms (see (1)), while it should be contained within the burner can. It is possible that insufficient air is entering the burner, or perhaps due to an error in the lower installation, the air swirl direction is incorrect.

TRIPARTITE MEETING

The first Tripartite Meeting between UNIDO, UNDP and ERDC/NEDA was held 16 March 1983 during the consultancy and included a tour of the new ERDC pyrolytic convertor facility (see Figure 9). The occasion of this important meeting provided an opportunity to formally consider and ratify several minor changes and/or enlargements in the Project Document that in the course of the project work, had been recognized as desirable. In the process of preparation for this meeting a number of documents were drafted, including:

(a) A Revised Work Plan

(b) A Project Progress Report

(c) A Technical Advisor's Report to the Tripartite Review

(d) A Project Document Revision

These documents are part of the project record, and will not be included here. However, because of the time and effort involved in this activity, a brief review of the reasons for the project revisions will be given and the main changes identified.

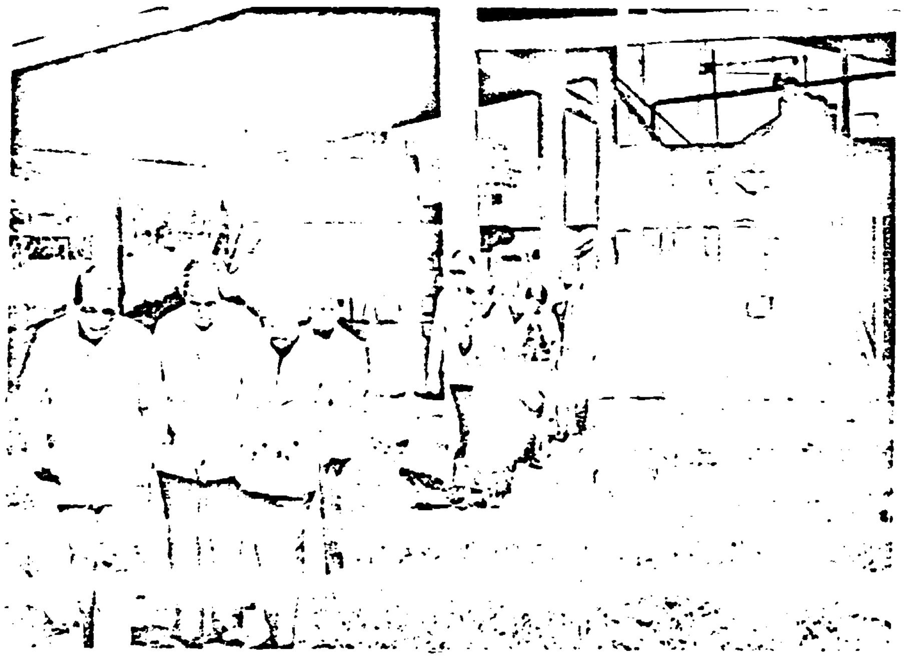

Figure 9

Tripartite Meeting Participants[1] leaving the ERDC Prototype Pyrolysis Facility

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1/ From left to right they include:

Dr. Ibarra E. Cruz	PNOC-ERDC
Mr. Ross Miley	UNDP
Mr. Romeo A. Reyes	NEDA
Mr. Edwin Sangoyo	NEDA
Dr. Ivan Pluhar	UNIDO
Ms. Betel Tassew	UNIDO
Mr. Aldwyn C. Santos	PNOC-ERDC
Dr. John W. Tatom	Consultant
Dr. Myint Maung	UNIDO

The reasons for the main changes in the Project Document include the following points:

(1) The recognition that by far the dominant process waste source in the Philippines is coconut shells whose production is five to ten times greater than ricehusks and woodwastes, which are the next most plentiful residues.

(2) The fact that a thriving market for the coconut shell charcoal already exists, and a market for the coconut shell pyrolytic oil is a likely possibility, whereas there is no existing market for either the rice husk charcoal or the sawdust charcoal.

(3) The technical simplicity in carbonizing the coconut shells.

(4) The fact that while there is a need for a larger scale carbonizing facility at centralized coconut charcoal plants and/or copra drying/processing plants, there is also a need for a small scale unit appropriate to the outerlying areas where transportation costs make the bigger plants impractical.

(5) The recognition of the potential of the rice husks as a mechanical energy source for the ricemills by means of

the process of gasification and subsequent replacement by the gas of a large percentage of the diesel fuel now being used to run the engines supplying power to the mills. This scheme will provide a means for making the mills nearly energy self-sufficient and avoids the marketing problems associated with the char and oil.

Thus, it appeared desirable to revise the Project Document to include the gasification of rice husks as a further activity within the work program. And additionally, it seemed more fruitful to give greater emphasis to the pyrolysis of coconut shells (at perhaps two scales of production) and a somewhat lesser importance to the carbonization of rice husks and sawdust. It is to be emphasized that the changes described above in no way diminish the overall project objectives. If anything they are enlarged. Moreover, the original project activities are not reduced, they are expanded. Basically, the original Project Activities, 3 and 11, are now complete and Activities 4, 5, 6, 7, 8, 9, 10, and 12 are almost halfway finished. Only Activity 13 remains unstarted. The new plan will simply extend Activities 4, 6, 7, 8, 9, and 10 to include gasification of rice husks, but will not diminish the original work objectives, all of which will be met under the revised program. Thus, the revised program really is nothing more than a reflection of a better understanding of the potential of pyrolysis and gasification in the Philippines than was possible when the project was originally conceived, and represents an improved focus towards activities having an increased pay-off and chance of success.

In addition to the need for the above revisions, it has become apparent that no further work should be made on and with the original pyrolysis unit developed in the prior RP/UNIDO project. This is because this unit was designed with a requirement for a high level of labor intensity, and was based on a philosophy that has been shown to be lacking in a similar pyrolysis project in Indonesia. In fact, the results of the Indonesian project, together with similar ones in Papua New Guinea and Costa Rica, have led to the adoption of the semi-automatic, intermediate capital intensive approach used in the design of convertors developed so far under this project. Therefore, because of its increased economic return and improved reliability, the latter design approach has been demonstrated superior to the earlier one, and thus it is believed that no useful purpose would be served in further operating and up-grading the original system.

Finally, because of delays in the arrival of the Technical Advisor, the project was almost one year late in its start up, and thus allowing for this factor and the enlarged scope of the program, a no cost extension of 18 months appeared justifiable and necessary. Moreover, because of the need for a variety of different skills to support the project, it has not been necessary or practical to maintain a continuous presence by the Technical Advisor, and therefore a series of short term consultants have been engaged to support the project. Thus the Project Document has been revised to reflect all of the above ideas.

DESIGN OF 200 KG/HR. COCONUT SHELL PYROLYSIS UNIT

DESIGN APPROACH

The design of an automated pyrolysis unit appropriate to coconut shells at larger centralized processing facilities such as for charcoal production and at integrated charcoal/copra drying plants requires making many hard decisions. Often these decisions are of necessity based on very limited data together with personal opinion and judgment. Perhaps the most fundamental is that of plant capacity. Yet, ironically, this particular question is one where there is a great lack of solid data; apparently because the concept of an integrated plant is relatively new to the Philippines. Only one reliable charcoaler/copra processor[1] has been identified, who has experience in this area and thus, his opinion takes on special significance to this project.

Based on his own work using an integrated charcoaling/copra processing plant of his design in the province of Bicol, in southern Luzon, he determined that the optimum design is a facility that can process about two tonnes/day of shells. At a smaller scale, the operating and capital costs of the plant per tonne of production become excessive, while above this capacity, the transportation costs become a problem. Conveniently, Chatterjee,

(1) Mr. Romulo Mesias, who has been often quoted before earlier reports (1, 2, 3) is this individual.

