GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: November 15, 1977

Project Title: Pyrolysis Demonstration Project: Ghana

Project No: A-2076

Project Director: Phillip W. Potts

Sponsor: Agency for International Development

Agreement Period: From 10/27/77 Until 12/31/77

Type Agreement: Contract No. AID/afr-C-1377

Amount: $77,401

Reports Required: Quarterly Progress, Final Reports

Sponsor Contact Person (s):

Technical Matters

Mr. D. Dibble, AFR/DR/SDP
Project Manager
Office of Science & Technology
USAID/Ghana, Africa

Contractual Matters
(thru OCA)

Mr. M. Kenyon
Agency for International Development
Regional Operations Division - Africa
Washington, DC 20523

Defense Priority Rating:

Assigned to: International Programs Office (School/Laboratory)

COPIES TO:

- Project Director
- Division Chief (EES)
- School/Laboratory Director
- Dean/Director—EES
- Accounting Office
- Procurement Office
- Security Coordinator (OCA) ✓
- Reports Coordinator (OCA)
- Library, Technical Reports Section
- EES Information Office
- EES Reports & Procedures
- Project File (OCA)
- Project Code (GTRI)
- Other

CA-3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 10/23/79

Project Title: Pyrolysis Demonstration Project: Ghana

Project No: A-2076

Project Director: Stone

Sponsor: Agency for International Development

Effective Termination Date: 12/31/79

Clearance of Accounting Charges: 12/31/79

Grant/Contract Closeout Actions Remaining:

- x Final Invoice and Closing Documents
- x Final Fiscal Report
- _ Final Report of Inventions
- x Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ______________________

Assigned to: EEL/IPD (School/Laboratory)

COPIES TO:

Project Director
Division Chief (EES)
School/Laboratory Director
Dean/Director—EES
Accounting Office
Procurement Office
Security Coordinator (OCA)
✓ Reports Coordinator (OCA)
Library, Technical Reports Section
EES Information Office
Project File (OCA)
Project Code (GTRI)
Other ______________________

CA-4 (1/79)

A-2076

FIRST PROGRESS REPORT ON DEMONSTRATING THE FEASIBILITY OF PYROLYTIC CONVERSION IN GHANA

Prepared for

The U. S. Agency for International Development

by

Kermit C. Moh

and

Phillip W. Potts

Office of International Programs
Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

Project A-2076

FIRST PROGRESS REPORT ON DEMONSTRATING THE FEASIBILITY OF PYROLYTIC CONVERSION IN GHANA

Prepared for

The U.S. Agency for International Development

by

Kermit C. Moh

and

Phillip W. Potts

Office of International Programs
Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia
June 1978

Table of Contents

*　　*　　*

Figures

Summary

Pyrolysis is a process as ancient as civilization itself. By definition, it is the subjection of organic compounds to very high temperatures and the resulting decomposition.

The use of pyrolysis by mankind can be traced back to the very beginnings of civilization when man first used earthen mounds to produce charcoal. These mounds were inefficient as they did not collect the pyrolytic oil and the combustible gas which were produced.

In today's energy-hungry world, these sources of energy cannot be ignored. The pyrolytic oils can be used in industrial and utility boilers and in some types of lamps and stoves. The combustible gas can be used to run an internal combustion engine at 60% of its rated efficiency. (In Ghana it will be used to dry the feed going into the convertors.)

Typically, there are two types of processes which cause a pyrolysis reaction -- a high temperature process which promotes gasification and a low temperature process which promotes char and oil yields.

Georgia Tech has been involved in designing and testing pyrolysis systems of the latter type. Presently it has a highly automated system for use in industrialized nations and is building and testing four 1.5-ton-a-day convertors in Ghana. These convertors are labor intensive, are mostly made out of locally available materials, and are appropriate for use in a developing country.

The first of four modules has been built and tested in Ghana. A dryer is now being built so as to reduce the moisture content in the feed material to 5%. This should help increase the oil yields which presently are being obtained in the convertor.

At this point it can be concluded that Ghana does have the technical expertise and necessary raw materials to build pyrolytic convertors. The only components which presently need to be imported are an air blower for the reactor and an electric motor to run it. However, Ghana does have the capability of manufacturing air blowers.

From preliminary cost data which have been obtained from the first module, it appears that when inflation is accounted for (150% per year), the cost of

the pyrolysis system falls well within the guidelines set forth by the feasibility study which was conducted by Georgia Tech in Ghana.

FIRST PROGRESS REPORT ON DEMONSTRATING
THE FEASIBILITY OF PYROLYTIC CONVERSION IN GHANA

Background

Pyrolysis is a process as ancient as civilization itself. By definition, it is the subjection of organic compounds to very high temperatures and the resulting decomposition. It is constantly taking place beneath the surface of the Earth. Organic matter is buried, subjected to some rather high temperatures (and pressures), and then decomposes to form coal, crude oil, and natural gas.

What man does when he causes a pyrolysis reaction to occur is simply to speed up what goes on within the Earth's surface, from several million years to a matter of hours.

Basically, a pyrolysis reaction is started by cooking a feed material. This material releases hot carbon monoxide gas, which in turn, cooks the material surrounding it. The material then decomposes and becomes char and gas. When condensed, part of this gas makes up the pyrolytic oil. The reaction which takes place is exothermic, in that once the reaction is initiated, it is capable of producing enough heat of its own to keep the process going.

The use of pyrolysis by mankind can be traced back to the very beginnings of civilization, when man first used earthen mounds to produce charcoal. These mounds were inefficient, as they did not collect the pyrolytic oil and the combustible gases which were produced.

In today's energy-hungry world, these sources of energy cannot be ignored. The pyrolytic oil can be used in industrial and utility boilers, and in some types of lamps and stoves. The combustible gas can be used to run an internal combustion engine at about 60% of its rated efficiency. (In Ghana, it will be used to run the dryers that will dry the raw material going to the convertor's reactor.)

When compared to the burning of wood, the by-products of pyrolysis are much more efficient. For example, it is estimated that charcoal is about twice as efficient for cooking as wood and pyrolytic oil is approximately five times as efficient because of reduced waste and the concentrated form of the fuels produced. Thus, if 5×10^6 Btu/yr. of wood energy is taken as the average heat required for one individual's cooking demands, only about 2.5×10^6

Btu/yr. of charcoal are required and 1 x 10^6 Btu/yr. of pyrolytic oil are needed to do the same job. Hence a ton of dry biomass will provide sufficient cooking energy for about 3.7 people. However, even after taking into account the losses occurring during pyrolytic conversion, the charcoal produced from the same ton of biomass would be sufficient for about 2.2 people and the oil sufficient for approximately 6.9 people or a total of 9.1 people. Therefore, the cooking needs of almost 2.5 times as many people can be met through pyrolytic conversion rather than through the direct burning of biomass.[1/]

Various types of modern continuous-flow pyrolysis processes have been developed recently in the United States and elsewhere to emphasize the production of one or more of the products of pyrolysis. Characteristically, these processes require the wastes to be shredded into relatively small pieces which can be easily handled. Primarily, these processes tend to maximize the production of gas, with the oil a secondary by-product and the char essentially reduced to ash. This is because most of these processes have been developed to deal with municipal wastes and have assumed the proximity of a large, gaseous-fueled industrial or utility type boiler. Clearly, emphasis on gas production for a system to convert agricultural and forestry wastes would be a serious mistake because of the problem of storing and/or transporting the gas to a user. There is a system (the Garret process) that emphasizes the production of oil, but it is very complex and requires significant preprocessing of the wastes.

Typically, high-temperature processes emphasize gas production, while low-temperature processes emphasize char and oil production. Conveniently, low-temperature processes can be fabricated of cheaper materials and can be made to operate in a simpler manner than the higher-temperature processes. This favors their use in rural environments, especially in developing nations, where spare parts are not always conveniently available.

A number of continuous low-temperature pyrolysis processes also have been developed recently throughout the world. Among them is the highly automated Georgia Tech system. This 50-ton-a-day system was designed to dispose of

---

[1/] John W. Tatom, "Demonstration of Alternative Fuel Production through Pyrolysis of Agricultural Waste at the UNEP Rural Energy Center in Senegal," November 1977.

the mountains of peanut hulls which accumulated yearly in south Georgia without creating a pollution problem. In doing so, this disposal method created profitable and useful forms of energy. However, the above-mentioned unit could be used economically only in industrialized nations, where labor costs were high. Thus, there was a great need for a small, labor-intensive pyrolytic convertor for use in less-developed countries where agricultural and forestry wastes were in abundance.

Recognizing this need, the Office of International Programs (IPO), Engineering Experiment Station, Georgia Institute of Technology, began preliminary design work on a small, labor-intensive pyrolytic system.

At about this same time (1976), the Agency for International Development (AID) contracted with IPO to determine the feasibility of using pyrolysis as an alternative source of energy in the Republic of Ghana. Pyrolysis was predicted to be feasible when a one-ton or six-ton-a-day system was operated as a two- or three-shift operation per day. A one-shift operation was found not to be feasible.

AID then contracted with IPO to demonstrate the feasibility of pyrolysis in Ghana. Basically, the contract stated that IPO would provide the following services in collaboration with the Technology Consultancy Centre (TCC) of the University of Science and Technology and the Building and Roads Research Institute (BRRI) in Kumasi, Ghana:

1. Design a six-ton-per-day pyrolytic convertor system and prepare working drawings for construction of this system at the TCC workshop in Kumasi, Ghana.

2. Provide technical assistance to TCC, which will undertake the manufacture of the unit.

3. Start up and test the pyrolytic convertor system and make field modifications in cooperation with TCC and BRRI until the final design has been adopted.

4. Assist in the preparation of an operating and maintenance manual.

5. Assist in the selection and training of local personnel to operate the pyrolytic convertor.

6. Evaluate the pyrolytic system.

Demonstrating that pyrolysis is feasible in Ghana has been a joint AID and Government of Ghana venture. AID, through Georgia Tech, has been supplying the technical assistance and some necessary materials not found in Ghana for the pyrolytic convertors. The Bank of Ghana has supplied BRRI with the necessary funds with which to build, operate, and maintain the convertors. BRRI is presently constructing the shed in which to house the convertors and has subcontracted with TCC to manufacture and assemble them.

It should be noted at this time that four 1.5-ton-per-day systems (preliminary rating) are being manufactured. These four units will provide a six-ton-per-day requirement for the Kumasi brick kiln and will also satisfy the Government of Ghana's request that the design be versatile so that a one- to two-ton-per-day system could be adapted from the brick kiln design for small, village-level industry.

Activity to Date

During the month of November 1977, project personnel designed a preliminary six-ton-per-day pyrolysis system (see Figure 1) and constructed a small prototype of it in Atlanta for testing purposes. A large dryer also was designed which would be capable of reducing the moisture content in the feed material to a desired 5% (see Figure 2). The drying of the sawdust is necessary in order to assure maximum oil and char yields. If the sawdust is too wet when it enters the convertor, gasification occurs and very little char and oil are produced.

In December, project personnel (Dr. John Tatom and Mr. Phillip Potts) traveled to Ghana to initiate and define TCC and BRRI activities relevant to the project, to check on the availability of materials and supplies that would be necessary for construction of the pyrolysis system, and to coordinate funding from the Bank of Ghana which was to be used by TCC and BRRI to cover upcoming pyrolysis experiments.

Project personnel (Dr. John Tatom and Mr. Kermit Moh) spent the months of January, February, and March in Ghana constructing, testing, and modifying the first of four modules that will make up the complete six-ton-per-day convertor (see Figure 3). They also supervised the design and initial building of the shed which will house the convertors. Schematics of the shed are shown in Figures 4 and 5.

