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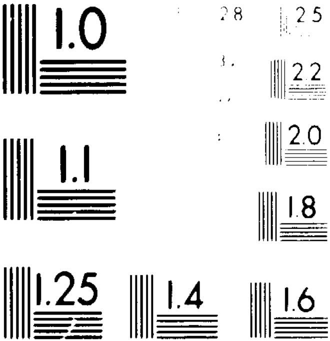

MICROCOPY RESOLUTION TEST CHART

13448

RESTRICTED

22 February 1984
English

ASSISTANCE TO ENERGY PRODUCTION
FROM BIOMASS WASTE MATERIALS
DP/PHI/78/022
PHILIPPINES .

Technical report: Design of a rice hull fueled gasification plant*

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 Robert O. Williams,
consultant on biomass pyrolysis

United Nations Industrial Development Organization
Vienna

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TABLE OF CONTENTS

I. SUMMARY

This document describes work accomplished during the period August to December 1983 under the subject program. The mission required the consultant to design an industrial gasification plant.

Following an introduction to the program and description of the site, presented in Section III, work undertaken by the consultant is summarized in Sections IV and V . Application and detailed description of the gasification plant are presented in Sections VI, VII and VIII. Projected economics are covered in Section IX and further requirements for the achievement of project objectives are given in Section X. Drawings, calculations, specifications, operating manual, etc., are included in the Appendices.

II. ACKNOWLEDGMENT

The author would like to thank UNIDO for inviting him to undertake this mission; Dr. Myint Maung, Vienna, and Dr. Ivan Pluhar and Ms. Betel Tassew, Manila, are acknowledged for their assistance during the mission.

Dr. Ibarra E. Cruz, Manager, PNOC-ERDC, assisted the consultant during his work as did Mr. Aldwyn C. Santos and Mr. Mario R. Carlos of the Conventional Fuels Department, PNOC-ERDC. Their generous cooperation is gratefully acknowledged.

III. INTRODUCTION

The Consultant was asked to design a rice hull gasification system for installation at an industrial location. The gasification system is to be the first of a series of projects conducted jointly by the Philippine National Oil Company - Energy Research & Development Center (PNOC-ERDC), and a host industry in the private sector. The objective of these projects is to transfer alternate energy technology being developed by PNOC-ERDC to commercial locations. Installation and operating costs are to be shared by ERDC and the host industry according to the guidelines developed by previous consultants (1).

Low-Btu gas from the system is to be used as fuel in an aluminium melting furnace which is currently being fired with Bunker Fuel Oil. The furnace has the capacity to melt 4 1/2 tonnes of aluminium per day. The cast product is used in the manufacture of collapsible tubes. Solid fuel for the gasifiers is to be rice hulls obtained from a neighboring rice mill of capacity 1 tonne/hour. The hulls are currently a disposal problem.

Both the aluminium furnace and rice mill are located in the town of Guimba in Nueva Ecija province. They are owned and operated by Milmore Products and Impact Corporation.

Design of the gasification system was undertaken by the consultant at the PNOC-ERDC facility in Manila. The consultant worked in close consultation, with the ERDC manager throughout the project.

Rice hulls constitute a potentially valuable source of fuel in the Philippines. According to Chatterjee (2), over 3 Million tonnes are available. Currently, their use is limited to a few direct combustion installations (power and process steam) and domestic cooking. For the most part hulls are not used and constitute a disposal problem. This project is to be the first of a number of innovative uses of hulls as fuel developed by PNOC-ERDC and established in the commercial sector.

IV. METHODOLOGY

A laboratory gasifier system, designed by the University of the Philippine Foundation, was set up for testing at the PNOC-ERDC facility. The consultant was requested to base his design of the industrial gasifier upon the laboratory system. Accordingly, a series of tests were undertaken with the laboratory unit and modifications were introduced. Data gathered during testing was then used in design of the industrial system. In particular, the arrangement for the gas clean up train was selected based on experiments with the laboratory unit.

V. TASKS ACCOMPLISHED

The consultant designed a double-reactor gasifier system including preparation of the following working drawings (Appendix I):

- Gasifier Reactor(s)
- Scrubber Tower
- Low-Btu Gas Flare
- Piping & installation of gasifier system

(The originals of the drawings are with PNOC/ERDC)
Working drawings were distributed to potential fabricators for bidding.