(3) used a 200 kg/hr, or slightly more than two tonne/day unit in his economic evaluation of the concept which can be interpreted to show that even with the plant capital costs included, the return on investment would be very attractive. Thus, while no justification for the choice of this capacity is apparently given in (3), there is still reason to believe that such a plant would be profitable.

Moreover, from a technical point of view, considering the associated risks of scaling up the current 100 kg/hr prototype, there would appear to be relatively few problems and uncertainties in building a 200 kg/hr plant. Thus the prospects for technical success would be favorable for such a unit.

Therefore, for the above reasons a 200 kg/hr plant capacity has been chosen as the nominal capacity for the new pyrolysis system. If later experience shows that a different size would be more desirable, then a simple scale-up or scale-down should be relatively straight forward. But in the meantime this capacity will be used in the planned system design.

It should be noted that this design is fundamentally similar to that of the present partial oxidation, moving bed system operating at the ERDC and described in an earlier section of this report. Thus the basic convertor shell, the off-gas system, the char grate mechanism, the access platform, the off-gas burner and many other components will be similar to those currently in use, except larger in scale. However, there will be some charges and/or simplifications in the new design to take advantage of the special properties of coconut shells and to accommodate the unique problems arising with use of the shells. The following paragraphs present a review of the reasons for these modifications and a justification for the approach chosen, while the subsequent section offers a discussion of the design details of components of the new convertor that are of special interest.

Ideally, in order to maximize pyrolytic oil/tar yields, the feedstock should be as dry as possible, e.g. 4 to 6 percent moisture. Coconut shells, as produced and air dried may range between 10 and 15 percent moisture. Thus there is a basic question as to whether or not to dry the shells down to the desired moisture content. The answer would probably be clearer, and most likely in the affirmative, if a proven market for the oil/tar product existed. However as of now, that is not the case. Thus even though the oil yields from pyrolysis of the as-received shells may range only between five and ten percent, as opposed to 15 and 20 percent for dry shells, there does not seem to be an economically acceptable justification, at present, for inclusion of this component in the planned coconut shell pyrolysis system. Should the market for the oil/tar develop, and if the economic return appears favorable, then a feed drier can be later added. Provision for inclusion of this drier should be made in design of the plant layout.

While coconut shells are a basically free flowing, relatively dense material that processes through the packed bed reactor without difficulty and with a minimum tendency to "bridge" or form cavities in the feed (that can disrupt operation of the system), there are problems associated with their use, particularly in their material handling. This is especially true when processing half coconut shells, an approach that happens to be the most desirable since it offers several economic advantages over using broken or crushed shells; i.e.

(1) The cost of the associated hammermilling/screening equipment is avoided, and the labor and power requirements for the plant are correspondingly reduced.

(2) The value[1] at the production site of the resulting greater yield of larger size (1/2 to 2 inches) pieces of charcoal, (which are most appropriate to the domestic market) are US$30 to US$50 dollars/tonne higher than that of the smaller (1/8 to 1/2 inch) pieces (which are best utilized for the export market).

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(1) Mesias reports as of March 1983 the following plant prices; i.e. ₱2000/tonne for charcoal pieces above 1/2 inch, US$160/tonne for pieces in the range 1/8 to 1/2 inch. The smallest pieces are briquetted and sold in the market for premium prices, but the production costs are high.

Thus, if half shells rather than broken or crushed shells are utilized, the production costs are reduced and the product price is increased, a compelling argument for selection of this approach.

But, while there are no serious problems in moving the shells and the charcoal around, nor in processing them once inside the reactor, there are difficulties in getting the shells into the convertor without jamming the airlock mechanism and/or breaking them. Thus a new, different approach to the airlock design is necessary compared with that utilized previously.

The airlock design concept chosen involves the use of inflatible bladders mounted internally on opposite sides of this component to regulate and restrict the flow of the shells. A simple, separate pneumatically operated butterfly valve, kept free of the shells by the bladders, will provide an airtight seal. The chosen design should result in a minimum of broken shells and no damage to the airlock even if an occasional jamming occurs. The drafted characteristics of the reactor, as discussed later, will always maintain a tendency for cool air to enter the system, rather than hot gases to leave. Thus, assuming the blower suction is not lost, the bladders should never be exposed to hot gases, and if the butterfly valve is temporarily jammed the only result will be air momentarily entering the reactor from above, an undesirable, but not a disastrous, situation.

The relatively high porosity, and thus low flow resistance, of a packed bed composed of half coconut shells provides the opportunity for eliminating the high pressure forced delivery process air system as used in the current ERDC prototype. This could be accomplished by inducing an air flow into the system by means of a relatively low suction blower located in the off-gas duct. If increased oil recovery becomes economically desirable, such an approach would have the additional advantage that the blower would also act as an oil scavenger, which could materially increase the quantity of oil recovered. Otherwise, the suction could be provided simply by the blower operating the copra drier, just as the drier blower serves an identical function in the present ERDC system. In eliminating the process air blower, the system would be simplified and its cost reduced.

Drafting the reactor with the coconut shells has other advantages besides those listed above, since in so doing, (1) there would be no problems in sealing the char recovery system, (2) access into the reactor, even during operation, is improved since there would be no tendency for smoke or hot gases to vent outward through any openings and (3) any leaks would result in air entering the system rather than smoke leaving.

The relatively free flowing character of the shells also makes the need for agitating the bed to prevent formation of cavities much less pressing than with bulkier materials such as rice husks and sawdust. Thus there is an opportunity to avoid the use of the "Airgitator" system, as utilized in the current ERDC design. Considering the cost of this component for a larger size convertor, it's elimination would result in substantial cost savings and foreign exchange benefits. However, coconut shells do bridge occasionally, and therefore, a simplified appropriate bridge-breaking system must still be included in the design.

The approach adopted for agitating the bed is to periodically and automatically lift the bridge-breaker which in some ways resembles an anchor, as will be seen later, vertically up through the shells, and to depend on the downward motion of the feed to return it to its lower position. A manually operated, battering ram mounted inside the hollow vertical shaft of the bridge breaker would act as a back up in the unlikely event a bridge forms during the downward motion of this component.

There still must be some means for introducing process air into the lower bed, and this becomes a fundamental problem once the Airgitator is eliminated, since the latter's function has been not only to stir the bed, but to supply the needed air. An obvious approach is to add air through the reactor sidewalls. But, because the reactor diameter is large relative to the current system, and since the off-gas manifold removes the pyrolysis gas at the sides of the convertor, there is a potential problem in achieving a uniform flow within the bed, especially near the center, with the possibility that a core of uncharred material might result. Thus a central air delivery system is also needed to prevent this from happening.

While the average reactor bed temperature may be no more than 1000°F to 1200°F, a temperature that even mild steel can sustain almost continuously, near the air supply ports, the local temperatures can approach the stokiometric flame temperature. At such temperatures steel even the highest carbon variety, melts. The "Airgitator" avoided this problem by locally cooling the metal near each orifice by means of heat conduction through the very heavy walls it was made of, and also took advantage of its motion through the bed, together with the internal cooling affect of the process air to maintain the metal at a temperature considerably less than the bed average, A fixed tuyere, or air supply pipe, will not have all these advantages, and over a period of time, if uncooled, will certainly be damaged or destroyed by the intense temperatures produced locally. One approach is to water cool the system, but experience has shown that this technique, while it may solve the temperature problem-assuming the water reservoirs are kept filled, produces another variety of long-term difficulties such as corrosion. An alternate approach is to use inexpensive expendable tuyeres and to simply plan to periodically replace them. This approach has been successfully used by a local gasifier company[1] in it's designs which operate at average bed temperatures 700°F to 900°F above that of the planned pyrolytic convertor. Because of their success, with this technique, and because of its obvious advantages, it has been decided that a similar approach would be appropriate for the planned design.