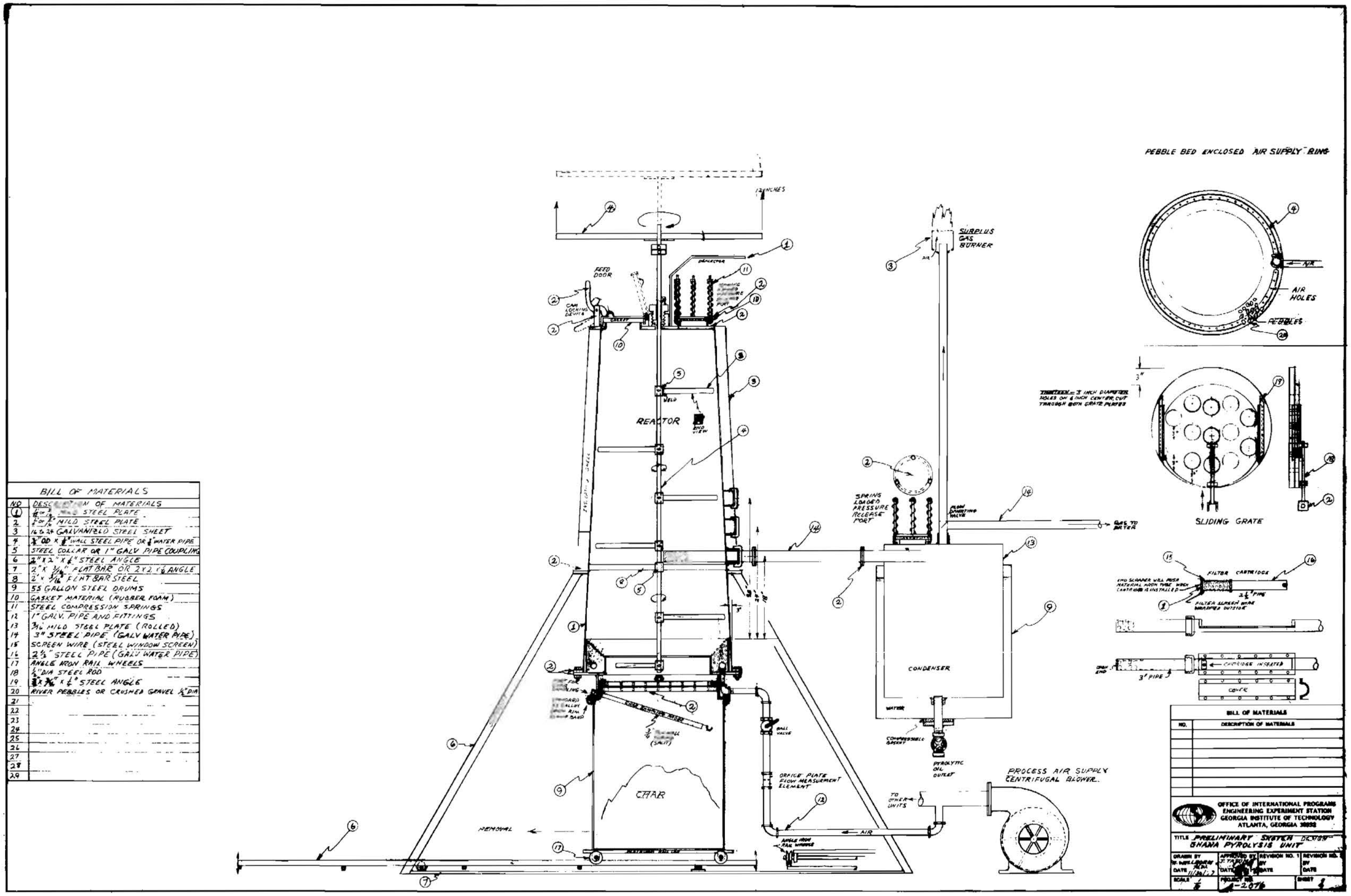


Figure 1. Preliminary drawing of the Ghana pyrolysis unit

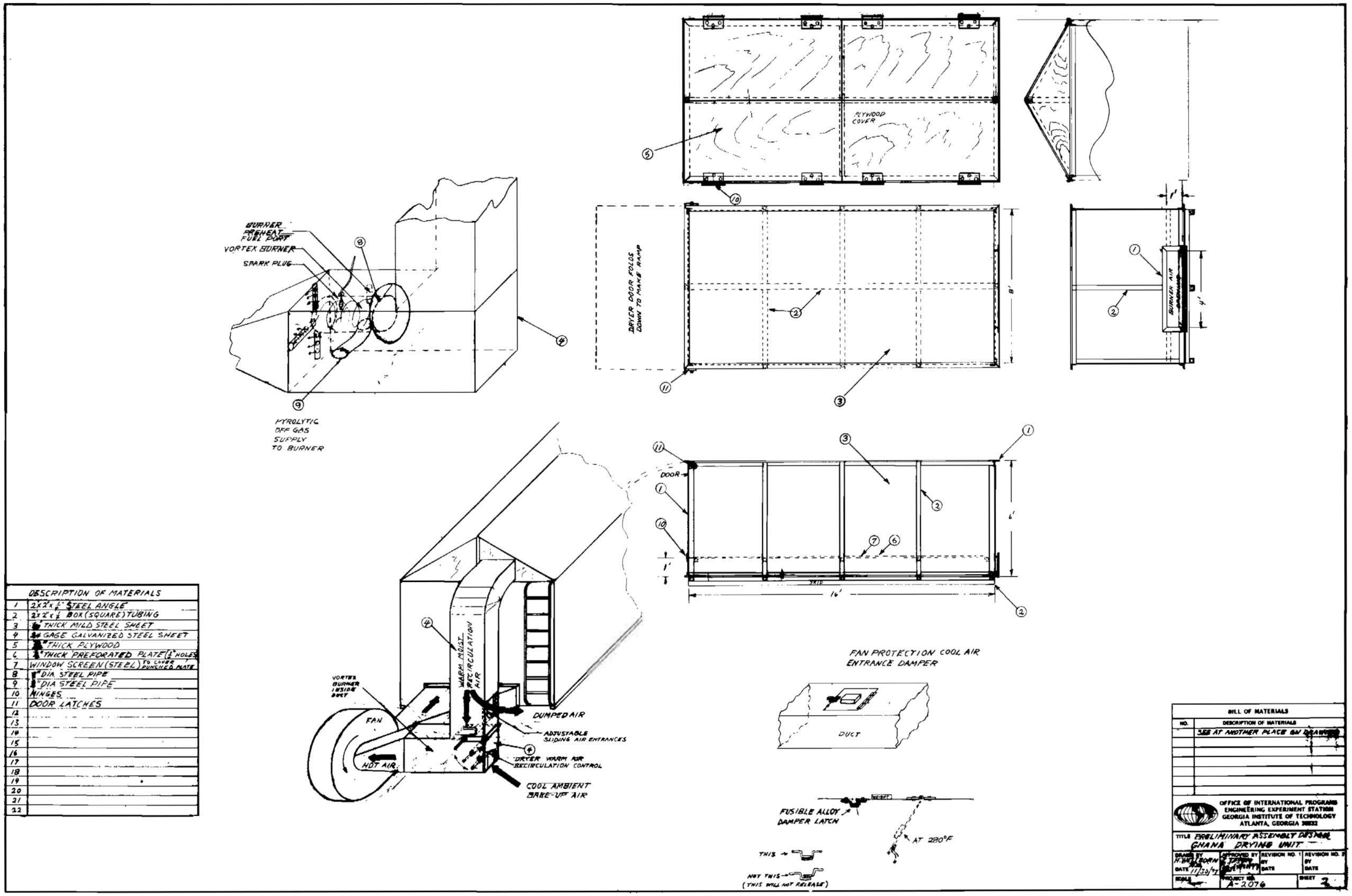


Figure 2. Preliminary drawing of the Ghana pyrolysis dryer

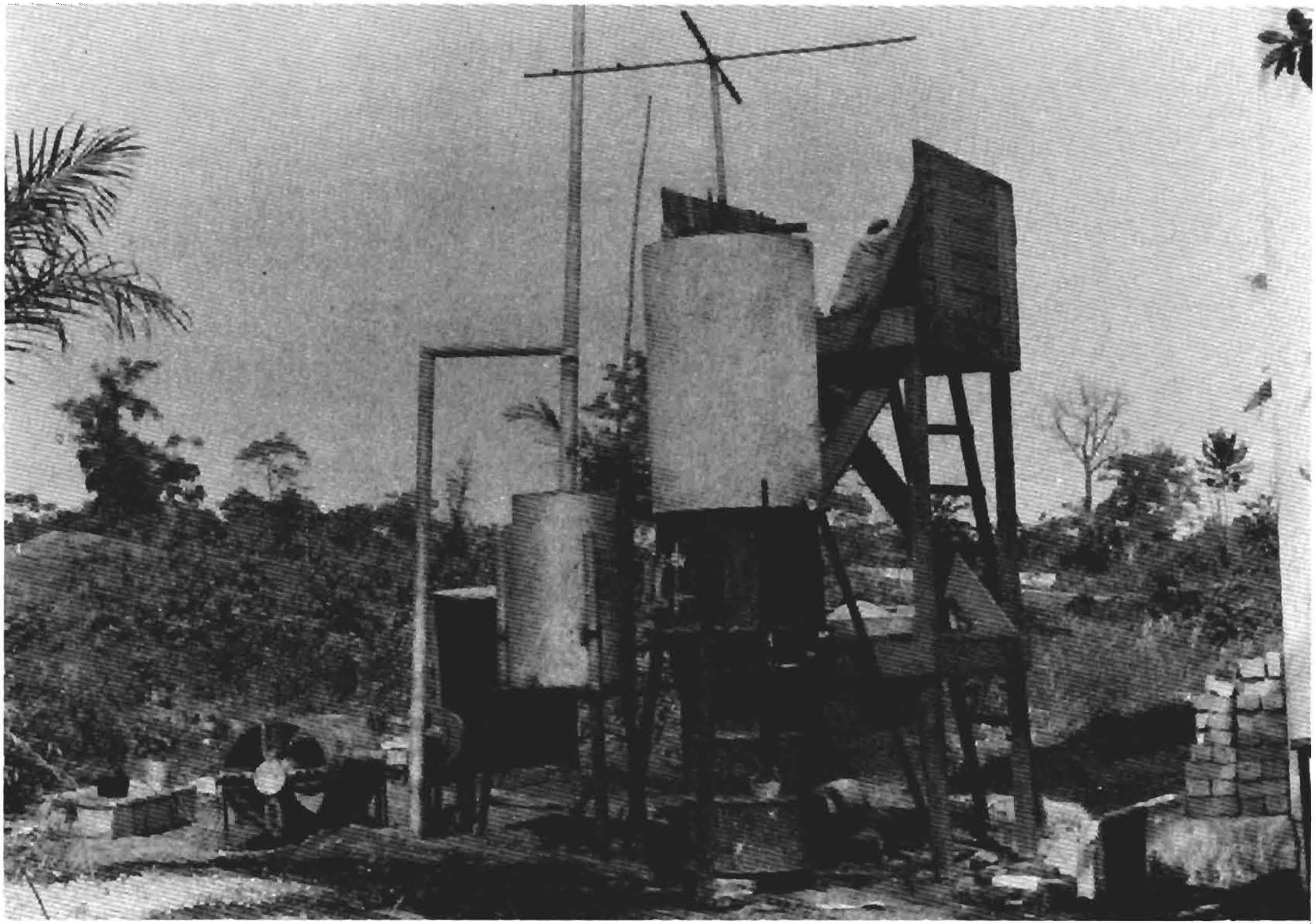


Figure 3. First of four modules of the pyrolytic convertor in Ghana

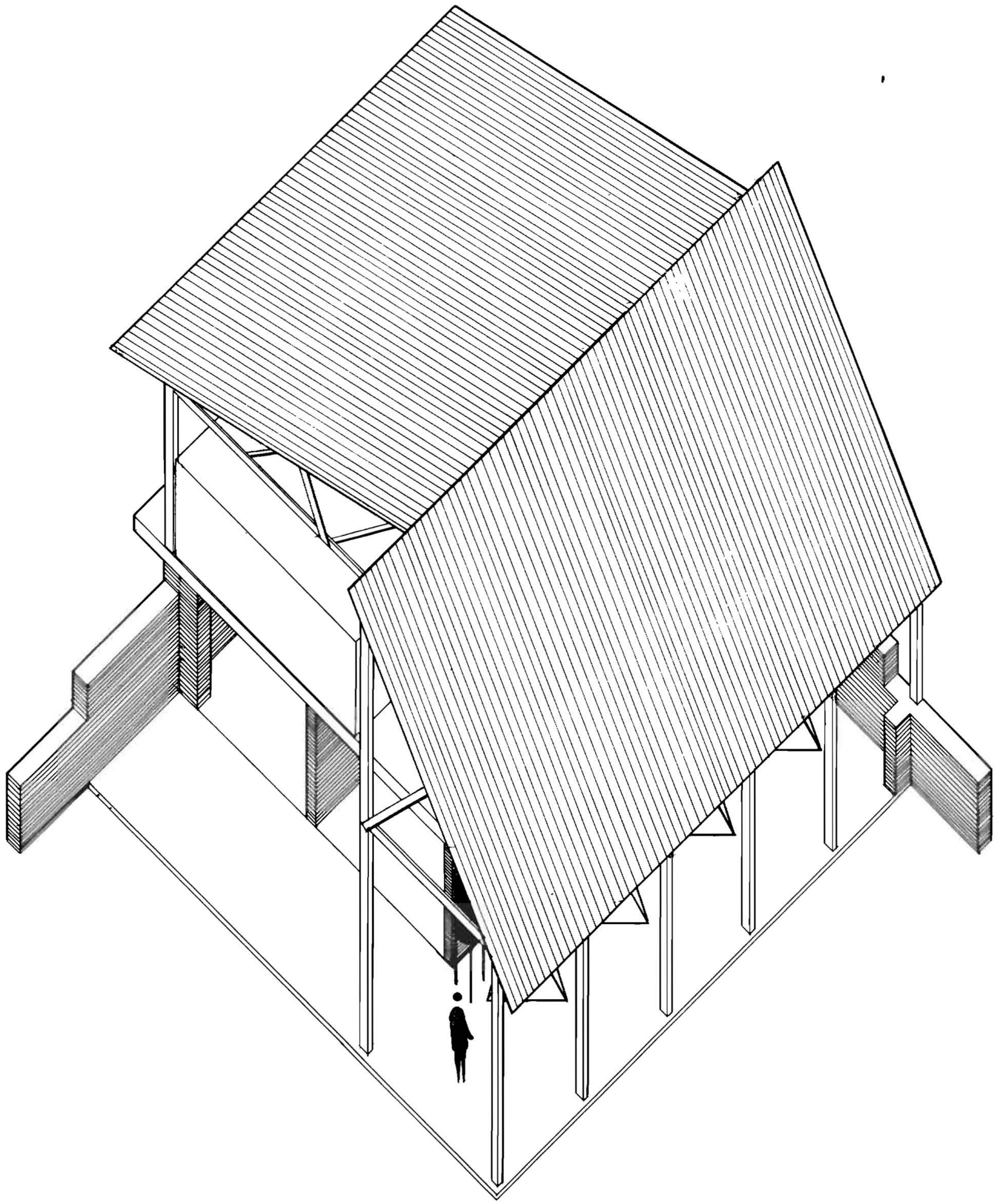


Figure 4. Artist's concept of the pyrolytic convertor shed

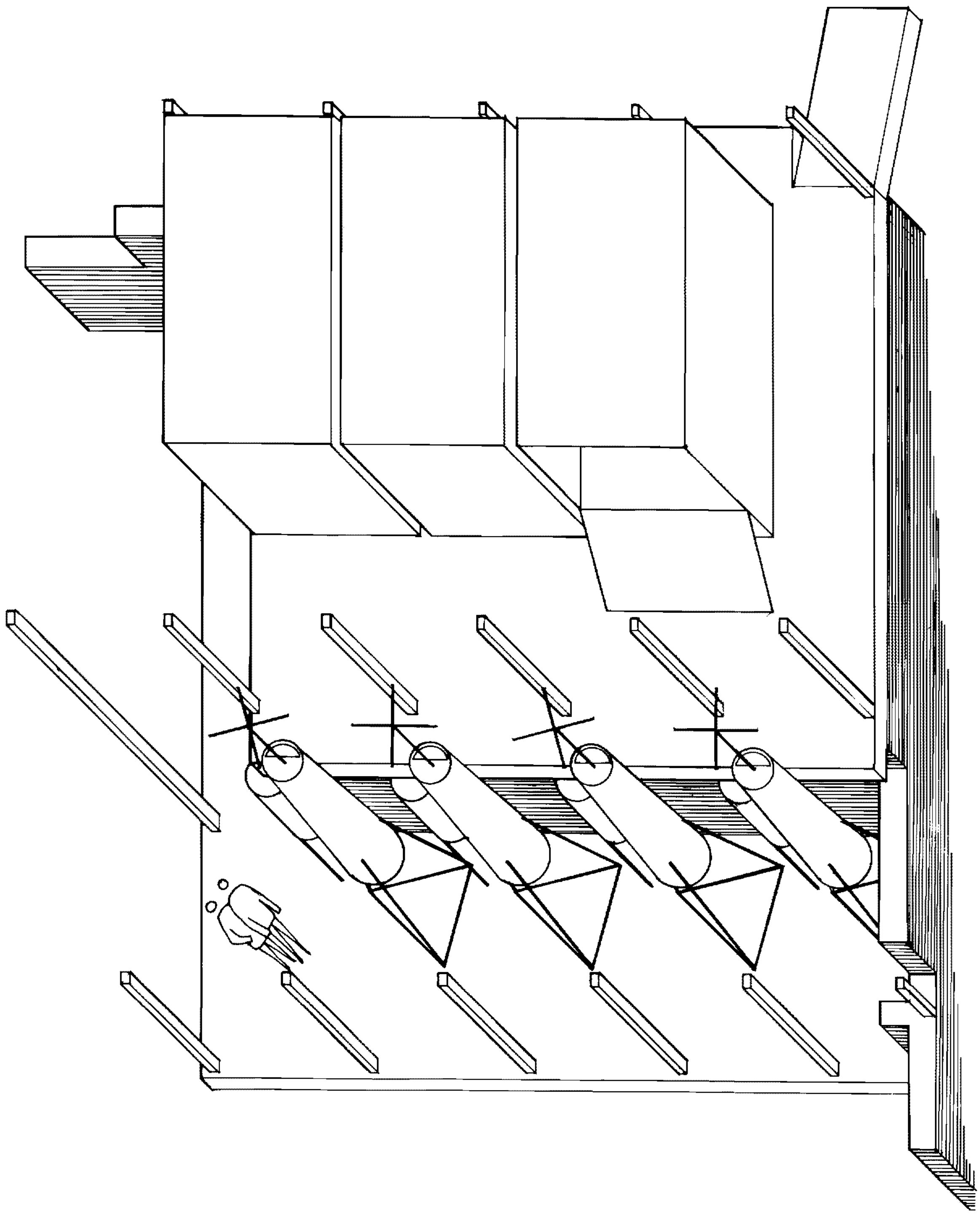


Figure 5. Layout of the convertors and dryers in the convertor shed

The first module is in operation and, when running, produces char, combustible oil, and combustible gas. This module currently is being fine tuned so as to increase the oil yields, which are presently rather low. The burner design for the dryer also has been tested and performed extremely well. Pyrolysis gas was fed from the condenser/cyclone directly to the burner and was then ignited. The gas burned cleanly and its heat was evenly distributed throughout the temporary duct work set up for this burner.

During the construction phase, problems were experienced in obtaining the necessary materials to build the module. In especially short supply were oxygen and acetylene gas for cutting the sheet metal and cement for the construction of the shed which will house the convertors. It also was found that there were no rolling machines in Kumasi which were large enough to roll the 3/16-inch sheet metal required for the walls of the reactor. As a result, the sheet metal had to be sent on a six-hour truck journey to the industrial port of Tema to be rolled.

When the first module was tested, three problems with the preliminary pyrolysis design were found. The first involved the agitator which stirs the feed and thus prevents any cavities from being formed while the sawdust is pyrolyzing. It was found that in Ghana the sawdust which was used as feed material in the first module was much finer and denser than that used to test the prototype in the U. S. As a result, it was extremely difficult to rotate the agitator. This problem was solved by removing the top three of the six blades on the agitator and adding wood shavings to the sawdust to reduce its density. The performance of the reactor was not affected by this change, as the reactor walls slant in at a 3-degree angle. This causes the sawdust to cave in on top of itself as it is consumed.

The second problem was concerned with the unevenness of the air distribution in the reactor. When the convertor was running and air was introduced into it, intense heating of the reactor shell occurred in an isolated area. This area was directly beneath the filter which filters the gases going into the condenser. The sawdust was less dense beneath this filter; as a result, the air coming into the convertor tended to concentrate at this one spot, causing intense burning. This problem is being addressed and has been corrected by redistributing the air away from the area where the sawdust is habitually less dense.

Problem three was caused by too-low temperatures in the condenser. As a result, water vapor was condensing with the oil. This will be resolved by insulating the present condenser and making the future condensers smaller in size.

During the past several months, there has been a concentrated effort to train TCC and BRRI personnel in the construction and operation of the completed module. Cooperation by both TCC and BRRI has been outstanding, and both organizations are now at a point where they are thoroughly familiar with the pyrolytic system and are beginning to advance their own ideas as to how to improve its operation.

Description of the Pyrolysis System and Its Operation

The pyrolysis system in Ghana has been manufactured mostly from locally available material. Its main components are the reactor, agitator, char barrel, filter, condenser/cyclone, and the oil barrel (see Figure 6).

Feed is added through the top of the reactor until it is full. The pyrolysis reaction takes place in the bottom third of the reactor, and the top two thirds is used as a storage area. The char which is formed drops through a grate and collects in a char barrel. When full, this barrel (an ordinary 55-gallon oil drum) is removed and replaced by another one. During this time, a manual agitator is used in order to prevent cavities from being formed in the sawdust. The gases produced from the pyrolysis reaction filter up through the sawdust bed, go through the filter and into the condenser (see Figure 7 and 8). The condenser condenses out the large particles of oil and the gas then enters a cyclone (see Figures 9 and 10) which spins the gas around at such a high velocity that the finer particles of oil are separated out. All of the pyrolytic oil is then collected from the bottom of the condenser. The rest of the gas, along with the water vapor, goes out the off-gas pipe to the dryers, where it is used to dry the raw material.

There are several innovative ideas in the design of the Ghana pyrolysis system. The two most outstanding ones concern the way the air is introduced into the reactor and the filter which is used so as to not allow particulate matter to enter the condenser.