This design, even though considerably less complex than the present convertor, will still require a control system of some sophistication. Rather than getting into the problems of microswitches and electronic sequences, it is believed that the use of simple mechanical timers to regulate the various input/output components would be the simplest, most reliable and economical approach. Moreover, the demand technique used in the current design appears to offer the best method for controlling the production rate and for calling for the feed. Thus it will be used in the planned system.

Throughout the entire design of the new system is a built-in capacity for change-in the event some of the approaches described above prove lacking. Thus if a pressurized process air system and/or an Airgitator turns out as necessary, it can be added with no change to the basic reactor design. Likewise, should the drafted approach be inadequate, a char recovery system compatible with a pressurized operation technique and with the

1) Appreciation is expressed to Col. D. Rio of GEMCO, Manila, who allowed free range of his production plant and free use of his design ideas to this project.

reactor design can be readily brought forward. Moreover, if the new airlock is not satisfactory, provision to install a different one has been made. Thus design flexibility is a key concept in the planned system, which though having a basic similarity to earlier pyrolytic convertors, clearly offers some new approaches and techniques.

Therefore, because of the several new design features, it is not unreasonable to expect that this system may face some extra difficulties during its initial operation, and thus special attention should be given to siteing the plant as conveniently accessible to Manila as possible. This will minimize the time and difficulty in making any needed corrections, and further will ultimately allow a greater public exposure to this first plant; a continuing consideration of particularly great significance, once the start-up phase has been completed.

KEY COMPONENTS DESCRIPTION

Presented in this section are brief discussions of the design details for the several new components to be used in the planned pyrolysis system. In addition, sketches and drawings of these elements, in an appropriate degree of detail, are also shown. There has not been sufficient time, since the design effort began, to produce a final set of drawings, adequate for manufacture of the system. The drawings presented here will be shortly superceded by such a detailed complete set of prints. Thus the primary object of this discussion is to explain and illustrate the new concepts only, and not to review the entire system design, which is composed of many previously proven components. However, there is an obvious need to first describe the overall system in broad detail in order to fix ideas and establish a reference frame for the discussion of the newer components.

Overall System Preliminary Design

Presented in Figure 10 is a simplified assembly drawing of the pyrolysis unit itself, but not including the off-gas burner, since the location of that component will depend on the particular installation. Referring to the figure, it is seen that the air dried coconut shells enter the 200 kg/hr pyrolysis system through the new airlock/hopper. After

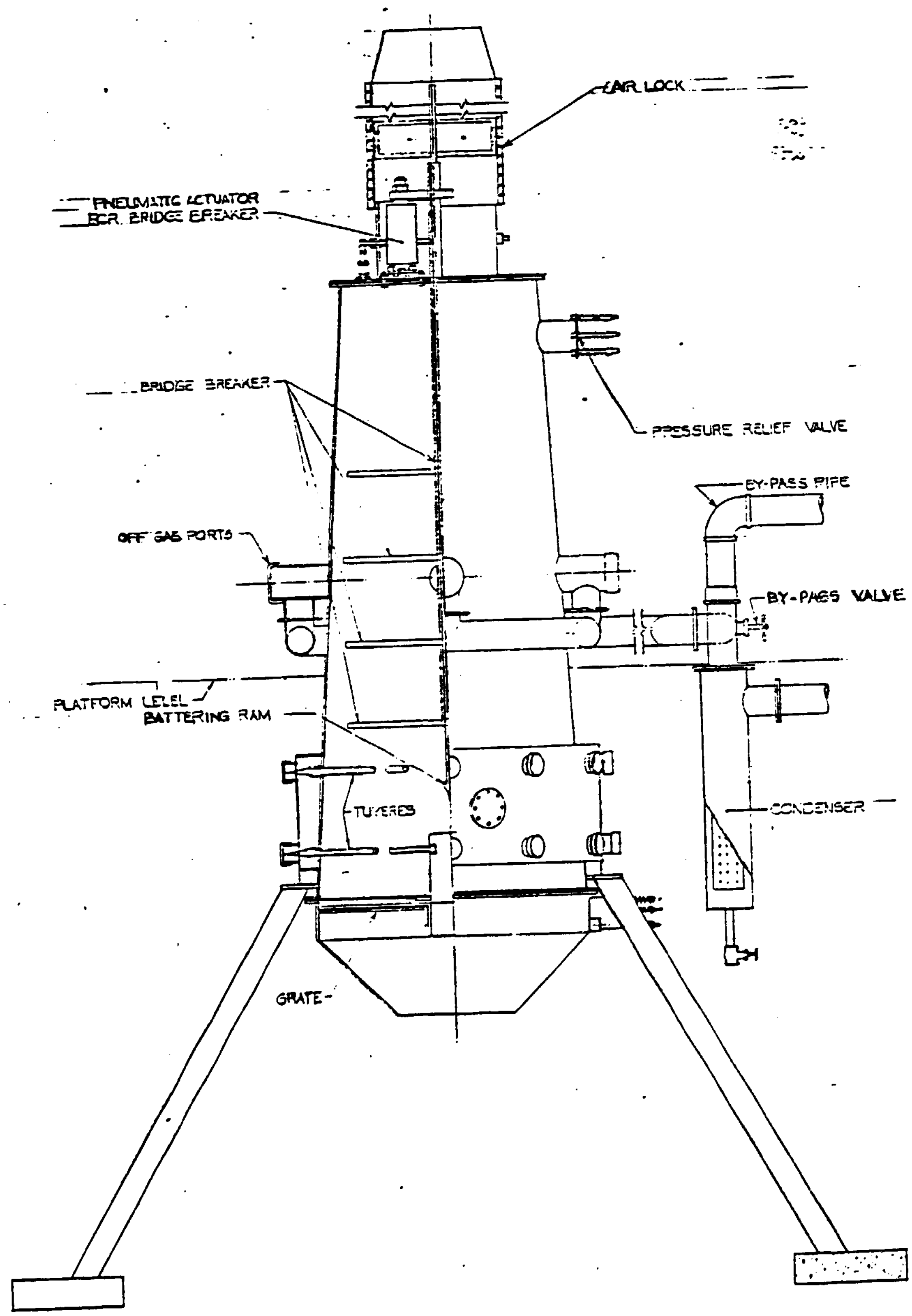

FIGURE 10

ASSEMBLY DRAWING, 200 KG/HR PYROLYTIC CONVERTOR passing through the airlock, the shells move downward through the bed, which is periodically stirred up by the action of the new, vertically moving bridge-breaker. In the lower region of the reactor the shells begin to be heated by the upward moving hot gases that are produced by introduction of air through the central and wall mounted tuyeres near the bottom of the system. Gradually, the shells carbonize, and finally exit the reactor through the "Star Grate". The charcoal is then quenched and moved, via a vibrating wire mesh belt conveyor, to the storage/ bagging point. The smaller pieces which fall through the conveyor are collected in pans located below this subsystem.

The off-gas is drawn from the convertor via a 4 inch I.D. pipe, past a by-pass valve which is connected to a condenser system, and then on to the burner. Depending on the energy demand of the burner and the value of the pyrolytic oil/tar, more or less of the off-gas can be diverted through the condenser.

The reactor, including its support system, will stand about 15 ft. above the ground and is 40 inches in diameter at its base. The reactor shell is 90 inches tall. At its nominal rating, it should process 200 kg/hr of coconut shells or about 50 lb/hr ft^2 grate area. This is about half what larger commercial state-of-the-art carbonizers can handle per unit of cross-sectional area. For this reason, there is an expectation that the throughput of this system can ultimately be raised considerably above its nominal rating. The reactor system is composed primarily of rolled mild steel plate and contains no ceramic insulation.