Air is introduced into the reactor by means of a curved pipe into which small holes have been drilled (see Figure 11). Pebbles are then added to the channel in which this pipe lies (see Figure 12). This pebble bed acts as a

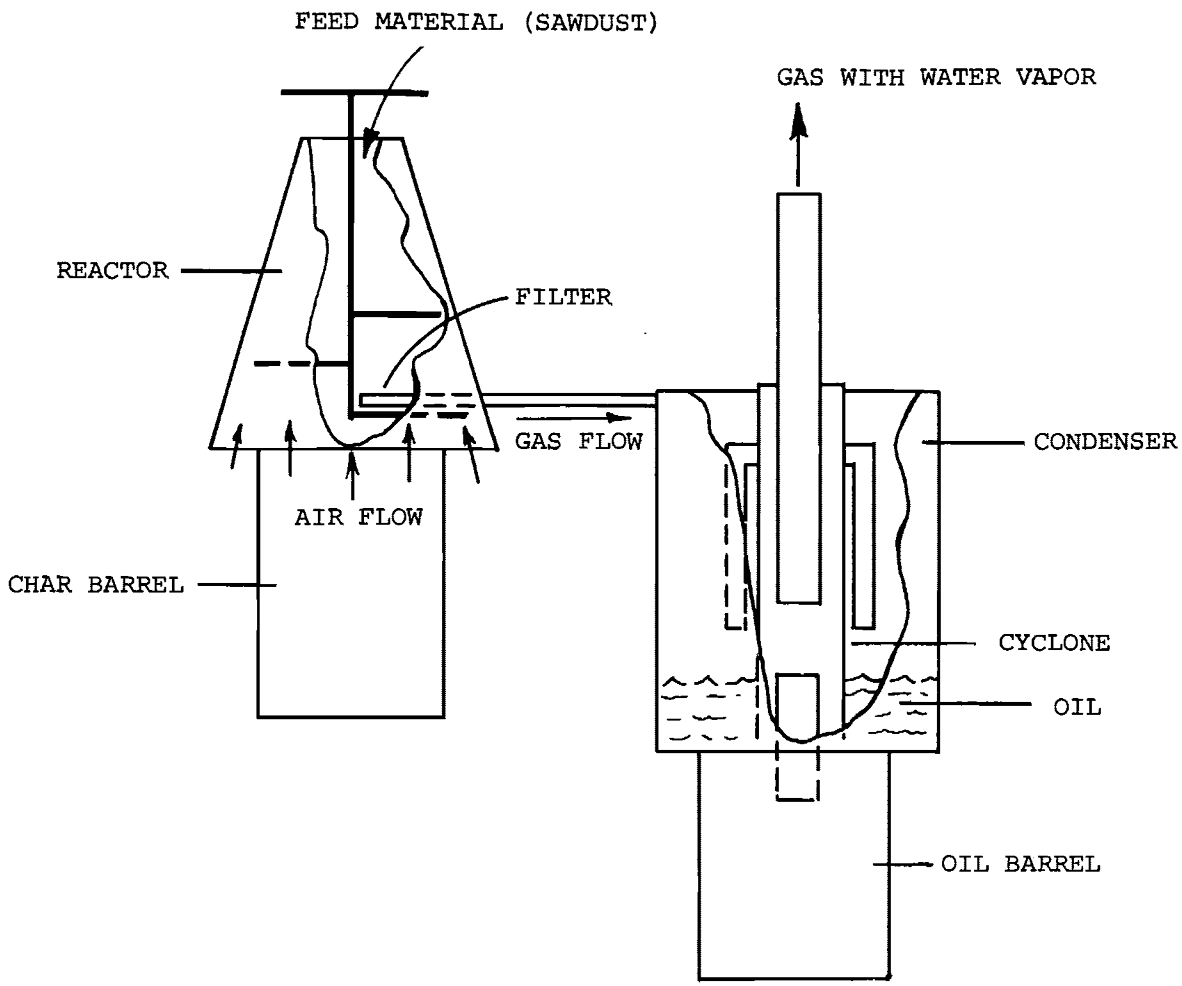


Figure 6. Schematic of Ghana pyrolysis unit

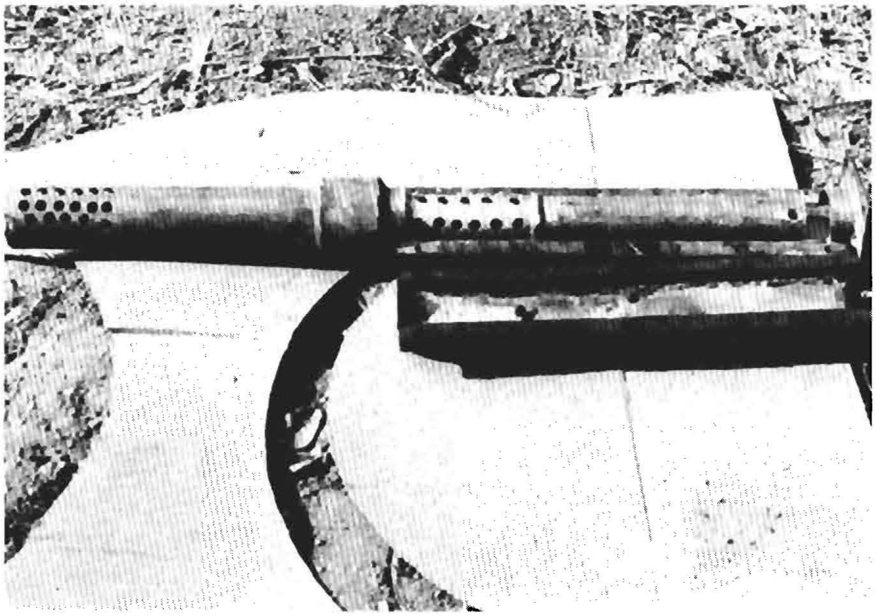


Figure 7. Exposed view of the filter which does not allow particulate matter to enter the condenser

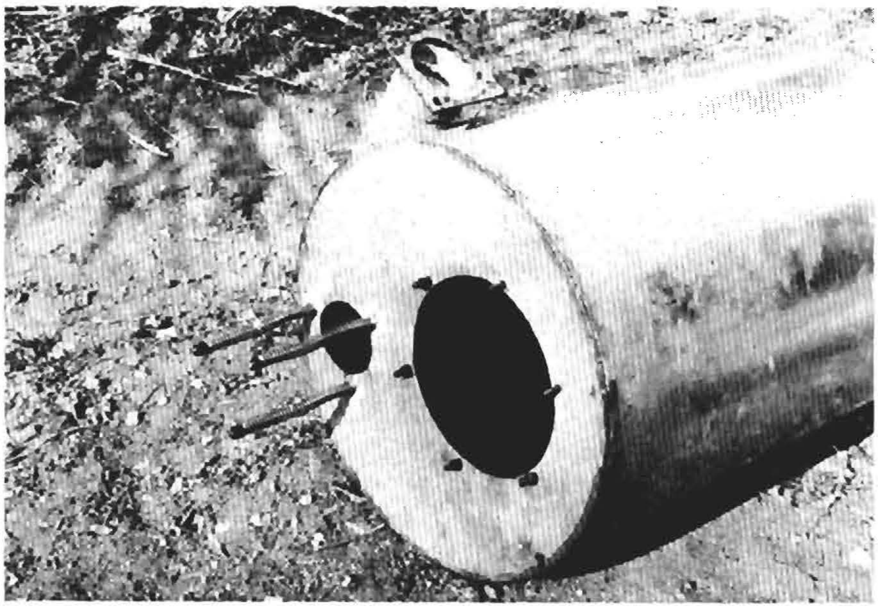


Figure 8. View of the condenser which shows where the cyclone (large hole) and pressure relief port (small hole) are located

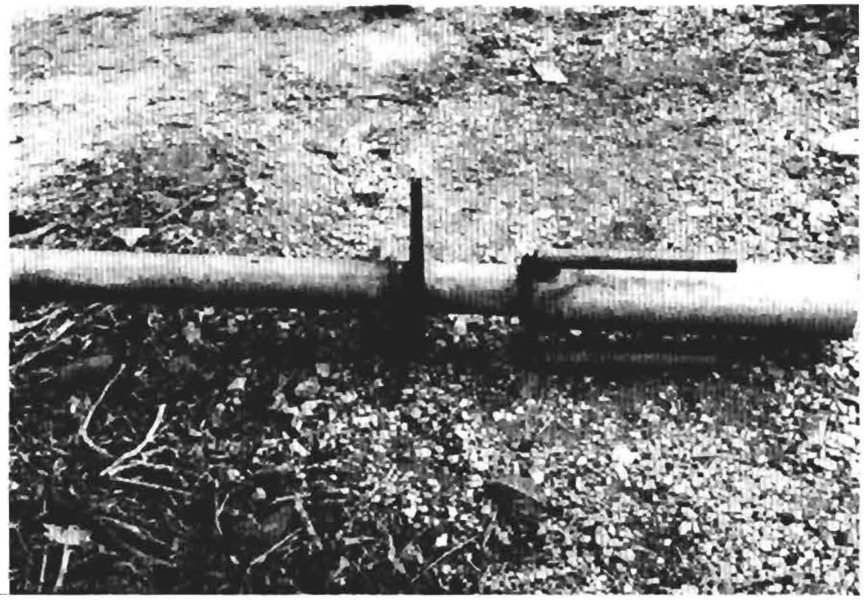


Figure 9. Side view of the cyclone

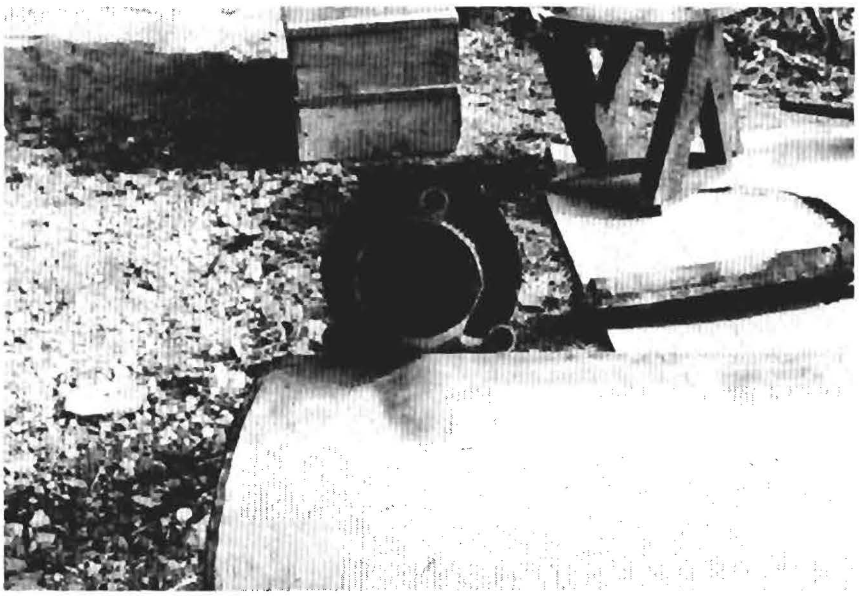


Figure 10. Bottom view of the cyclone

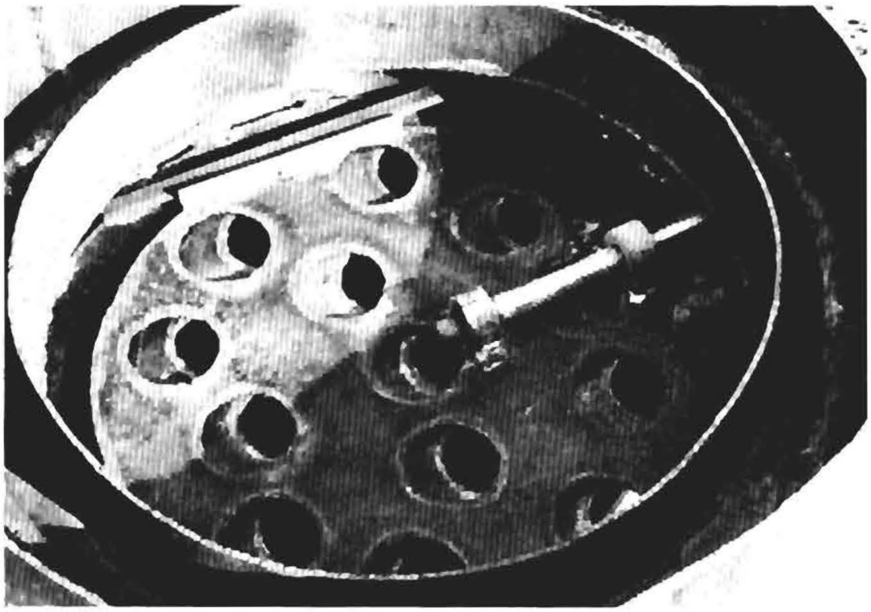


Figure 11. Top view of grate and air ring before the pebbles are put in place

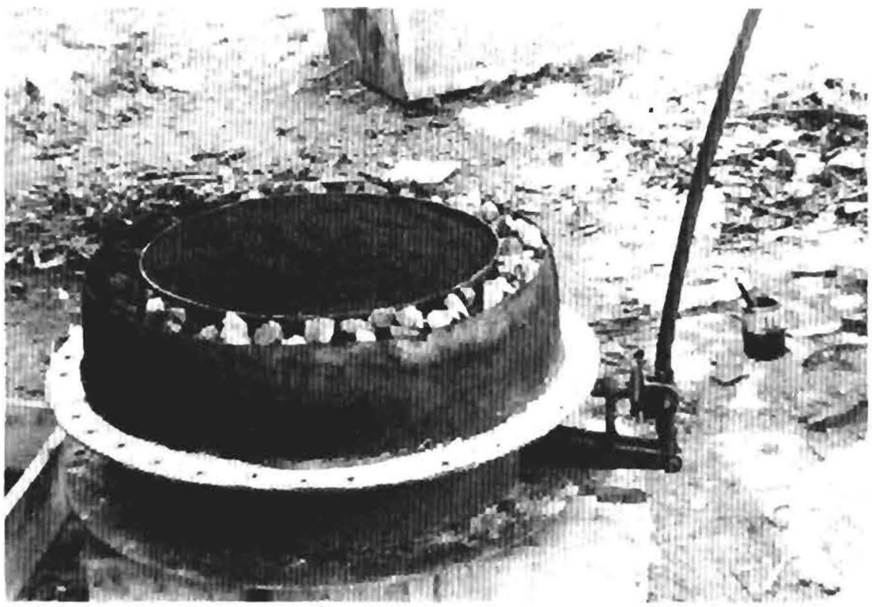


Figure 12. View of grate and air supply system with pebbles and char in place

heat sink. It absorbs the heat from the pyrolysis reaction and never allows the air pipes to become very hot. This reduces the amount of maintenance required on the system.

The filter is simply a perforated pipe which fits into another pipe. The inner pipe has a screen wrapped around it so as to prevent particulate matter from going through it. This whole filter assembly lies within the reactor, surrounded by the bed of sawdust. When in operation, the screen does not allow particulate matter to pass through it and the bed itself acts as a filter by screening out any particulate matter which is approaching the exit to the condenser. (Imagine a vacuum cleaner with a hose connected to its inlet side. A screen is on the other end of the hose. When turned on and the end of the hose is put into a sawdust pile and then withdrawn, a large clump of sawdust will become "stuck" to the hose. The screen does not allow the sawdust to go into the vacuum cleaner and the surrounding sawdust does not allow other particulate matter to approach the screen.)

At this point, it must be noted that the pyrolysis reaction produces both hydrogen and carbon monoxide gas. As a result, safety considerations have received much thought and attention since the very beginning of this project; therefore, the probability of any type of overpressure occurring in the system is extremely low. However, in the event of an overpressure, the Ghana system has three pressure-relief ports: one at the bottom of the convertor in the event of an overpressure in the char barrel, one at the top of the reactor, and one at the top of the condenser.

Naturally, the safety features which have been incorporated into the system are there to protect the convertor and the people who are working around it. It is hoped that these features will never have to be used. In accordance with this philosophy, a start-up and operating procedure incorporating many safety features has been established and followed. These procedures are described below.

Before doing any type of start-up, operators remove the filter and check to see if it is clogged. This is done by merely pouring water into it and checking to see if this water freely flows out from the filter. When the operators are satisfied that the filter is free-flowing, it is put back into the convertor. The pressure-relief ports are hand-tested to make sure that none of them are stuck. Then the air blower and the draft fan are switched on so as to vent the system. This releases any type of volatile gases to the atmosphere. Next, the air is turned off and sawdust is added to the convertor until it is level with the pebble bed. Hot glowing char is added to the char barrel through the grain sampling hole. The glowing char burns up any air that is present in the barrel, thus virtually eliminating the possibility of hydrogen mixing with air in the char barrel. Glowing charcoal is then added to the convertor and smothered with sawdust. The air blower is again turned on, and the sawdust allowed to smolder for about 45 minutes so as to establish a char bed. During the beginning of this smoldering process, the cover of the convertor is loosely put in place. This allows the air to seep out of the convertor and smoke to replace it -- again virtually eliminating the possibility of a hydrogen-air combination in the reactor. Once the char bed has been established, the blower is turned off and the convertor is completely filled with sawdust. The blower is switched back on and, again, the cover of the convertor is loosely put back in place so as to allow the air to flow out. The cover is later firmly tightened into place. Every time a char barrel becomes full and is replaced with an empty one, some glowing char is put into the bottom of the barrel. Also, whenever the convertor is opened, the air is removed from the reactor before it is completely resealed.

Once the pyrolysis system reaches operating temperature (350-400^{o}F entering the condenser -- 180-200^{o}F leaving the condenser), the char processing can begin. The operator shakes the grate and allows the char to fall into the char barrel. Occasionally, he will take samples of the char. If the char is brown, it is not quite char yet and he is processing too quickly; if it is grey, the char is burning up and he is processing too slowly; if it is black, he is processing at the correct rate of speed. When processing for a period of time, a noticeable decrease in the temperature going into the condenser will occur. When this happens, the operator must stop processing and wait for the off-gas temperature to rise again.

Due to the long period of time which it takes for the convertor to reach operating temperature, it is advisable to operate the units on a continuous basis until the required amounts of char and oil are produced. Continuous operation also decreases the need for maintenance on the system, as the filters must be removed and cleaned every time a unit is shut down.

The convertors will be housed in a shed which is open to the elements on all four sides. There will be a smokestack which will be sufficiently above the roof of the shed so as to dissipate the gases (including the carbon monoxide) freely into the atmosphere in the event that they are not used by the dryers.

Future Activities

Three additional pyrolytic convertor modules, each with an estimated 1.5-ton-per-day capacity, and two dryers must be constructed before the final system is assembled (it is estimated that these units will be completed by September of this year). At the same time, the construction of a shed to house the entire pyrolysis system also will have been completed. Electricity will have to be brought to the site and hooked up.

Project personnel (Mr. Kermit Moh and Mr. Phillip Potts) will then travel to Ghana to assist in the installation and operation of the complete system, the training of additional operating personnel, and the preparation of an operating and maintenance manual. During this trip, they will gather and analyze all historical cost data on the construction and operation of the pyrolysis system to determine the economics of pyrolysis in Ghana. They also will perform an analysis of the social soundness of the pyrolysis system at this time.

Conclusions

Ghana does have the technical expertise and necessary raw materials to build pyrolytic convertors. The only component which presently would have to be imported is the air blower for the reactor and an electric motor to operate it. However, Ghana has the capabilities for manufacturing air blowers.

From the preliminary cost data which have been obtained during the construction of the first module, it appears that when inflation is accounted for (150% per year), the cost of the pyrolysis system falls well within the guidelines set forth in the Georgia Tech report entitled Pyrolytic Conversion of Agricultural and Forestry Wastes in Ghana -- A Feasibility Study.

Project A-2076

SECOND PROGRESS REPORT ON DEMONSTRATING THE FEASIBILITY OF PYROLYTIC CONVERSION IN GHANA

Prepared for

The U.S. Agency for International Development

by

Kermit C. Moh

and

Phillip W. Potts

Office of International Programs
Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

October 1978

Project A-2076

SECOND PROGRESS REPORT ON DEMONSTRATING THE FEASIBILITY OF PYROLYTIC CONVERSION IN GHANA

Prepared for

The U.S. Agency for International Development

by

Kermit C. Moh

and

Phillip W. Potts

Office of International Programs
Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia
October 1978

Table of Contents

Acknowledgments

This project of demonstrating the feasibility of pyrolytic conversion in Ghana would never have been possible without the help of the many individuals and organizations who have supplied us with large amounts of factual information and who have freely given their time so that project personnel could profit from their seasoned judgment.

While it is impossible to list all individuals who have rendered assistance to the program, the authors of the report would especially like to acknowledge the following:

Dr. Joseph de Graft-Johnson, Director, Building and Roads Research Institute (BRRI) in Ghana

Dr. John Powell, Director, Technology Consultancy Centre (TCC), in Ghana

Mr. Irvin Coker, Mission Director, USAID/Accra

Mr. John Cooper, Chief, Office of Science and Technology, USAID/Accra

Mr. M. F. Owiredu, Executive Director, Bank of Ghana in Ghana

Mr. A. K. Chatterjee, Past Head of the Materials Division, BRRI in Ghana

Dr. Tackie, Chairman, Council of Scientific and Industrial Research (CSIR) in Ghana

Dr. Ben Ntim, Deputy Director, TCC in Ghana

Mr. Kenneth Yeboah, Mechanical Engineer, BRRI in Ghana

Dr. John Goodrum, Research Engineer, Georgia Institute of Technology in the U.S.A.

Dr. John Tatom, Consultant in the U.S.A.

Mr. Gerald K. Webb, Artist in the U.S.A.

Summary

Pyrolysis is a process as ancient as civilization itself. By definition, it is the subjection of organic compounds to very high temperatures and the resulting decomposition.

The use of pyrolysis by mankind can be traced back to the very beginnings of civilization when man first used earthen mounds to produce charcoal. These mounds were inefficient as they did not collect the pyrolytic oil and the combustible gas which were produced.

In today's energy-hungry world, these sources of energy cannot be ignored. The pyrolytic oils can be used in industrial and utility boilers and in some types of lamps and stoves. The combustible gas can be used to run an internal combustion engine at 60% of its rated efficiency. (In Ghana it will be used to dry the feed going into the convertors.)

Typically, there are two types of processes which cause a pyrolysis reaction -- a high temperature process which promotes gasification and a low temperature process which promotes char and oil yields.

Georgia Tech has been involved in designing and testing pyrolysis systems of the latter type. Presently it has a highly automated system for use in industrialized nations and is building and testing four 1.5-ton-a-day convertors in Ghana. These convertors are labor intensive, are mostly made out of locally available materials, and are appropriate for use in a developing country.

The first of four modules has been built and tested in Ghana. A dryer is now being built so as to reduce the moisture content in the feed material to 5%. This along, with a better operating procedure, should help increase the oil yields which presently are being obtained in the convertor.

At this point, the manufacturing of the pyrolytic convertors, dryers and shed is very much behind schedule. One convertor and almost one dryer have been completed, leaving most of three convertors and one dryer still to be fabricated. The shed to house the convertors is estimated to be 30% complete, including the fact that electricity is not yet at the site.

However, Ghana does have the technical expertise to build pyrolytic convertors. The only components which presently need to be imported are an

air blower for the reactor and an electric motor to run it, although Ghana does have the capability of manufacturing air blowers.

From preliminary cost data which have been obtained from the first module, it appears that when inflation is accounted for (150% per year), the cost of the pyrolysis system falls well within the guidelines set forth by the feasibility study which was conducted by Georgia Tech in Ghana.

SECOND PROGRESS REPORT ON DEMONSTRATING
THE FEASIBILITY OF PYROLYTIC CONVERSION IN GHANA

Background

Pyrolysis is a process as ancient as civilization itself. By definition, it is the subjection of organic compounds to very high temperatures and the resulting decomposition. It is constantly taking place beneath the surface of the Earth. Organic matter is buried, subjected to some rather high temperatures (and pressures), and then decomposes to form coal, crude oil, and natural gas.

What man does when he causes a pyrolysis reaction to occur is simply to speed up what goes on within the Earth's surface, from several million years to a matter of hours.

Basically, a pyrolysis reaction is started by cooking a feed material. This material releases hot carbon monoxide gas, which in turn, cooks the material surrounding it. The material then decomposes and becomes char and gas. When condensed, part of this gas makes up the pyrolytic oil. The reaction which takes place is exothermic, in that once the reaction is initiated, it is capable of producing enough heat of its own to keep the process going.

The use of pyrolysis by mankind can be traced back to the very beginnings of civilization, when man first used earthen mounds to produce charcoal. These mounds were inefficient, as they did not collect the pyrolytic oil and the combustible gases which were produced.

In today's energy-hungry world, these sources of energy cannot be ignored. The pyrolytic oil can be used in industrial and utility boilers, and in some types of lamps and stoves. The combustible gas can be used to run an internal combustion engine at about 60% of its rated efficiency. (In Ghana, it will be used to run the dryers that will dry the raw material going to the convertor's reactor.)

When compared to the burning of wood, the by-products of pyrolysis are much more efficient. For example, it is estimated that charcoal is about twice as efficient for cooking as wood and pyrolytic oil is approximately five times as efficient because of reduced waste and the concentrated form of the fuels produced. Thus, if 5×10^6 Btu/yr. of wood energy is taken as the average heat required for one individual's cooking demands, only about 2.5×10^6

Btu/yr. of charcoal are required and 1×10^6 Btu/yr. of pyrolytic oil are needed to do the same job. Hence a ton of dry biomass will provide sufficient cooking energy for about 3.7 people. However, even after taking into account the losses occurring during pyrolytic conversion, the charcoal produced from the same ton of biomass would be sufficient for about 2.2 people and the oil sufficient for approximately 6.9 people or a total of 9.1 people. Therefore, the cooking needs of almost 2.5 times as many people can be met through pyrolytic conversion rather than through the direct burning of biomass.[1/]

Various types of modern continuous-flow pyrolysis processes have been developed recently in the United States and elsewhere to emphasize the production of one or more of the products of pyrolysis. Characteristically, these processes require the wastes to be shredded into relatively small pieces which can be easily handled. Primarily, these processes tend to maximize the production of gas, with the oil a secondary by-product and the char essentially reduced to ash. This is because most of these processes have been developed to deal with municipal wastes and have assumed the proximity of a large, gaseous-fueled industrial or utility type boiler. Clearly, emphasis on gas production for a system to convert agricultural and forestry wastes would be a serious mistake because of the problem of storing and/or transporting the gas to a user. There is a system (the Garret process) that emphasizes the production of oil, but it is very complex and requires significant preprocessing of the wastes.

Typically, high-temperature processes emphasize gas production, while low-temperature processes emphasize char and oil production. Conveniently, low-temperature processes can be fabricated of cheaper materials and can be made to operate in a simpler manner than the higher-temperature processes. This favors their use in rural environments, especially in developing nations, where spare parts are not always conveniently available.

A number of continuous low-temperature pyrolysis processes also have been developed recently throughout the world. Among them is the highly automated Georgia Tech system. This 50-ton-a-day system was designed to dispose of

---

[1/] John W. Tatom, "Demonstration of Alternative Fuel Production through Pyrolysis of Agricultural Waste at the UNEP Rural Energy Center in Senegal," November 1977.

the mountains of peanut hulls which accumulated yearly in south Georgia without creating a pollution problem. In doing so, this disposal method created profitable and useful forms of energy. However, the above-mentioned unit could be used economically only in industrialized nations, where labor costs were high. Thus, there was a great need for a small, labor-intensive pyrolytic convertor for use in less-developed countries where agricultural and forestry wastes were in abundance and labor costs were low.

Recognizing this need, the Office of International Programs (IPO), Engineering Experiment Station, Georgia Institute of Technology, began preliminary design work on a small, labor-intensive pyrolytic system.

At about this same time (1976), the Agency for International Development (AID) contracted with IPO to determine the feasibility of using pyrolysis as an alternative source of energy in the Republic of Ghana. Pyrolysis was predicted to be feasible when a one-ton or six-ton-a-day system was operated as a two- or three-shift operation per day. A one-shift operation was found not to be feasible.

AID then contracted with IPO to demonstrate the feasibility of pyrolysis in Ghana. Basically, the contract stated that IPO would provide the following services in collaboration with the Technology Consultancy Centre (TCC) of the University of Science and Technology and the Building and Roads Research Institute (BRRI) in Kumasi, Ghana:

1. Design a six-ton-per-day pyrolytic convertor system and prepare working drawings for construction of this system at the TCC workshop in Kumasi, Ghana.

2. Provide technical assistance to TCC, which will undertake the manufacture of the unit.

3. Start up and test the pyrolytic convertor system and make field modifications in cooperation with TCC and BRRI until the final design has been adopted.

4. Assist in the preparation of an operating and maintenance manual.

5. Assist in the selection and training of local personnel to operate the pyrolytic convertor.

6. Evaluate the pyrolytic system.

Demonstrating that pyrolysis is feasible in Ghana has been a joint AID and Government of Ghana venture. AID, through Georgia Tech, has been supplying the technical assistance and some necessary materials not found in Ghana for the pyrolytic convertors. The Bank of Ghana has supplied BRRI with the necessary funds with which to build, operate, and maintain the convertors. BRRI is presently constructing the shed in which to house the convertors and has subcontracted with TCC to manufacture and assemble them.

It should be noted at this time that four 1.5-ton-per-day systems (preliminary rating) are being manufactured. These four units will provide a six-ton-per-day requirement for the Kumasi brick kiln and will also satisfy the Government of Ghana's request that the design be versatile so that a one- to two-ton-per-day system could be adapted from the brick kiln design for small, village-level industry.

Activity to Date

During the month of November 1977, project personnel designed a preliminary six-ton-per-day pyrolysis system and constructed a small prototype in Atlanta for testing purposes. A large dryer also was designed which would be capable of reducing the moisture content in the feed material to a desired 5%. The drying of the sawdust is necessary in order to assure maximum oil and char yields. If the sawdust is too wet when it enters the convertor, gasification occurs and very little char and oil are produced.

In December, project personnel (Mr. Phillip Potts and Dr. John Tatom) traveled to Ghana to initiate and define TCC and BRRI activities relevant to the project, to check on the availability of materials and supplies that would be necessary for construction of the pyrolysis system, and to coordinate funding from the Bank of Ghana which was to be used by BRRI and TCC to cover upcoming pyrolysis experiments.

Project personnel (Mr. Kermit Moh and Dr. John Tatom) spent the months of January, February, and March in Ghana constructing, testing, and modifying the first of four modules that will make up the complete six-ton-per-day convertor (see Figure 1). They also supervised the design and initial building of the shed which will house the convertors. Schematics of the shed are shown in Figures 2 and 3.