Airlock

To handle half coconut shells without breakage and without jamming the airlock mechanism is not a simple task. But after considerable thought and discussion the following design, shown conceptually in Figure 11, has been chosen. Referring to the figure, it can be seen that expandable bladders are used to produce a holding chamber for the shells while a simple butterfly valve is utilized to produce an airtight seal. Ideally, readily available rubber sheet would be used as the bladder material. Thus upon the demand for feed from the level control mechanism within the reactor, a timer controlled solenoid, pneumatic powered mechanism begins a sequence of actions which first involves opening the mechanical valve and then exhausting the lower two air-filled bladders. The result is that the bladders collapse and the shells in the holding chamber fall into the convertor without contacting the mechanical valve. Then the sequencing timer, solenoid, pneumatic-powered system pressurizes the lower bladders and closes the butterfly valve, while nearly simultaneously releasing the air in the upper bladders. With the upper bladders collapsed, the control system turns on the conveyor for a preselected interval, and it fills

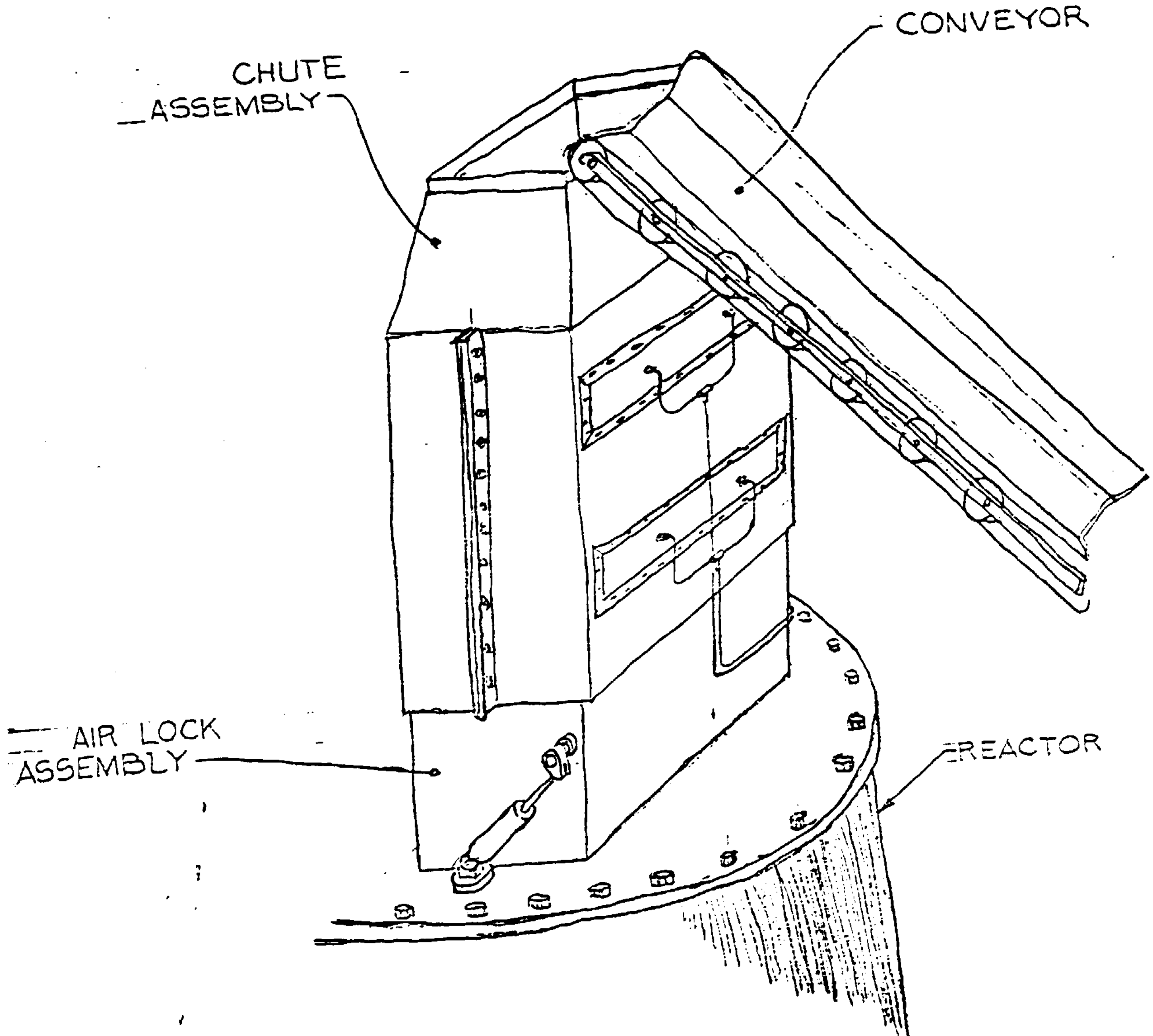

FIGURE 11-A

AIR LOCK WITH FEEDING SYSTEM

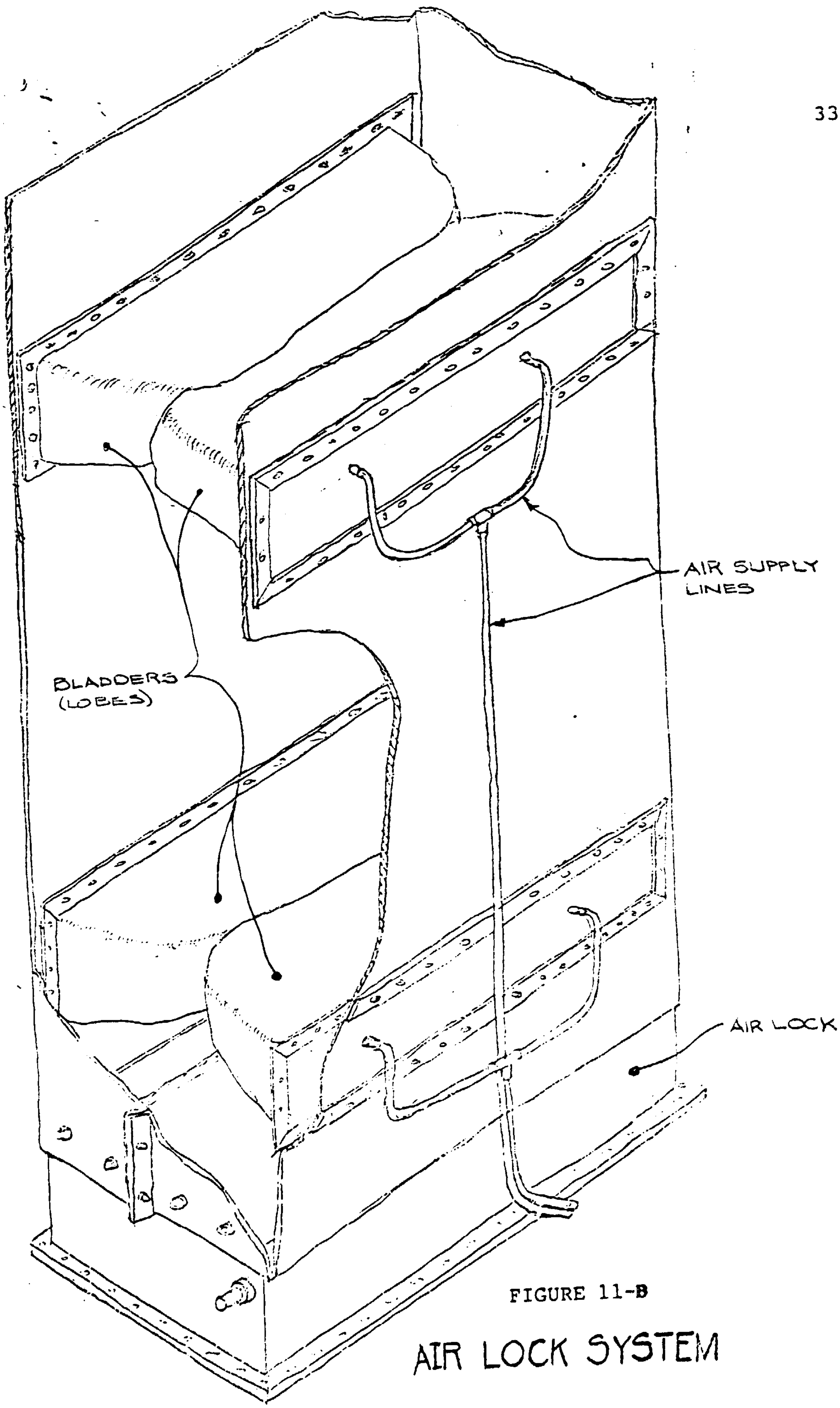

FIGURE 11-B

AIR LOCK SYSTEM

the holding chamber about two thirds full. Then the upper bladders are filled and the sequencer is reset to zero. If the level control system still calls for feed, the cycle is repeated on and on until the convertor is filled to the desired level.