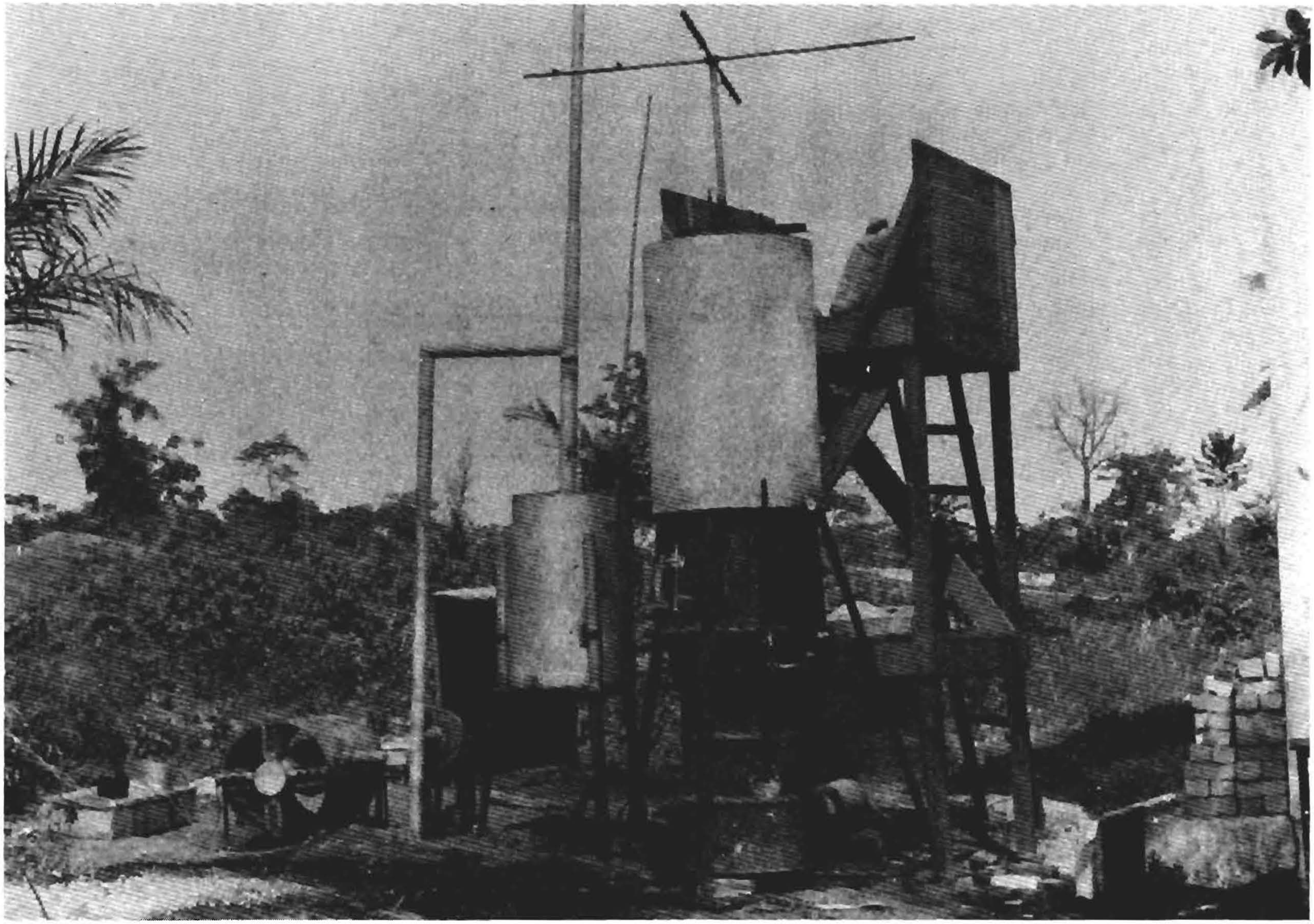


Figure 1. First of four modules of the pyrolytic convertor in Ghana

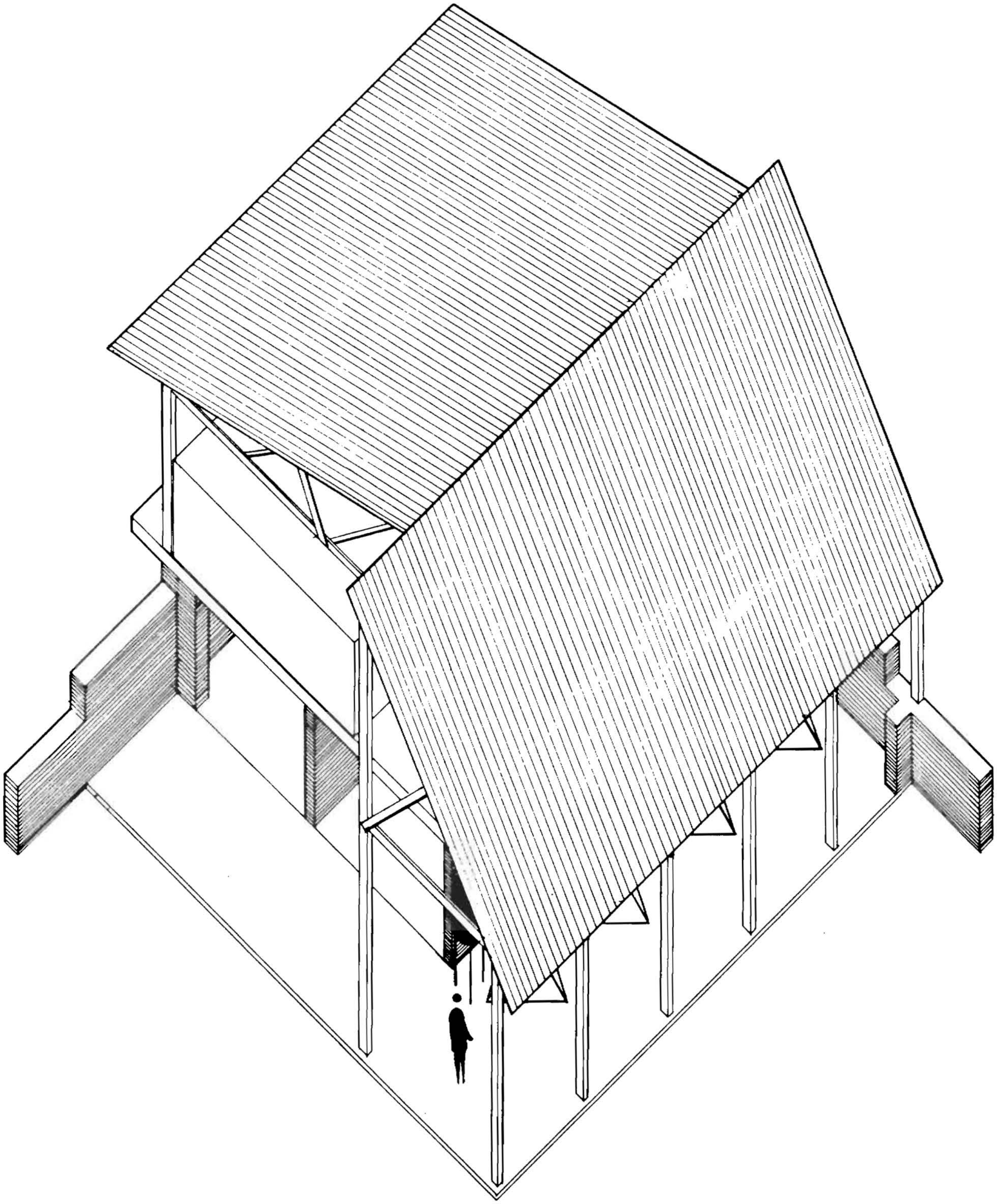


Figure 2. Artist's concept of the pyrolytic convertor shed

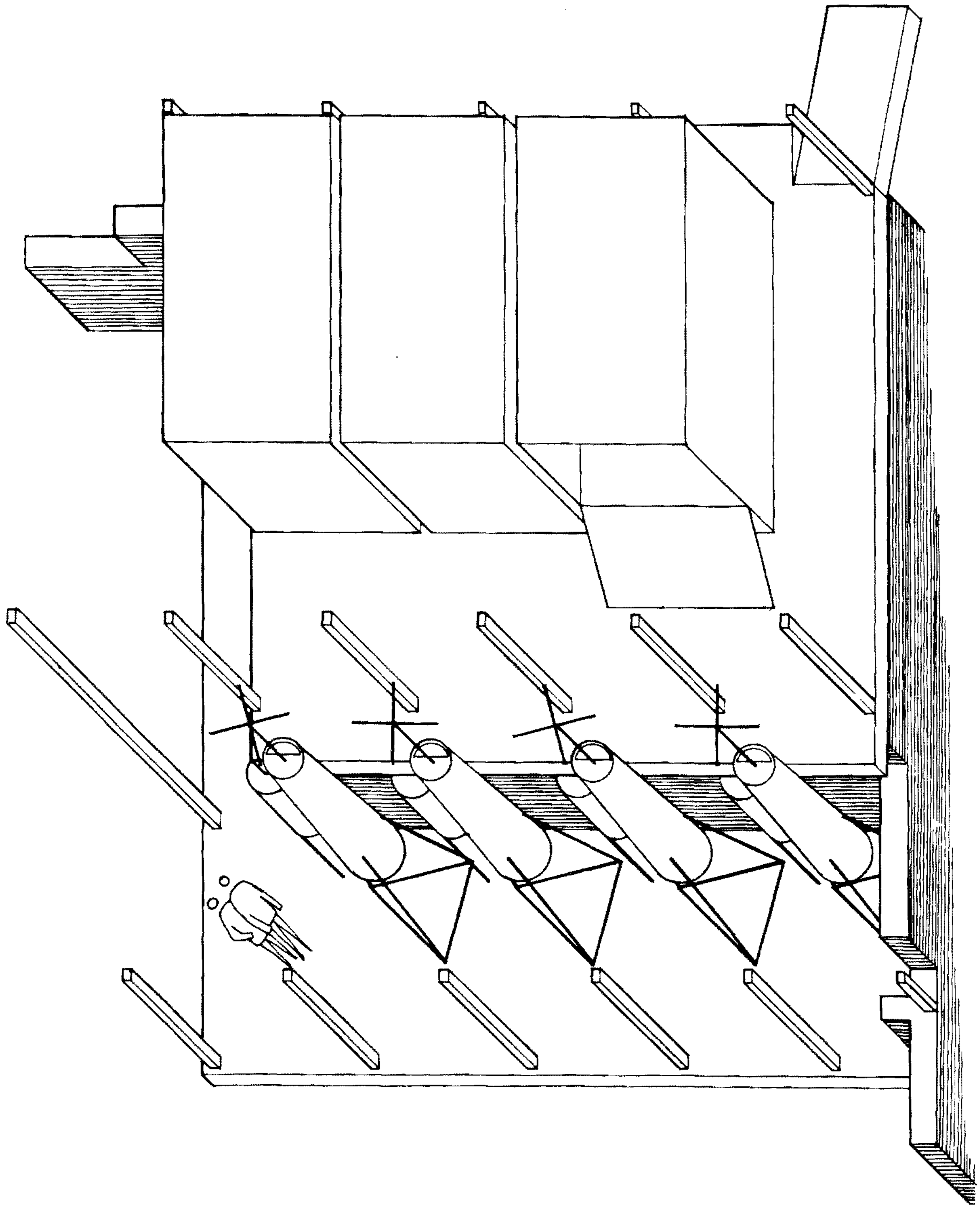


Figure 3. Layout of the convertors and dryers in the convertor shed

The first module is in operation and, when running, produces char, combustible oil, and combustible gas. By dry weight, 25% of the feed material becomes char, 6% becomes oil, and a large amount of gas is produced. This module is currently being fine tuned and a better operating procedure is being established so as to increase the oil yields. The burner design for the dryer also was tested and performed extremely well. Pyrolysis gas was fed from the condenser directly to the burner and the heat from the burner then ignited it in a self-sustaining reaction. The gas burned cleanly, and its heat was evenly distributed throughout the temporary duct work set up for the burner.

During the construction phase, problems were experienced in obtaining the necessary materials to build the module. In especially short supply were oxygen and actylene gas for cutting the sheet metal and cement for the construction of the shed which will house the convertors. It also was found that there were no rolling machines in Kumasi which were large enough to roll the 3/16-inch sheet metal required for the walls of the reactor. As a result, the sheet metal had to be sent on a six-hour truck journey to the industrial port of Tema to be rolled into their conical shape (see Appendix A).

When the first module was tested, three problems with the preliminary pyrolysis design were found. The first involved the agitator which stirs the feed and thus prevents any cavities from being formed while the sawdust is pyrolyzing. It was found that in Ghana the sawdust which was used as feed material in the first module was much finer and denser than that used to test the prototype in the U.S. As a result, it was extremely difficult to rotate the agitator. This problem was solved by removing the top three of the six blades on the agitator and adding wood shavings to the sawdust to reduce its density. The performance of the reactor was not affected by this change, as the reactor walls slant in at a 3^{o} angle. This causes the sawdust to cave in on top of itself as it is consumed.

The second problem was concerned with the unevenness of the air distribution in the reactor. When the convertor was running and air was introduced into it, intense heating of the reactor shell occurred in an isolated area. This area was directly beneath the filter which filters the gases going into the condenser. The sawdust was less dense beneath this filter; as a result, the air coming into the convertor tended to concentrate at this one spot, causing intense burning. This problem was solved by dividing the air intake in quadrants with a control on each quadrant, by reducing the size of the pebbles in the pebble bed, and by water jacketing the hottest zone of the reactor.

Problem three was caused by the temperature in the condenser being too low. As a result, water vapor was condensing with the oil instead of staying in a vapor state. This will be resolved by raising the temperature of the gases entering the condenser, thus raising the temperature of those leaving it. The condenser also will be insulated if necessary.

A concentrated effort also was made to train BRRI and TCC personnel in the operation of the completed module. Georgia Tech personnel then left Ghana with plans to return when all the units and dryers were manufactured and the pyrolytic shed completed. Their job then would be to install the units and teach the Ghanaians how to operate the system as a whole.

However, due to statements from people in Ghana concerning low oil yields from the convertor and at the request of USAID/Accra, a Georgia Tech team consisting of Dr. John Goodrum, Mr. Kermit Moh, and Dr. John Tatom returned to Ghana to analyze and solve the problem. The team was eager to inspect the progress of the pyrolytic project, but the inspection findings were discouraging. One of the dryers which was supposed to have been completed was nowhere close to completion (estimated 50%), and it had been a month since any tests had been run on the convertor. Very little had been accomplished in the building of the other convertors or the shed to house the four convertors. Shed completion was estimated to be 30%, which included the fact that electricity was not yet at the site.

In spite of all this, it was decided to try to accomplish as much as possible. Of special importance was getting the convertor in operating condition, obtaining dry feed, and fabricating condenser modifications. Work was immediately begun on repairing the agitator. During the last test, it had warped and had not been straightened. The grate was rusted over and had to be loosened before being reinstalled into the convertor. In all, over a week was spent getting the unit operational instead of completely concentrating on the problem of low oil yields, and only three good tests were run before the team had to return to the U.S. However, oil yields were substantially increased -- from 0.4% to 5.4%, assuming the same processing rate of feed material. It appears that the low oil yield is more a problem of operating procedure than a technical problem. Different types of condensers were tested, but they all had a tendency to yield the same results. It was noted that virtually all the oil that the reactor produced was condensed out.

From the information gathered from the test results, it was concluded that the way the unit was operated contributed greatly toward an increase or decrease in oil yields. As a result, a written operating procedure was drawn up and established before returning to the U.S.

Description of the Pyrolysis System and Its Operation

The pyrolysis system in Ghana has been manufactured mostly from locally available material. Its main components are the reactor, agitator, char barrel, filter, condenser, demister, and the oil barrel (see Figure 4).

Feed is added through the top of the reactor until it is full. The pyrolysis reaction takes place in the bottom third of the reactor, and the top two thirds is used as a storage area. The char which is formed drops through a grate and collects in a char barrel. When full, this barrel (an ordinary 55-gallon oil drum) is removed and the char is sealed from the atmosphere so that it will not burn while it cools. The barrel is then replaced by another one. During this time, the feed is agitated in order to prevent cavities from being formed in the sawdust. The gases produced from the pyrolysis reaction filter up through the sawdust bed, go through the filter and into the condenser (see Figure 5 and 6). The condenser condenses out the large particles of oil and the gas, then enters a demister which removes any of the remaining oil in the gas. All of the pyrolytic oil is then collected from the bottom of the condenser and the demister, while the rest of the gas, along with the water vapor, goes out the off-gas pipe to the dryers, where it is ignited and used to dry the raw material.

There are several innovative ideas in the design of the Ghana pyrolysis system. The two most outstanding ones concern the way the air is introduced into the reactor and the filter which is used so as to not allow particulate matter to enter the condenser.

Air is introduced into the reactor by means of a curved pipe into which small holes have been drilled (see Figure 7). Pebbles are then added to the channel in which this pipe lies (see Figure 8). This pebble bed acts as a

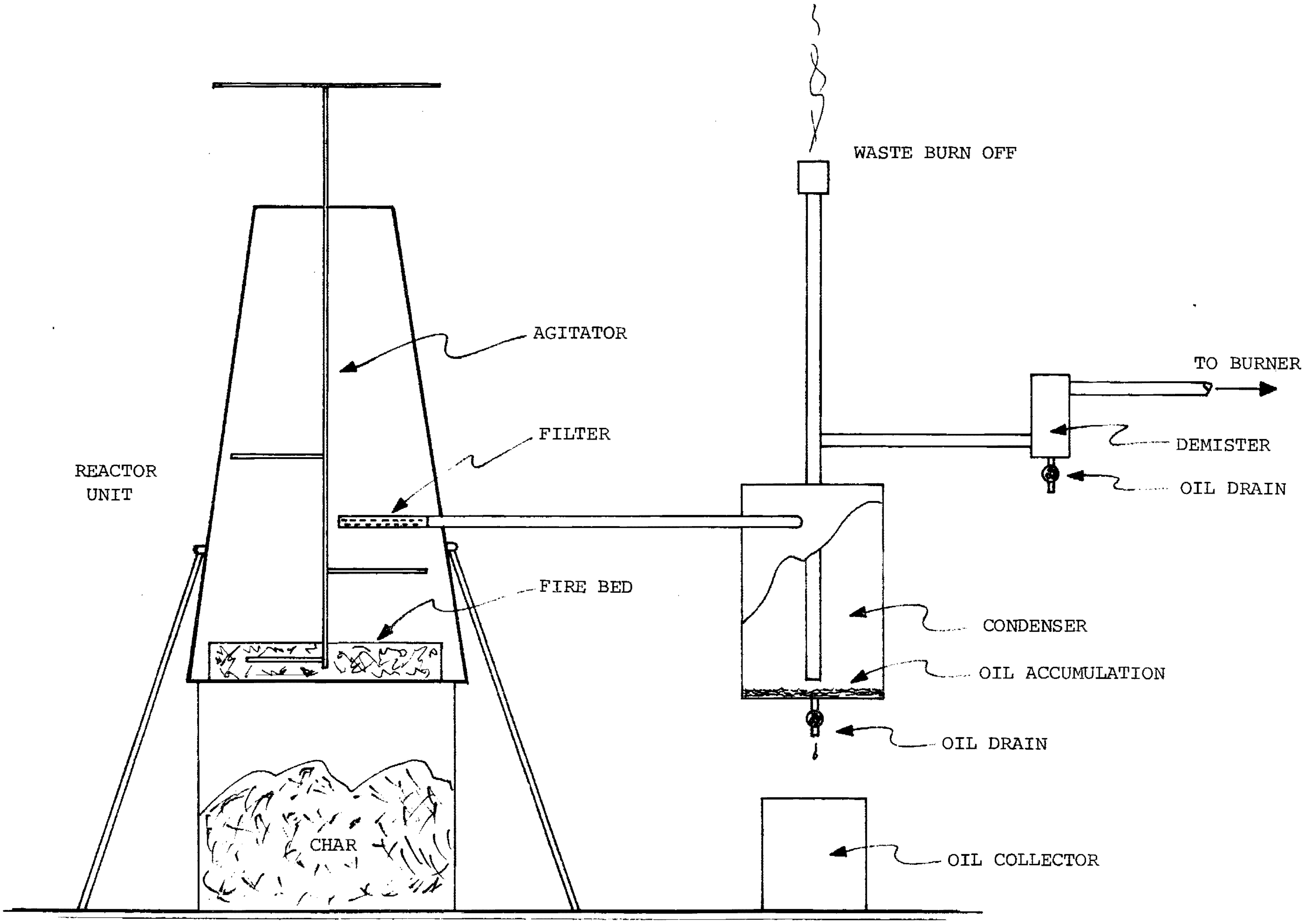


Figure 4. Schematic of Ghana pyrolysis unit.

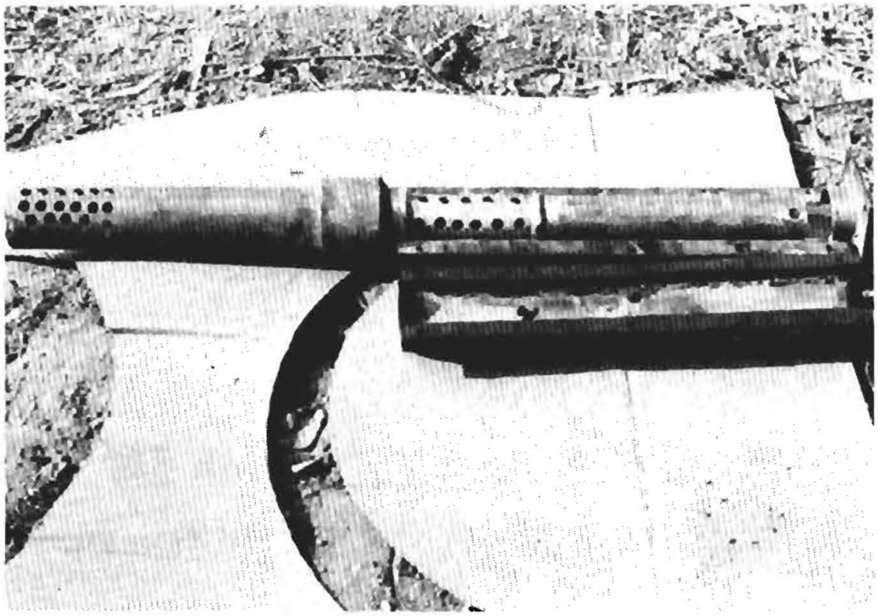


Figure 5. Exposed view of the filter which does not allow particulate matter to enter the condenser

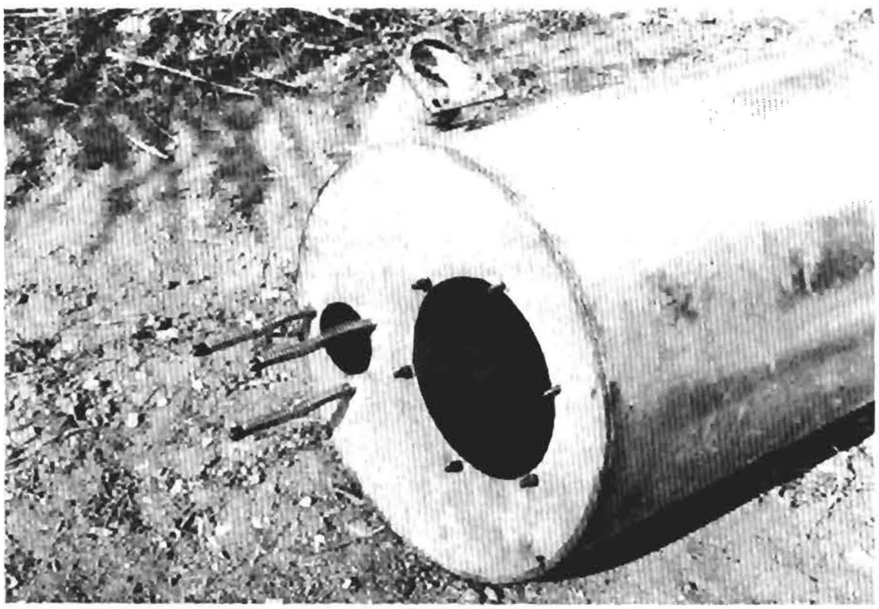


Figure 6. View of the condenser which shows where the cyclone (large hole) and pressure relief port (small hole) are located

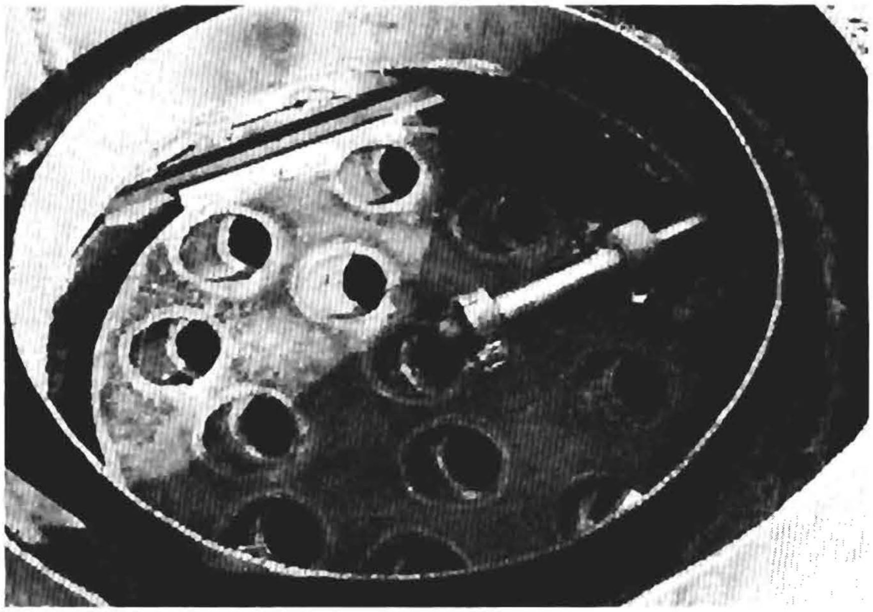


Figure 7. Top view of grate and air ring before the pebbles are put in place

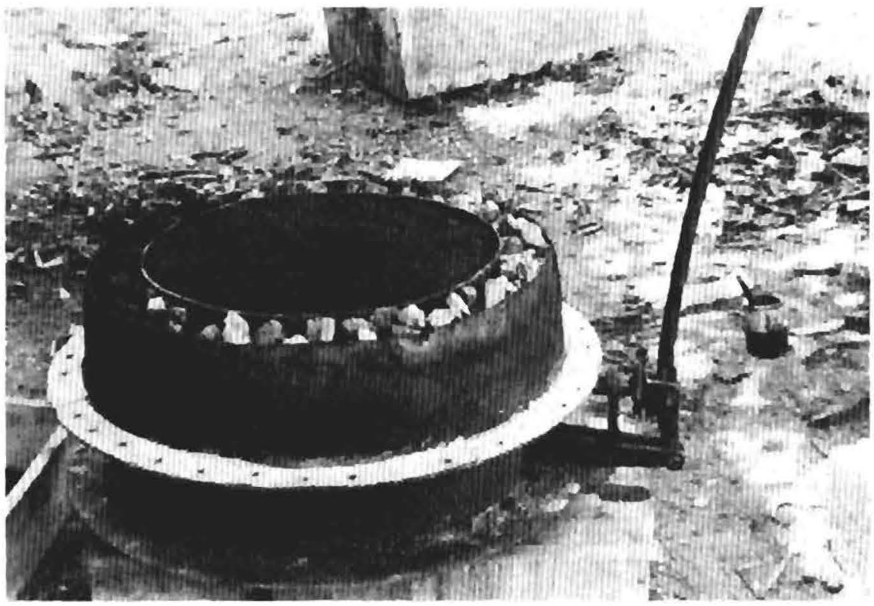


Figure 8. View of grate and air supply system with pebbles and char in place

heat sink. It absorbs the heat from the pyrolysis reaction and never allows the air pipes to become very hot. This reduces the amount of maintenance required on the system.