By careful sequencing of the processes described above, using simple, adjustible, mechanical timers, the system can be easily controlled and operated, and should never jam or break any shells. However, in the unlikely event that a shell jammed the butterfly valve, there would simply be an air leak into the reactor during the period between cycles of the airlock. Nothing would break because pneumatic operated components are used throughout, and the force generated by these elements can be controlled by regulating the delivery pressure of the air supply system. Presented in Figures 12 and 13 are more complete and detailed drawings of the airlock mechanism. It should be noted that with these drawings the airlock could be fabricated now.

Since this device could be built readily at the ERDC using the shop facilities available, it would be prudent to do so at the earliest time possible to gain a maximum opportunity, prior to field installation, to test this new, untried mechanism.

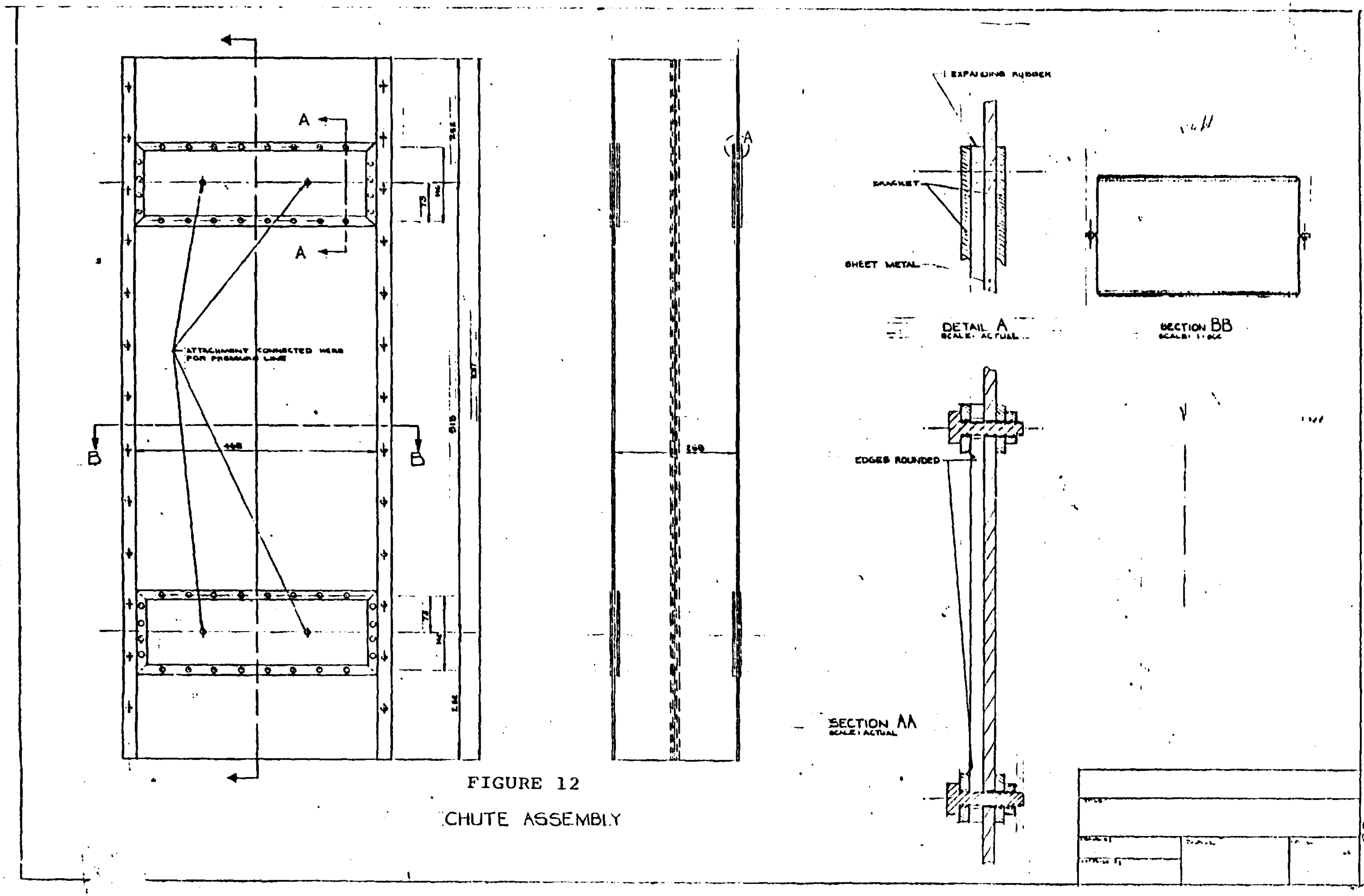

FIGURE 12

CHUTE ASSEMBLY

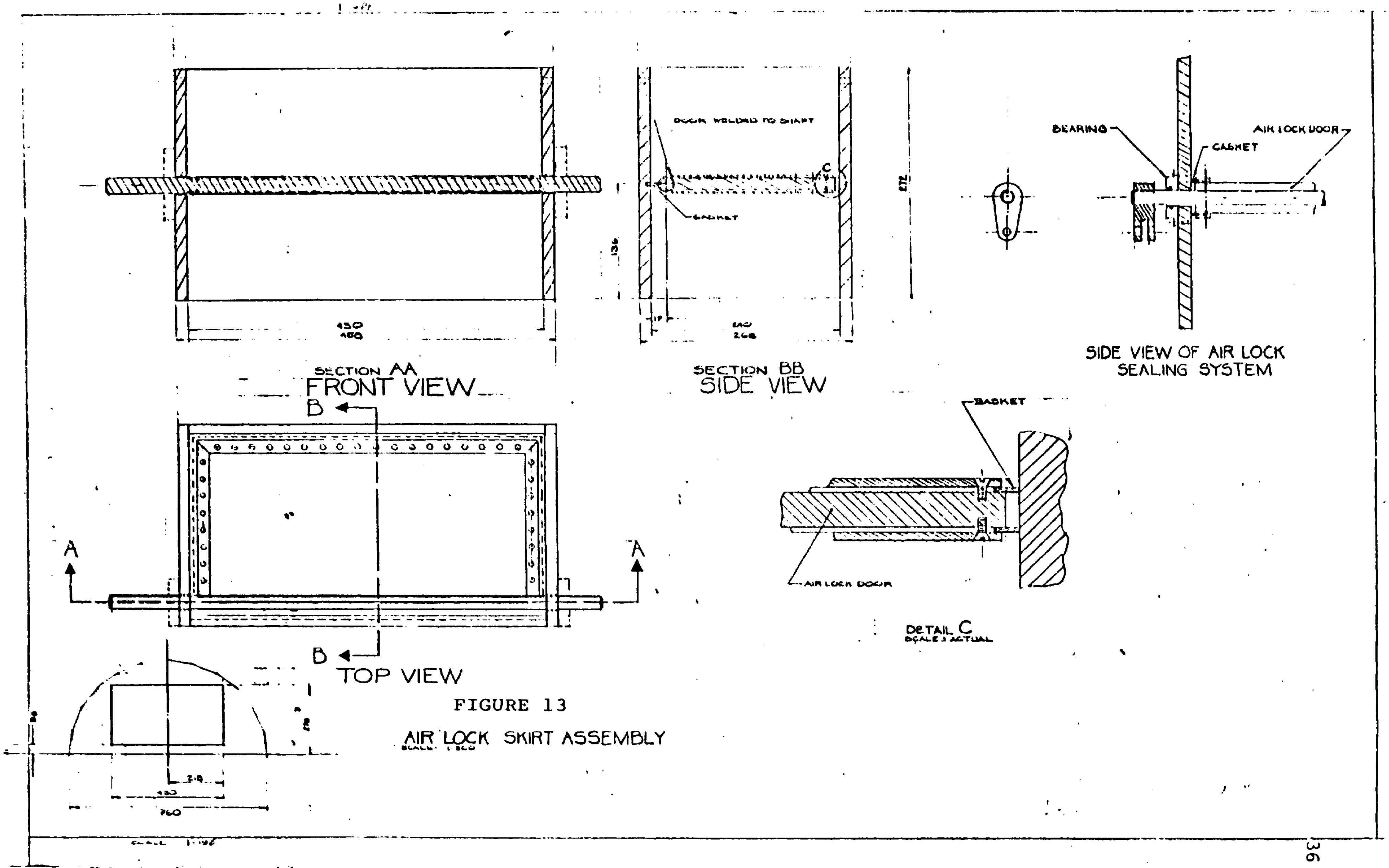

FIGURE 13

AIR LOCK SKIRT ASSEMBLY

Process Air Delivery System

This system is shown in Figures 14, 15 and 16, and is composed of an outer away of expendible tuyeres and an inner array. In both cases air would be drawn into the reactor by maintaining it at a slightly subambient pressure. In the case of the outer away of tuyeres, air enters the large supply manifold through several openings and then is carried to the tuyeres and thence into the reactor. The tuyeres would be made of a common stainless steel available locally. Installation and removal of the tuyeres could be made easily and quickly through the separate ports provided. In the case of the inner array air would enter the "steel top hat", which is mounted to the movable upper grate surface and which supports the tuyeres. Again the tuyeres are removable and made of an available stainless steel.

A basic principle in the design of the tuyeres is to avoid any tight connections such as threaded fittings, that will be located in a high temperature environment. This should prevent difficulty in removal of these pipes which will oxidize and corrode with time. Another concept is to design the system so that if a pressurized operation is necessary, it can be readily added. Hence, the external manifold could be pressurized if necessary by closing off all but one of the ports, and a simple rotary coupling mounted to a circular plate attached to the