The filter is simply a perforated pipe which fits into another pipe. The inner pipe has a screen wrapped around it so as to prevent particulate matter from going through it. This whole filter assembly lies within the reactor, surrounded by the bed of sawdust. When in operation, the screen does not allow particulate matter to pass through it and the bed itself acts as a filter by screening out any particulate matter which is approaching the exit to the condenser. (Imagine a vacuum cleaner with a hose connected to its inlet side. A screen is on the other end of the hose. When turned on and when the end of the hose is placed into a sawdust pile and withdrawn, a large clump of sawdust will become "stuck" to the hose. The screen does not allow the sawdust to go into the vacuum cleaner and the surrounding sawdust does not allow other particulate matter to approach the screen.)

At this point, it must be noted that the pyrolysis reaction produces both hydrogen and carbon monoxide gas. As a result, safety considerations have received much thought and attention since the very beginning of this project; therefore, the probability of any type of overpressure occurring in the system is extremely low. However, in the event of an overpressure, the Ghana system has three pressure-relief ports: one at the bottom of the convertor in the event of an overpressure in the char barrel, one at the top of the reactor, and one at the top of the condenser.

Naturally, the safety features which have been incorporated into the system are there to protect the convertor and the people who are working around it. It is hoped that these features will never have to be used. In accordance with this philosophy, a start-up and operating procedure incorporating many safety features has been established and followed. These procedures are described below.

Before doing any type of start-up, operators remove the filter and check to see if it is clogged. This is done by merely pouring water into it and checking to see if this water freely flows out from the filter. When the operators are satisfied that the filter is free-flowing, it is put back into the convertor. The pressure-relief ports are hand-tested to make sure that none of them are stuck. Then the air blower and the draft fan are switched on so as to vent the system. This releases any type of volatile gases to the atmosphere. Next, the air is turned off and sawdust is added to the convertor until it is level with the pebble bed. Hot glowing char is added to the char barrel through the grain sampling hole. The glowing char burns up any air that is present in the barrel, thus virtually eliminating the possibility of hydrogen mixing with air in the char barrel. Glowing charcoal is then added to the convertor and smothered with sawdust. The air blower is again turned on, and the sawdust allowed to smolder for about 45 minutes so as to establish a char bed. During the beginning of this smoldering process, the cover of the convertor is loosely put in place. This allows the air to seep out of the convertor and smoke to replace it -- again virtually eliminating the possibility of a hydrogen-air combination in the reactor. Once the char bed has been established, the blower is turned off and the convertor is completely filled with sawdust. The blower is switched back on and, again, the cover of the convertor is loosely put back in place so as to allow the air to flow out. The cover is later firmly tightened into place. Every time a char barrel becomes full and is replaced with an empty one, some glowing char is put into the bottom of the barrel. Also, whenever the convertor is opened, the air is removed from the reactor before it is completely resealed.

Once the pyrolysis system reaches operating temperature (350-400^{o}F entering the condenser -- 180-220^{o}F leaving the condenser), the char processing can begin. The operator shakes the grate and allows the char to fall into the char barrel. Occasionally, he will take samples of the char. If the char is brown, it is not quite char yet and he is processing too quickly; if it is grey, the char is burning up and he is processing too slowly; if it is black, he is processing at the correct rate of speed. When processing for a period of time, a noticeable decrease in the temperature going into the condenser will occur. When this happens, the operator must stop processing and wait for the off-gas temperature to rise again.

Due to the long period of time which it takes for the convertor to reach operating temperature, it is advisable to operate the units on a continuous basis until the required amounts of char and oil are produced. Continuous operation also decreases the need for maintenance on the system, as the filters must be removed and cleaned every time a unit is shut down.

The convertors will be housed in a shed which is open to the elements on all four sides. There will be a smokestack which will be sufficiently above the roof of the shed so as to dissipate the gases (including the carbon monoxide) freely into the atmosphere in the event that they are not used by the dryers.

Future Activities

Three additional pyrolytic convertor modules, each with an estimated 1.0 to 1.5-ton-per-day capacity, and one dryer must be constructed before the final system is assembled. At the same time, the construction of a shed to house the enitre pyrolysis system will also have to be completed. Electricity will have to be brought to the site and hooked up.

Project personnel (Mr. Kermit Moh) will then travel to Ghana to assist in the installation and operation of the complete system, the training of additional operating personnel, and the preparation of a final operating and maintenance manual. During this trip, he will gather and analyze all historical cost data on the construction and operation of the pyrolysis system to determine the economics of pyrolysis in Ghana. He also will perform an analysis of the social soundness of the pyrolysis system at this time.

Conclusions

Ghana does have the technical expertise and necessary raw materials to build pyrolytic convertors. The only components which presently have to be imported are the air blower for the reactor and an electric motor to operate it. However, Ghana has the capabilities for manufacturing air blowers. At present, the pyrolysis project is very much behind schedule. This is due to many reasons; among them, crippling shortages of essential material such as oxygen, acetylene, cement, roofing material, and even gasoline. It is hoped that these problems can be solved and that the manufacturing phase of this program can be completed on a timely basis.

From the preliminary cost data which have been obtained during the construction of the first module, it appears that when inflation is accounted for (150% per year), the cost of the pyrolysis system falls well within the guidelines set forth in the Georgia Tech report entitled Pyrolytic Conversion of Agricultural and Forestry Wastes in Ghana -- A Feasibility Study.

Appendix A

CALCULATIONS USED TO ARRIVE AT THE CONICAL SHAPE FOR THE PYROLYTIC CONVERTOR

CALCULATIONS USED TO ARRIVE AT THE CONICAL SHAPE FOR THE PYROLYTIC CONVERTOR

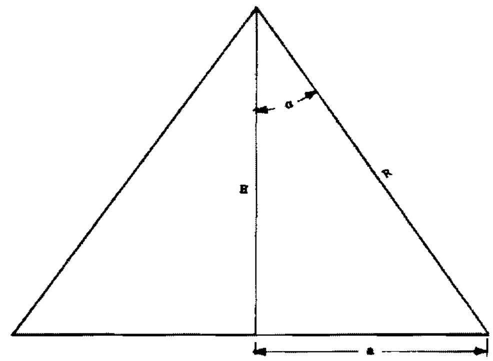


Figure 1

From Figure 1,

$\tan \alpha = a/H$

$\therefore H = a/\tan \alpha$

$\sin \alpha = a/R$

$\therefore R = a/\sin \alpha$

From Figure 2,

$\sin(\theta/2) = a/R$

$\therefore 2a = 2R\sin(\theta/2) = \text{Maximum Chord} = MC$

So, the four equations are:

1. $H = a/\tan \alpha$
2. $R = a/\sin \alpha$
3. $R = MC/2\sin(\theta/2)$
4. $\theta = 2a\pi/R$

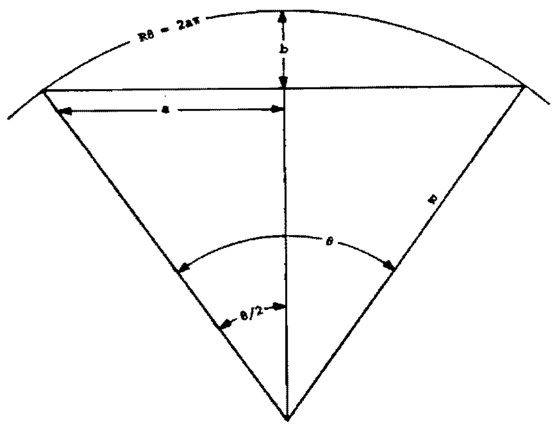


Figure 2

Assume a very small θ ($<5^{\circ}$),

$\therefore \sin(\theta/2) \simeq \theta/2$

From the above and (3),

$$R = \frac{MC}{2(\theta/2)} = \frac{MC}{\theta}$$

Combining (4) with (3),

$$R = \frac{MC(R)}{2a\pi}$$

From (2),

$$a = R \sin \alpha \qquad (5)$$

So, combining the last two equations:

$$R = \frac{MC(R)}{2\pi R\sin\alpha} = \frac{MC}{2\pi\sin\alpha} \qquad (6)$$

Combining (6) with (5),

$$a = \frac{MC \sin \alpha}{2\pi \sin \alpha} = \frac{MC}{2\pi} \qquad (7)$$

Combining (7) with (1),

$$H = \frac{MC}{2\pi \tan \alpha} \qquad (8)$$

Combining (2) with (4),

$$\theta = 2\pi \frac{R \sin \alpha}{R} = 2\pi \sin \alpha \qquad (9)$$

For our particular problem,

$$\text{Assume} \quad MC = 96'' \qquad \alpha = 3^{\circ}$$

Then from (6),

$$R = \frac{96^{\circ}}{2\pi \sin 3^{\circ}} = 291.94''$$

From (7),

$$a = \frac{96''}{2\pi} = 15.28''$$

From (9),

$$\theta = 2\pi \sin 3^{\circ} \simeq 0.329 \text{ rads} = 18.84^{\circ}$$

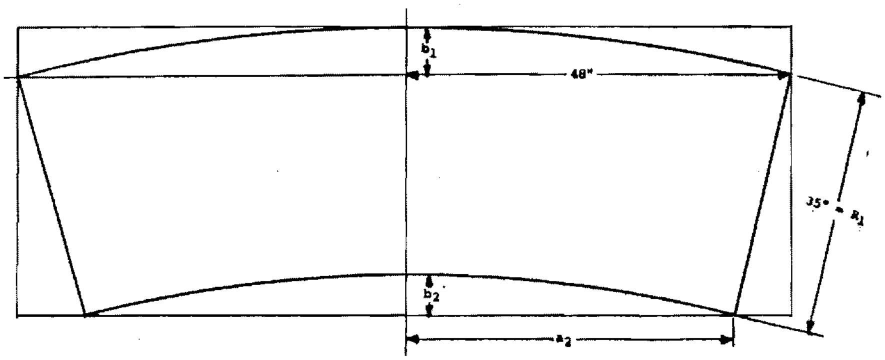


Figure 3

General,

$$\cos(\theta/2) = \frac{R - b}{R}$$

$$\therefore R - b = R \cos(\theta/2)$$

$$\therefore b = R(1 - \cos(\theta/2))$$

There are two cones that must be rolled: the larger bottom one, and the small upper one.

$$R = 291.94''$$
$$R_2 = (R - 35.00) = 256.94''$$

For the large cone,

$$b_1 = 291.94\,(1 - \cos(18.84/2)) = 3.94''$$
$$b_2 = (291.94 - 35.00)\,(1 - \cos(18.84/2)) = 3.46''$$
$$a_2 = R_2 \sin(\theta/2) = 256.94 \sin(18.84/2) = 42.05''$$

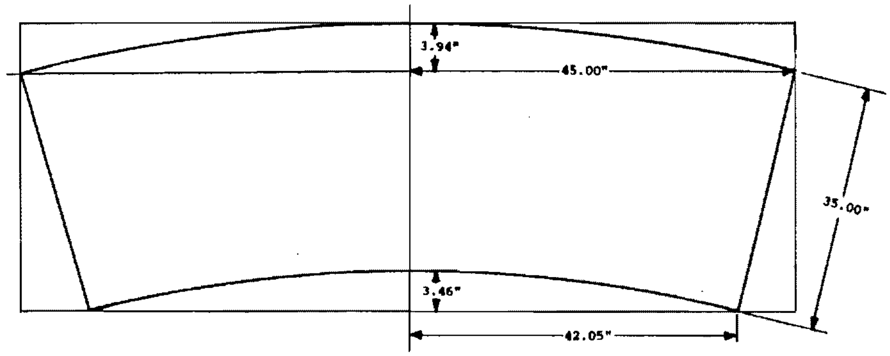


Figure 4

For small cone,

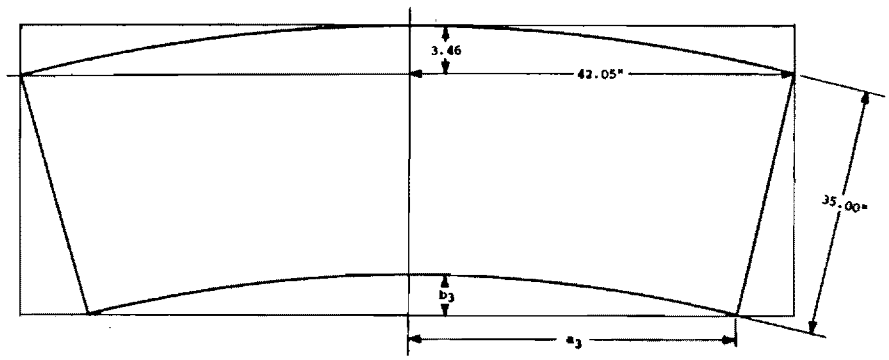


Figure 5

R_3 = (291.94 - 70.00) = 221.94"
a_3 = R_3 sin (θ/2) = 221.94" sin (18.84/2) = 36.32"
b_3 = R_3 (1 - cos (θ/2) = 221.94(1 - cos (18.84/2)) = 2.99"

By applying the formula,

$$x = (R^2 - (R - y)^2)^{1/2}$$

Where R is the different radius of the area, y is a given distance from a reference point in the vertical direction and x is the respective distance in the horizontal direction, the area can be accurately determined and cut. Thus,

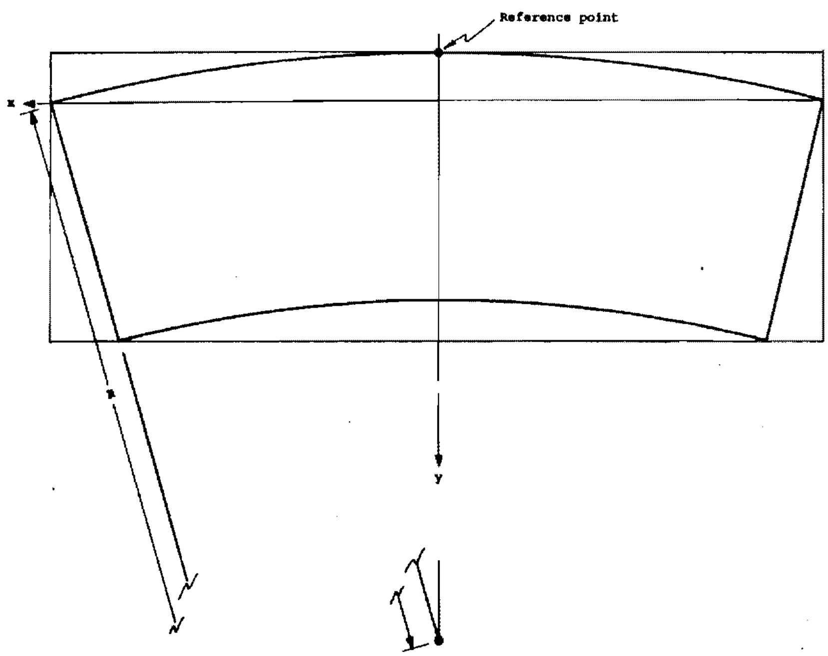
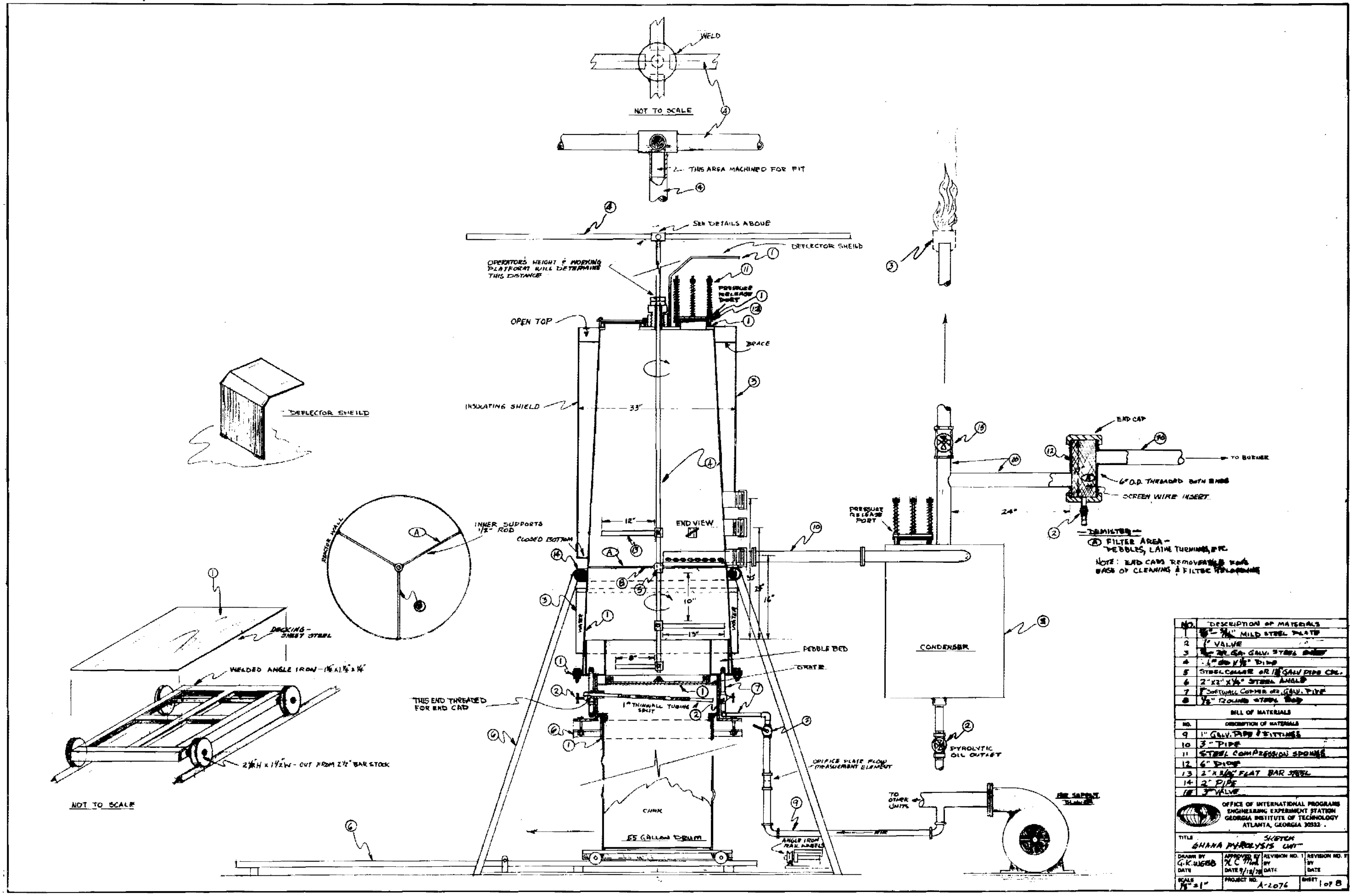


Figure 6

Appendix B

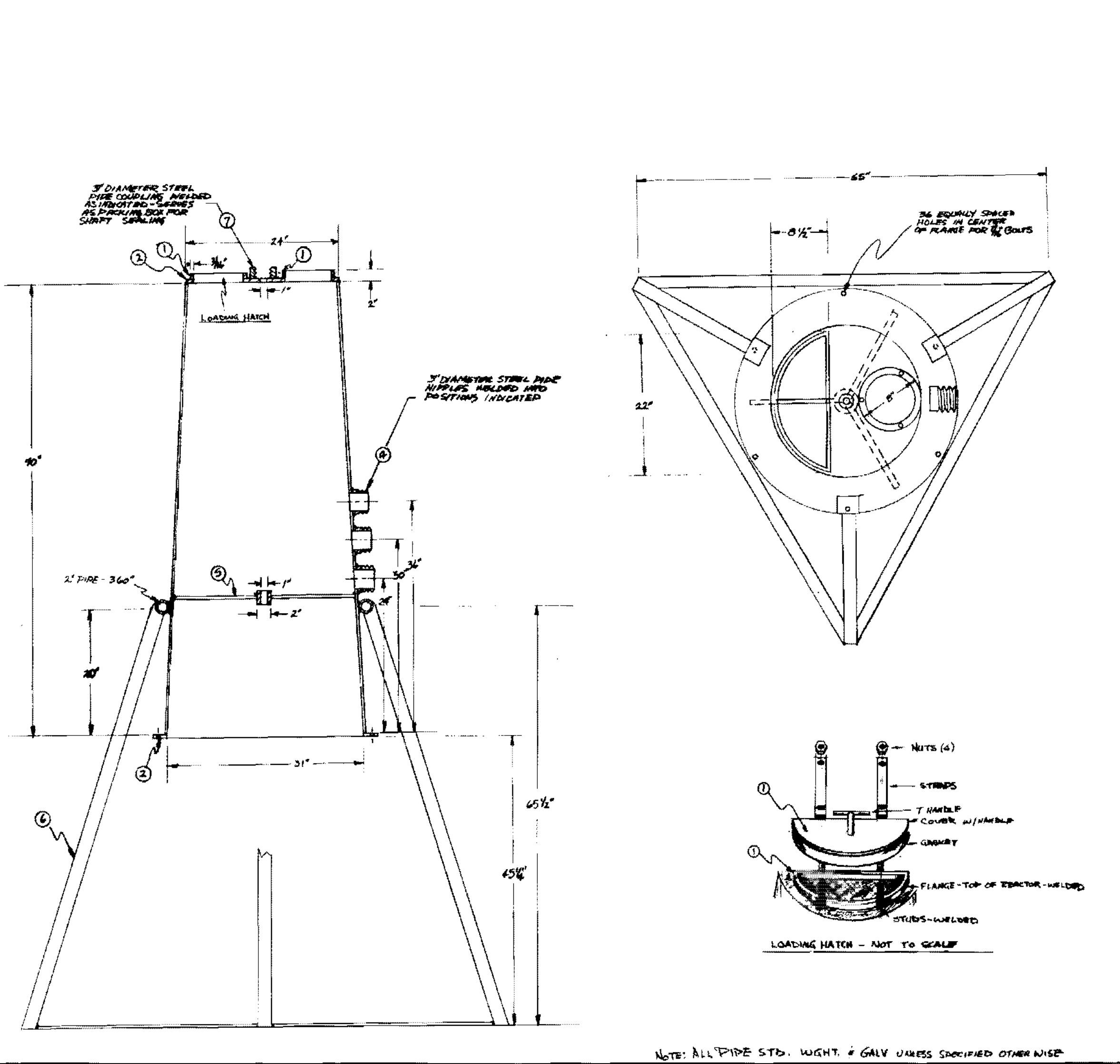
WORKING DRAWINGS
FOR PYROLYTIC CONVERTOR IN GHANA



NO.	DESCRIPTION OF MATERIALS
1	[illegible] MILD STEEL PLATE
2	1" VALVE
3	[illegible] GA. GALV. STEEL SHEET
4	1" [illegible] PIPE
5	STEEL COLLAR OR 1" GALV PIPE COL.
6	2"x2"x1/4" STEEL ANGLE
7	1" SOFTWALL COPPER OR GALV. PIPE
8	1/2" ROUND STEEL ROD

BILL OF MATERIALS

NO.	DESCRIPTION OF MATERIALS
9	1" GALV. PIPE & FITTINGS
10	3" PIPE
11	STEEL COMPRESSION SPRINGS
12	6" PIPE
13	2" x [illegible]" FLAT BAR STEEL
14	2" PIPE
15	3" VALVE



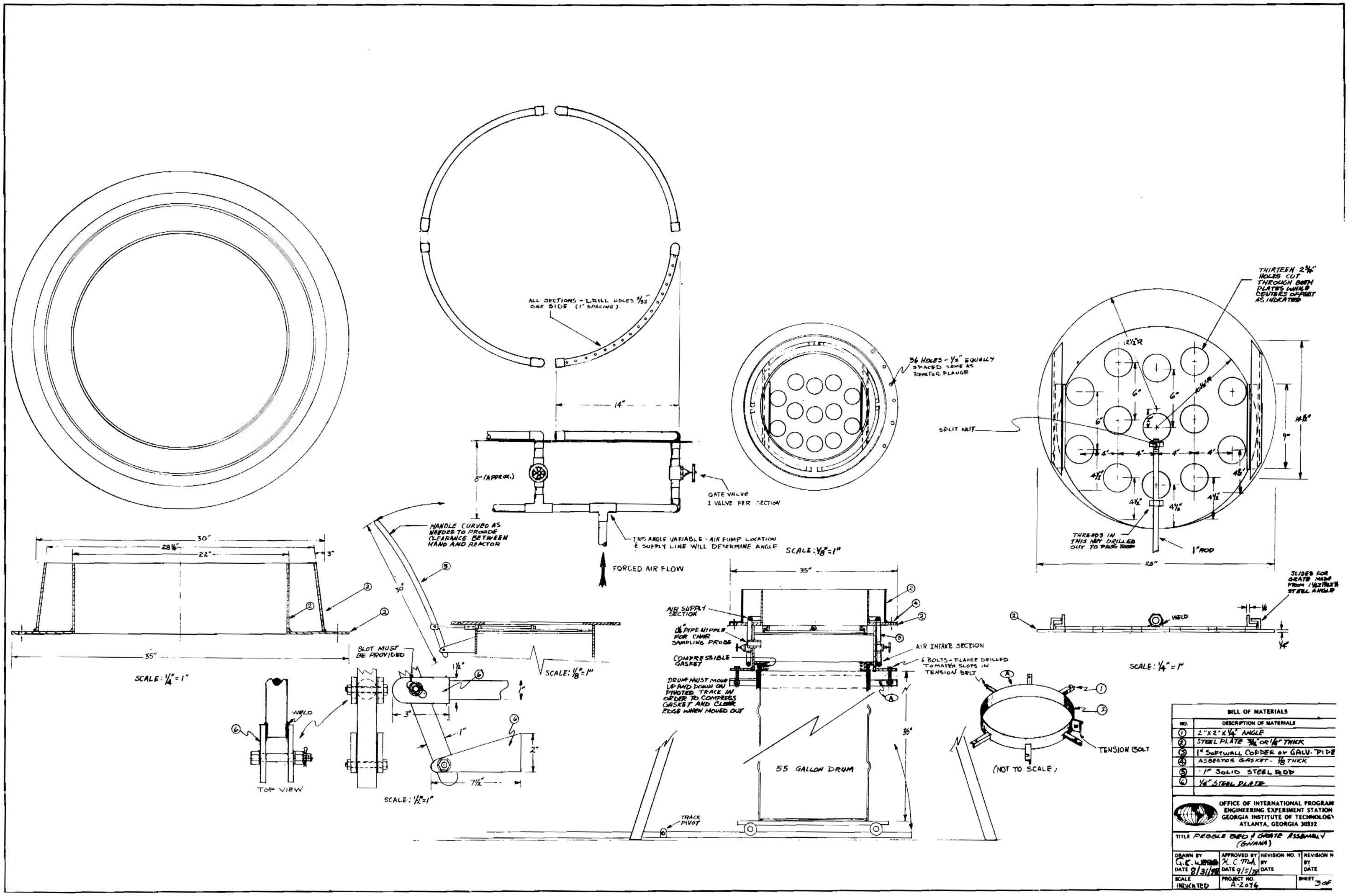
NOTE: ALL PIPE STD. WGHT. & GALV UNLESS SPECIFIED OTHER WISE

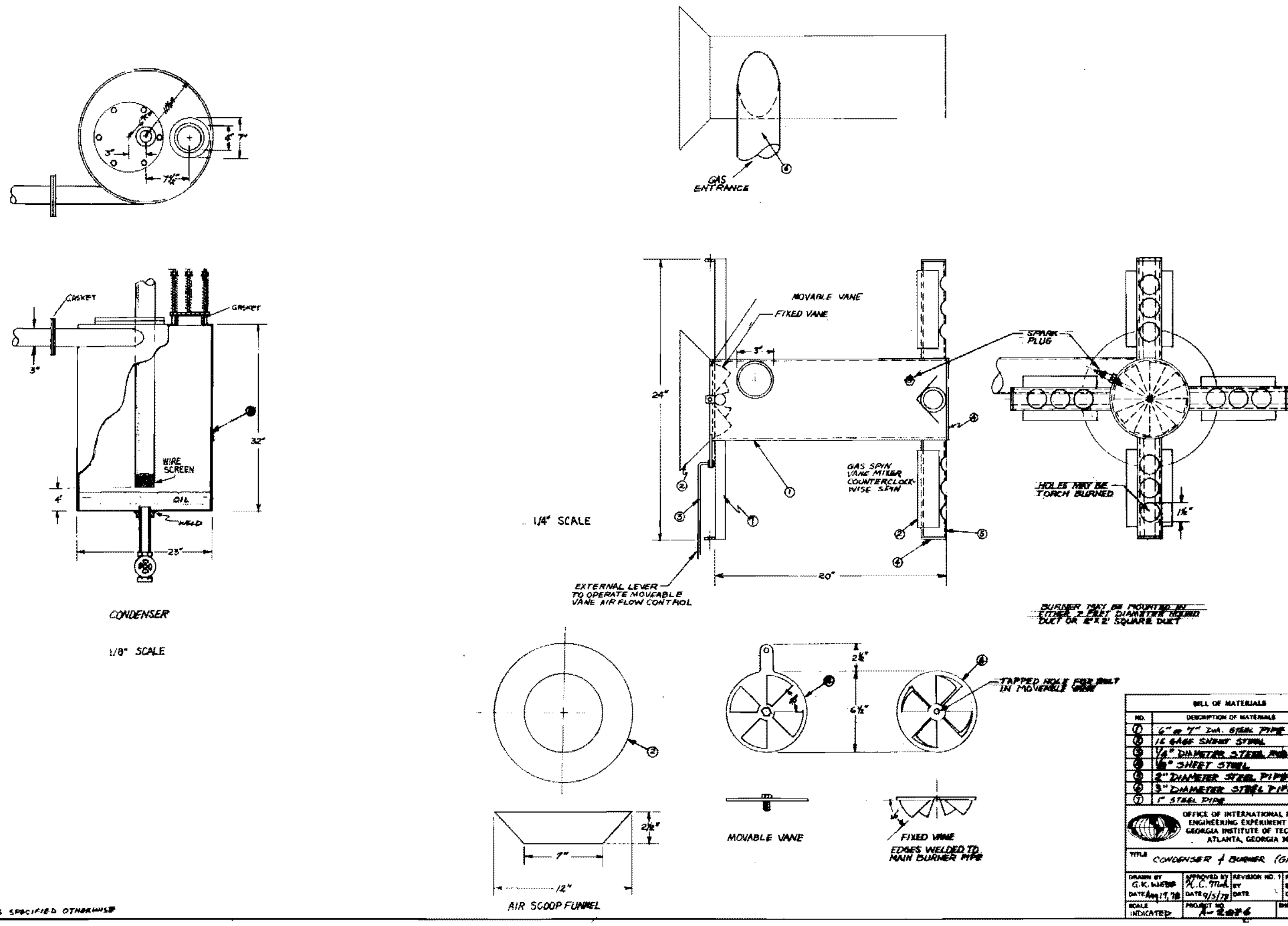
BILL OF MATERIALS	
NO.	DESCRIPTION OF MATERIALS
1	[illegible] STEEL PLATE
2	[illegible] STEEL PLATE
3	¼" x 2" STEEL STRIP
4	3" STD. PIPE NIPPLES, STEEL
5	½" ROUND BAR
6	2" x 2" x ¼ STEEL ANGLE
7	3" STEEL PIPE CPL. STD.

OFFICE OF INTERNATIONAL PROGRAMS
ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

TITLE REACTOR UNIT - WELDED CONSTRUCTION ([illegible])

DRAWN BY	APPROVED BY	REVISION NO. 1	REVISION NO. 2
[illegible] DATE [illegible]	H. C. [illegible] DATE 9/17/7[illegible]	BY DATE	BY DATE
SCALE [illegible]	PROJECT NO. A-2076		SHEET 2 of 8


ALL SECTIONS - DRILL HOLES 3/32" ONE SIDE (1" SPACING)
14"
8" (APPROX.)
GATE VALVE
1 VALVE PER SECTION
THIS ANGLE VARIABLE - AIR PUMP LOCATION & SUPPLY LINE WILL DETERMINE ANGLE
FORCED AIR FLOW
SCALE: 1/8" = 1"
36 HOLES - 1/2" EQUALLY SPACED SAME AS REACTOR FLANGE
SPLIT NUT
THIRTEEN 2 3/4" HOLES CUT THROUGH BOTH PLATES WITH CENTERS OFFSET AS INDICATED
2 1/2"R
THREADS IN THIS NUT DRILLED OUT TO PASS ROD
1" ROD
25"
9"
14 1/2"
30"
28 1/4"
22"
3"
35"
SCALE: 1/4" = 1"
HANDLE CURVED AS NEEDED TO PROVIDE CLEARANCE BETWEEN HAND AND REACTOR
SLOT MUST BE PROVIDED
WELD
TOP VIEW
SCALE: 1/2" = 1"
SCALE: 1/8" = 1"
AIR SUPPLY SECTION
1/4" PIPE NIPPLE FOR CHAR SAMPLING PROBE
COMPRESSIBLE GASKET
DRUM MUST MOVE UP AND DOWN ON PIVOTED TRACK IN ORDER TO COMPRESS GASKET AND CLEAR EDGE WHEN MOVED OUT
AIR INTAKE SECTION
6 BOLTS - FLANGE DRILLED TO MATCH SLOTS IN TENSION BELT
55 GALLON DRUM
TRACK PIVOT
TENSION BOLT
(NOT TO SCALE)
SLIDES FOR GRATE MADE FROM 1 1/2 x 1 1/2 x 1/4 STEEL ANGLE
WELD
SCALE: 1/4" = 1"
BILL OF MATERIALS
NO. | DESCRIPTION OF MATERIALS
① 2" X 2" X 1/4" ANGLE
② STEEL PLATE 3/16" OR 1/8" THICK
③ 1" SOFTWALL COPPER or GALV. PIPE
④ ASBESTOS GASKET - 1/8 THICK
⑤ 1" SOLID STEEL ROD
⑥ 1/4" STEEL PLATE
OFFICE OF INTERNATIONAL PROGRAMS
ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332
TITLE PEBBLE BED & GRATE ASSEMBLY (GHANA)
DRAWN BY G.E. WEBB DATE 8/31/78
APPROVED BY K. C. Mah DATE 9/5/78
REVISION NO. 1 BY DATE
REVISION NO. BY DATE
SCALE INDICATED
PROJECT NO. A-2076
SHEET 3 OF