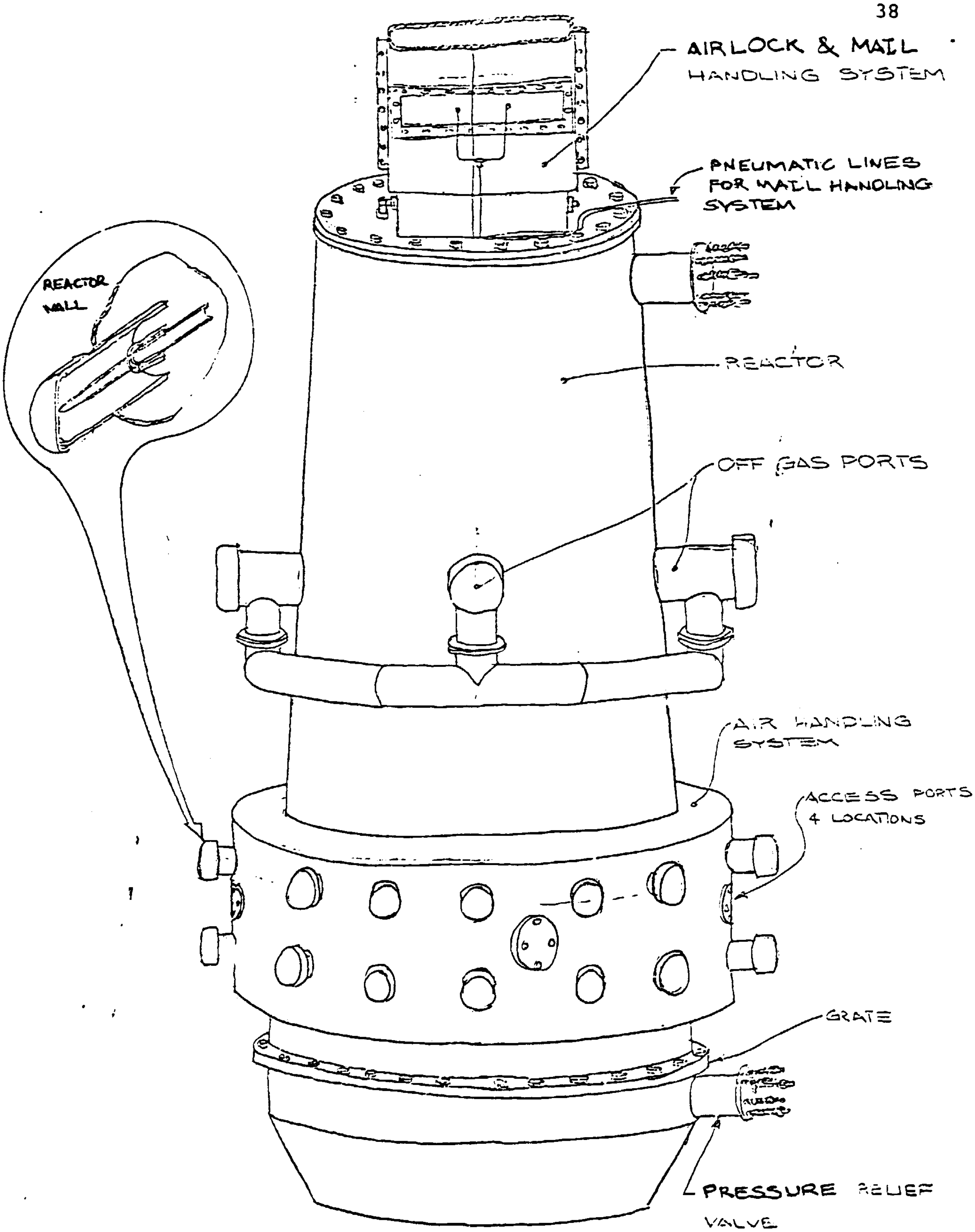

FIGURE 14

PYROLYTIC CONVERTOR - PICTORIAL VIEW

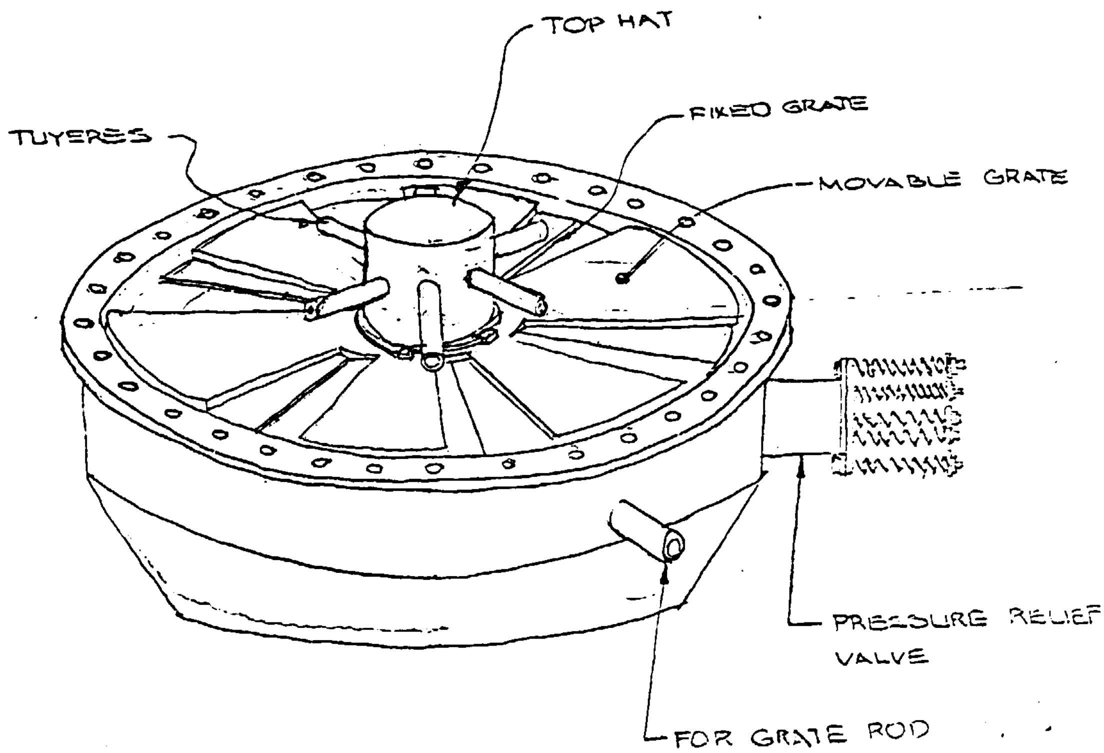

FIGURE 15

GRATE WITH TOP HAT

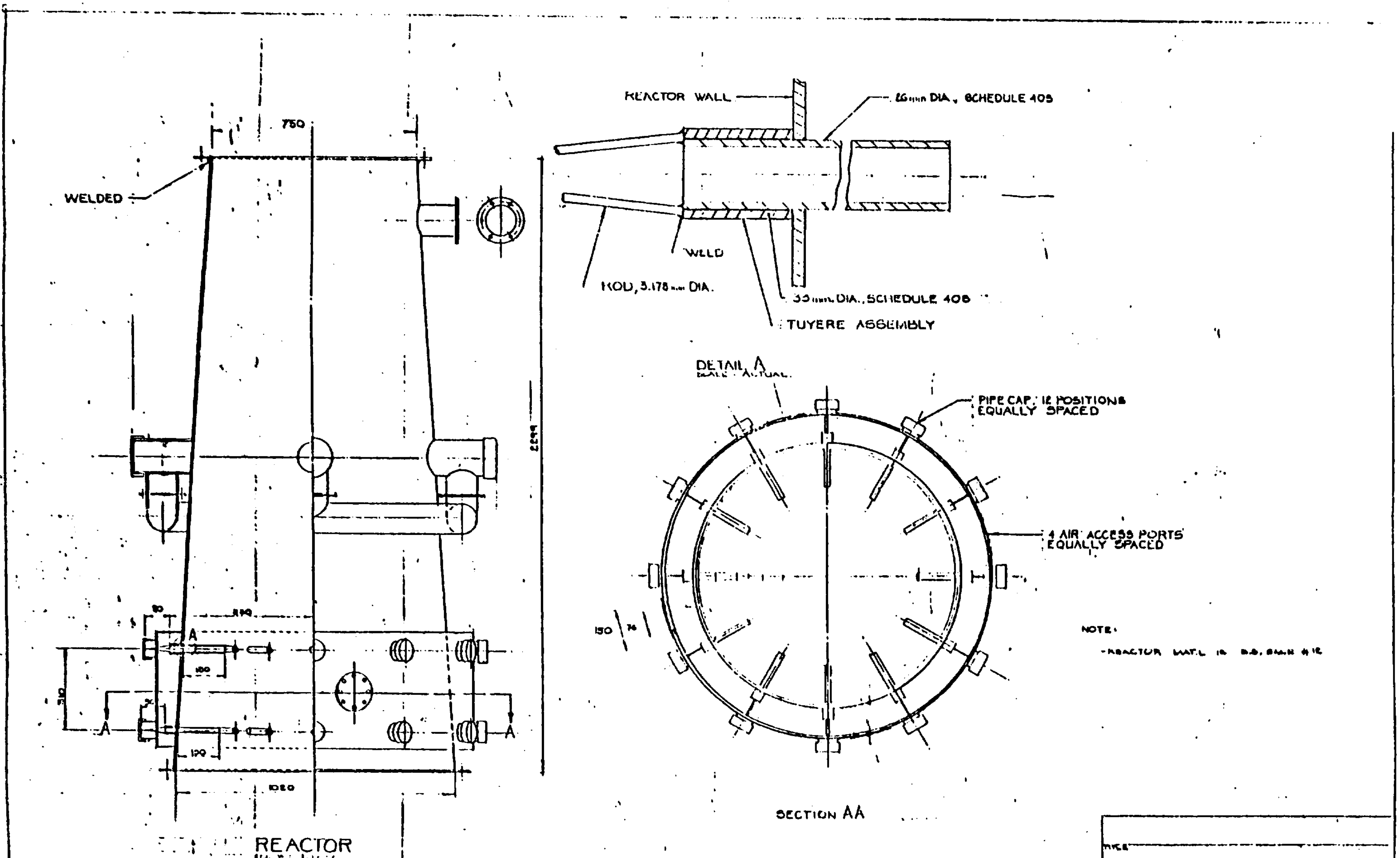

FIGURE 16

REACTOR AND PROCESS AIR SYSTEM DETAIL

lower surface of the grate cam would be sufficient to pressurize the inner array of tuyeres. Alternately, an Airgitator could be added, and provision has been made in the design for the required components.

Bridgebreaker System

Cavities or 'bridges' form in all containers, bins or hoppers into which and from which granular materials are moved, and thus they represent a very common problem in material handling. The denser and more uniform a material is, the easier the problem is solved, and the less is the tendency for bridging. On the other hand, bulky, inhomogeneous materials are especially difficult to handle because of their bridging properties. Bridging in a moving bed, partial oxidation pyrolysis reactor can result in localized channeling of the hot gases with the result that the desired uniform upward flow is disrupted, and the pyrolysis process impeded. It can also completely stop the passage of material through the convertor. Thus bridging must be prevented at all costs.

Luckily, coconut shells present few bridging tendencies, and usually will move nicely through a vertical bed under the action of gravity alone, especially if the bed dimensions are large compared with those of the shells. But for the reactor in mind, the diameter is only five to seven times that of the shells, and so bridging would be expected occasionally, if no measures for prevention were taken. A device such as the Airgitator, which is more appropriate to bulkier materials, is not really necessary and if used with coconut shells would no doubt result in a lot of small broken pieces of charcoal. Thus a gentler, simpler, less expensive and less strenous system is needed to occasionally stir up the bed and thus prevent/minimize bridge formation for coconut shells.

The approach taken is pictured in Figures 17 and 18 and consists of a centrally mounted, vertically-moving agitator having a series of horizontal arms approximately 20 inches apart. The object of the system is to periodically move upward through the shells, thus agitating and losening the bed so that any cavities that might have formed are destroyed. Then this system would be carried down by the motion of the bed to repeat the cycle. Such an action should effectively prevent the formation of cavities during all but a few rare occasions when they might occur during the downward phase. In such a case, a simple, manually operated battering ram, also shown in Figure 18, would be used to break them up. Since the effort in lifting the bridge-breaker through the bed would be hardly more than raising its weight, and no work[1] would be expended in lowering it, a simple pneumatic powered actuator should be sufficient to operate this component.

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1) It should be noted that one of the primary advantages of this technique is that the downward travel is not forced. If it were, much more effort would be required, and a much stronger device would be necessary. Ironically, such an action would probably only worsen the bridging problem, since it might jam the shells together so powerfully that they would act like a solid body under a compressive load.