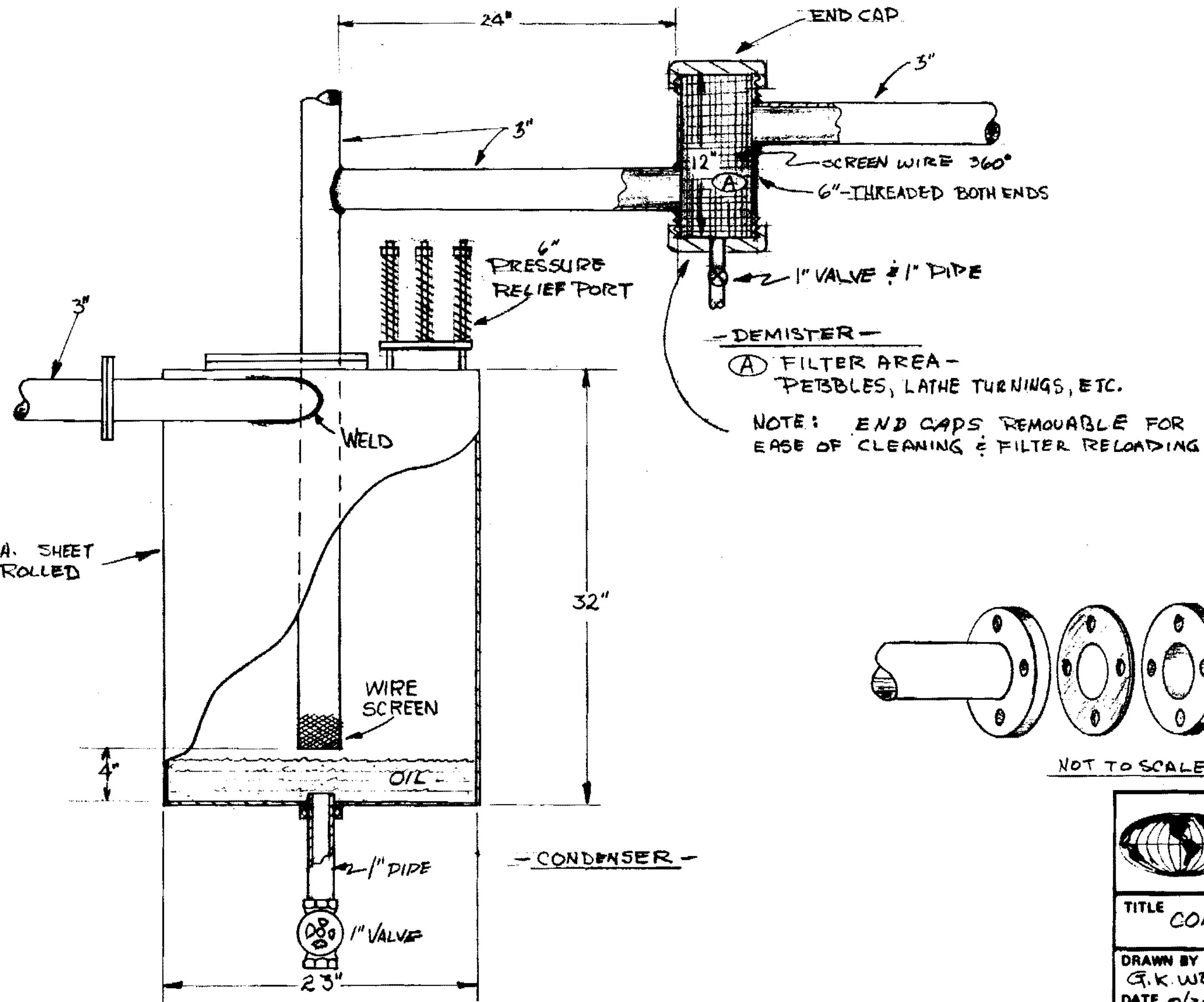
BILL OF MATERIALS	
NO.	DESCRIPTION OF MATERIALS
①	6" or 7" DIA. STEEL PIPE
②	16 GAGE SHEET STEEL
③	1/4" DIAMETER STEEL ROD
④	1/8" SHEET STEEL
⑤	2" DIAMETER STEEL PIPE
⑥	3" DIAMETER STEEL PIPE
⑦	1" STEEL PIPE

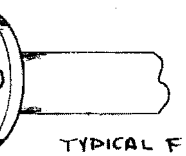
OFFICE OF INTERNATIONAL PROGRAMS
ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

TITLE CONDENSER & BURNER (GHANA)

DRAWN BY G.K. WEBB DATE Aug 17, 78	APPROVED BY H.C. Mad DATE 9/5/78	REVISION NO. 1 BY DATE	REVISION NO. 2 BY DATE
SCALE INDICATED	PROJECT NO. A-2076		SHEET 4 of 8

NOTE: ALL PIPE STD. WEIGHT & GALV. UNLESS SPECIFIED OTHERWISE



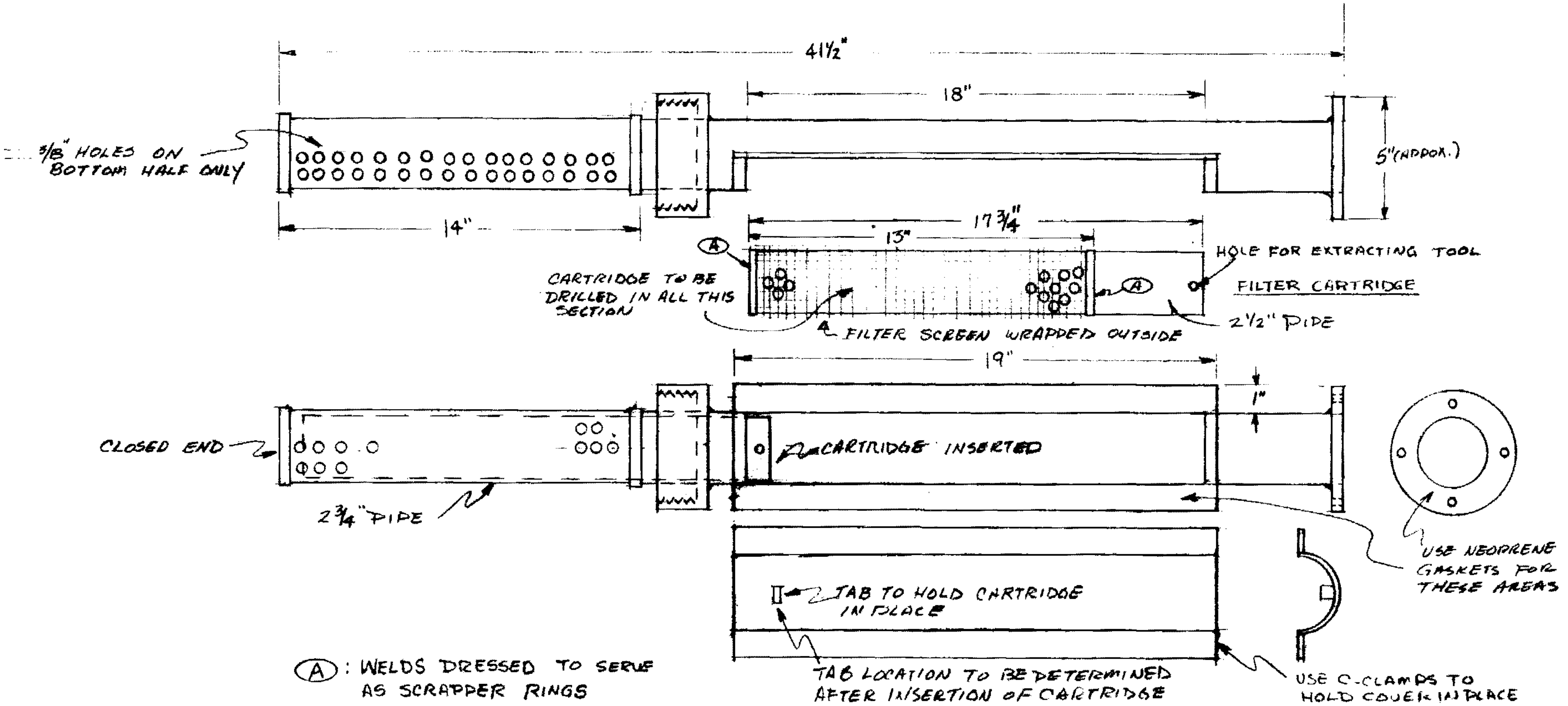


NOTE: ALL PIPE STANDARD WEIGHT & GALVANIZED

OFFICE OF INTERNATIONAL PROGRAMS
ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

TITLE CONDENSER & DEMISTER (GHANA)

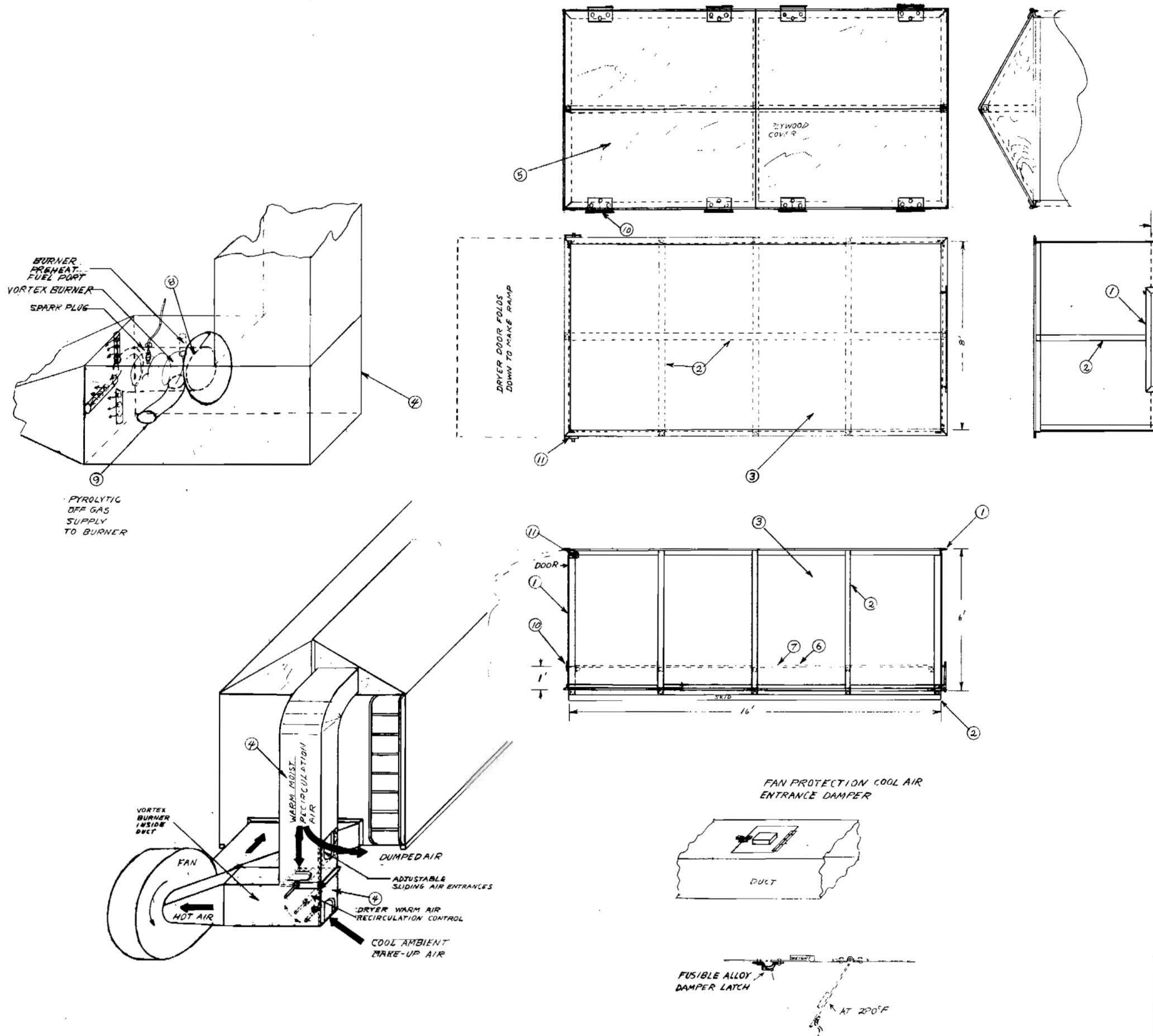
DRAWN BY	APPROVED BY	REVISION NO. 1	REVISION NO. 2
G.K. WEBB DATE 8/31/78	K.C. [illegible] DATE 9/1/78	BY DATE	BY DATE
SCALE 1/8" = 1"	PROJECT NO. A-2076		SHEET 5 OF 8



OFFICE OF INTERNATIONAL PROGRAMS
ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

TITLE REACTOR FILTER — GHANA			
DRAWN BY G.K. Welt DATE 9/11/78	APPROVED BY H. C. Moh DATE 9/11/78	REVISION NO. 1 BY DATE	REVISION NO. 2 BY DATE
SCALE 1/4" = 1"	PROJECT NO. A-2076		SHEET 6 OF 8

NOTE: ALL PIPE STANDARD WEIGHT & GALVANIZED UNLESS SPECIFIED OTHERWISE



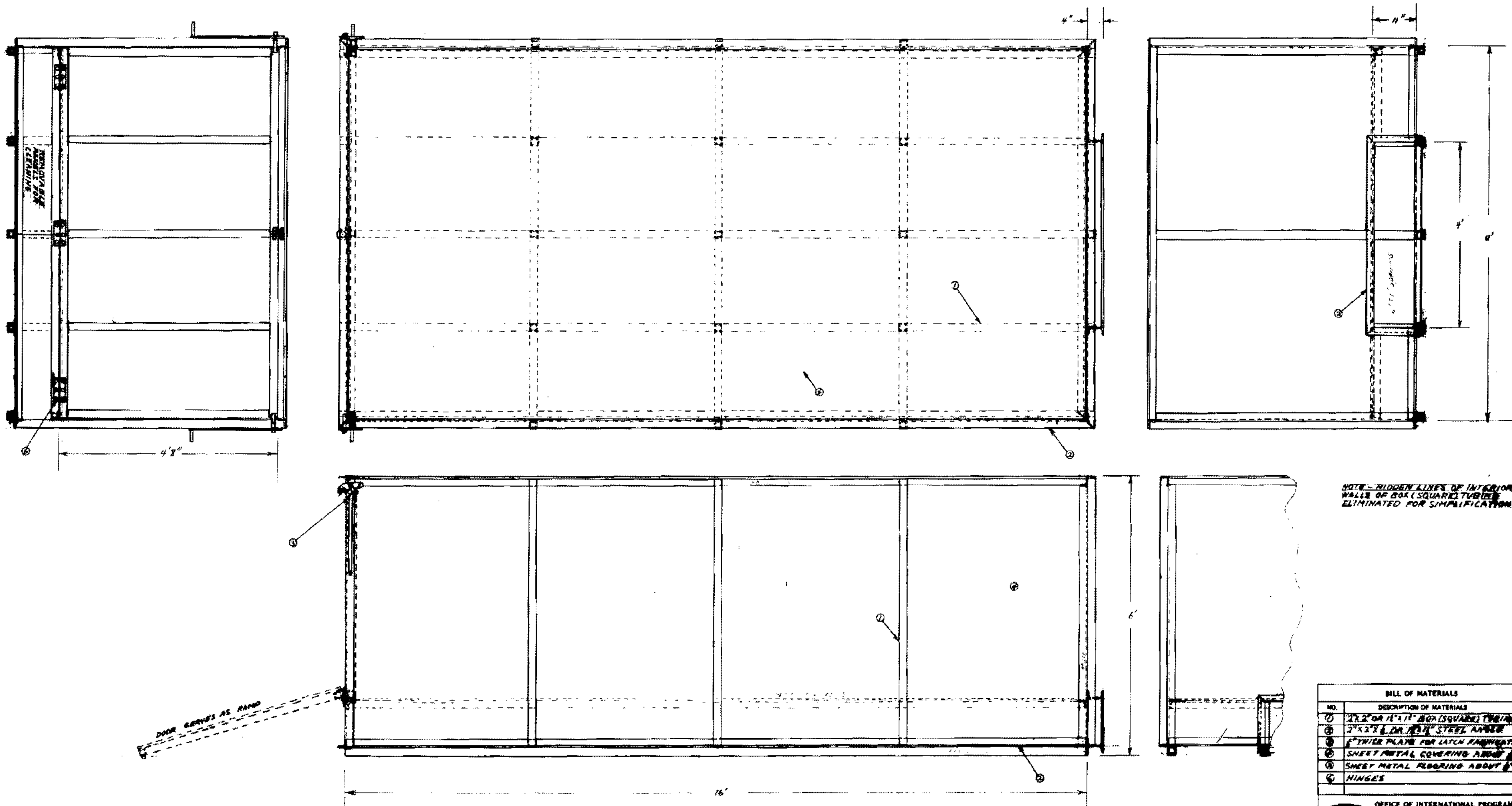
	DESCRIPTION OF MATERIALS
1	2"X2"X 1/4" STEEL ANGLE
2	2"X2"X 1/4 BOX (SQUARE) TUBING
3	[illegible]" THICK MILD STEEL SHEET
4	[illegible] GAGE GALVANIZED STEEL SHEET
5	[illegible]" THICK PLYWOOD
6	[illegible]" THICK PREFORATED PLATE (1/4" HOLES)
7	WINDOW SCREEN (STEEL) TO COVER PUNCHED PLATE
8	[illegible]" DIA. STEEL PIPE
9	[illegible]" DIA STEEL PIPE
10	HINGES
11	DOOR LATCHES

OFFICE OF INTERNATIONAL PROGRAMS
ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

TITLE: ASSEMBLY DESIGN GHANA DRYING UNIT

DRAWN BY	APPROVED BY	REVISION NO. 1	REVISION NO. 2
H. WELLBORN DATE 11/30/77	11/30/77	BY DATE	BY DATE

SCALE	PROJECT NO.	SHEET
—	A-2076	7 of 8



BILL OF MATERIALS

NO.	DESCRIPTION OF MATERIALS
①	2"x2" OR 1½"x1½" BOX (SQUARE) TUBING
②	2"x2"x¼ OR ⅛"x⅛" STEEL ANGLE
③	¼" THICK PLATE FOR LATCH FABRICATION
④	SHEET METAL COVERING ABOUT ⅛"
⑤	SHEET METAL FLOORING ABOUT ⅛"
⑥	HINGES

OFFICE OF INTERNATIONAL PROGRAMS
ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

TITLE GHANA PYROLYSIS UNIT DRYER

DRAWN BY	APPROVED BY	REVISION NO. 1	REVISION NO. 2
H. WELLBORN		BY	BY
DATE	DATE	DATE	DATE
SCALE 1" = 12"	PROJECT NO. A-2076		SHEET 6 of 6