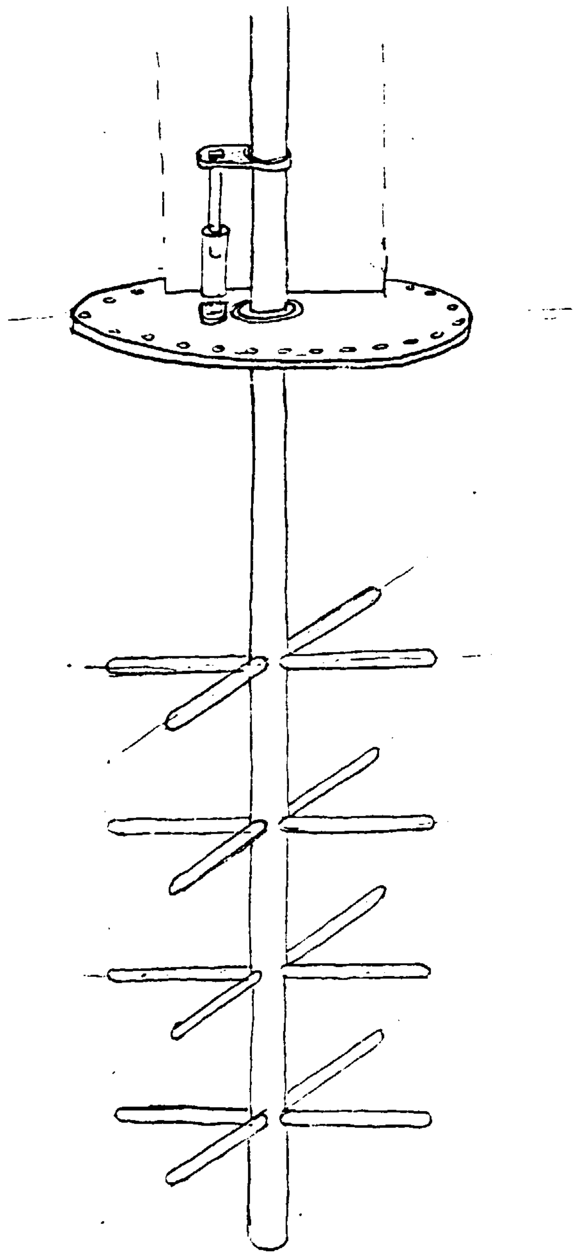

FIGURE 17

BRIDGEBREAKER PICTORIAL

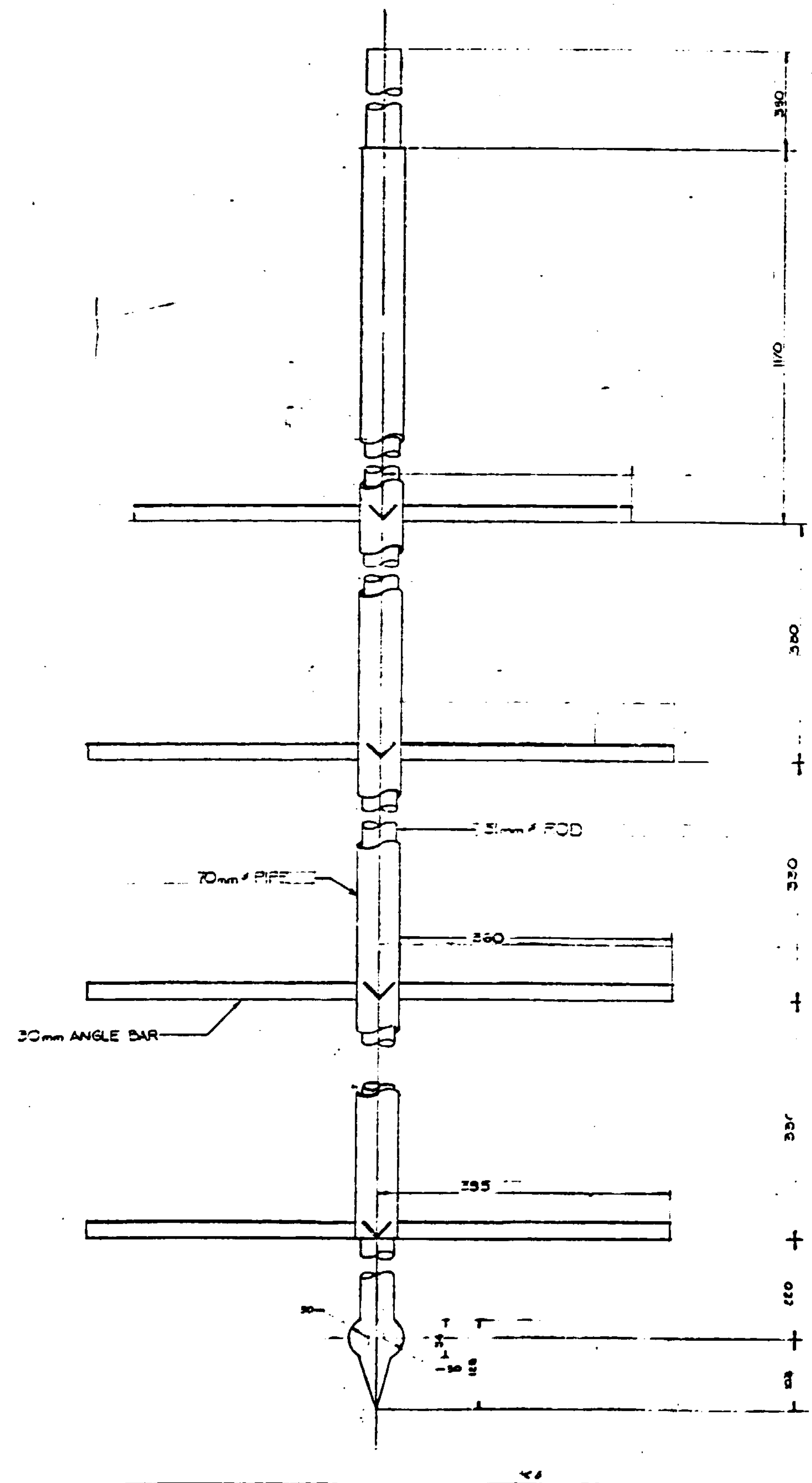

FIGURE 18

BRIDGEBREAKER DETAIL WITH BATTERING RAM

RECOMMENDATIONS

The following recommendations regarding the ERDC Prototype Pyrolysis Facility are offered:

(1) The grate should be returned to the fabricator to correct the problem in its original manufacture.

(2) The airlock should be likewise returned to improve its tolerances.

(3) The drier burner should be examined to see if it is properly assembled.

(4) If further development of a better procedure to prevent 'blowouts' from the drier bed is not productive, then thought should be given to the design of a heat exchanger to transfer heat from the exhaust stream to the cool incoming air, prior to the burner.

(5) Insulation of the off-gas system should be added.

(6) The system should include more complete instrumentation with (1) several layers of perhaps four thermocouples each on the reactor sidewalls, (2) pressure and temperature measurements thoughout the drier system, (3) an off-gas analyzer and (4) a feed moisture meter.

(7) The char recovery clamps need to be made of heavier metal and the tolerances of the char drum elevator-trolley need to be improved to prevent jamming.

(8) The drier gear drives need to be inclosed, for safety's sake.

(9) The temporary drier screen on the low pressure side and the wooden skirts at the ends should be made permanent.

The following recommendations regarding the new coconut shell pyrolysis facility are offered:

(1) If possible, and with all things equal, it will be highly desirable to achieving the project objectives that this plant be located as near Manila as possible.

(2) The new airlock should be built and tested at ERDC as soon as practical, to evaluate its performance, before the final construction of the facility.

(3) A very careful review of the control system should be made as quickly as possible, together with an assessment of equipment availability in Manila, to insure that this critical component is ready on time.

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