The following documents were prepared:

- Specifications of Operating Instrumentation (Appendix 3)
- Operating Manual (Appendix 4)

Using quotations for system components, an estimate of total installed cost was prepared (Section 9). An economic analysis using simple pay-back criteria was undertaken. In addition, the consultant cooperated with PNOC-ERDC staff in developing and conducting an experimental procedure for a laboratory scale gasifier. Refinements were made to this system and later incorporated in the design of the double reactor unit.

VI. DETAIL OF THE ALUMINIUM FURNACE & RETROFIT CONCEPT

The furnace is an "open hearth" type which is used to melt aluminium metal (scrap and ingot). The molten charge of metal is cast into strip from which slugs are punched out for the production of collapsible tubes. It requires from 5-7 hours to melt a full charge of 4.5 tonnes of metal. One charge is melted and cast each day.

Two Bunker oil burners are installed in the furnace. Products of combustion are in direct contact with the surface of the charge of metal. From six to seven hundred litres of Bunker oil are required per melt, (consumption of about 100 litres per hour).

The furnace is to be retrofitted with a gasifier system of output capacity 1.2 x 10^6 Btu/hour (1300 MJ/hour). The two oil burners, currently installed, consume 100 litres/hour or about 4050 MJ/hour (4 x 10^6 Btu/hour). The gasifier system consists of two reactors with the provision for the installation of further reactors at some future date. This concept of "ganged units" is considered preferable to the installation of one large gasifier reactor with the attendant scale-up problems.

Low-Btu gas will be delivered to a burner installed between the two existing oil burners. Gas from the two reactors running simultaneously will constitute about 25% of the total furnace energy requirement. With only two reactors installed, it will still be necessary to burn Bunker Fuel at the oil burners.

VII. SYSTEM OPERATION & DESIGN

The use of a double reactor system avoids the problem of refueling and removing char from a reactor which is operating under positive pressure. When one reactor is empty, it can be shut down and isolated from the sytem for refueling. The cost of expensive and troublesome airlock, fuel feed systems is avoided. However, when one reactor is shut down, system output is cut in half. Design system output capacity of 1300 MJ/hour will consequently be intermittent. A schematic drawing of the complete system is presented in Appendix 2. Combustion air from a medium pressure blower is delivered to the two zones of each reactor via a vertical manifold. Valves are provided for the modulation (or shut off) of air to each reactor. From each reactor, hot gas is delivered to a cyclone for removal of coarse particulate matter.

A refractory lined gas burner and flare is provided, for the safe and environmentally acceptable disposal of poor quality gas at start up of a reactor and following shut down. A valve system enables the hot gas to be delivered to either the flare or the clean up train and ultimately the furnace. When a reactor has reached equilibrium, and the gas will sustain combustion in the flare, it is diverted to an air condenser for the removal of heavy tar. From the condensers, the gas from each reactor is delivered to a scrubber tower for the removal of the remaining particulate and aerosol contaminants. In the scrubber, the gas flows countercurrent to a descending water cascade. Water is cooled in a separate vessel and returned to the top of the tower. Gas flows from the two reactors are combined in the scrubber tower.

Leaving the scrubber, gas enters a condenser for the removal of mist carry over. The aqueous condensate is returned to the scrubber sump. Clean gas is then delivered to the aluminium melting furnace via a four-inch pipeline. Gas is burned in the furnace at a gun-type low-Btu gas burner. A safety shut-off valve is provided in the gas line at the furnace. Other than "on-off", the control of gas flow to the furnace is not required since the oil burners will always be operating at the same time as the low-Btu gas burner. Furnace modulation (such as reduction in burner output after the metal is molten), will be obtained from modulation of the oil burner system. If necessary, one gasifier reactor can be shut down, reducing low-Btu gas supply by 50%.

VIII. DESCRIPTION OF GASIFIER REACTORS

The system design requires two gasifier reactors with a combined output capacity of 1300 MJ/hour (1.2 x 10^6 BTU/hour), for a rice hull fuel consumption rate of 185 kg/hour, (design conditions). Rach reactor has an internal diameter, measured at grate level, of 60 cm. Each reactor is operated in batch mode and must be isolated from the system for refueling and char removal.

The reactors are the fixed-bed, downdraft type wherein the gases pass down through a restriction in fuel bed area. High bed temperatures in the region of the restriction cause tar and other products of pyrolysis, which are generated in the upper levels of the bed, to be cracked into permanent hydrocarbon gases.

The throat section is formed from an inverted conical frustum, made of cast steel, and supported between the reactor shell flanges. Holes are drilled into the conical frustum. Combustion air is introduced to the fuel bed at two locations. Primary air enters through a pipe inserted, vertically through the top of the bed. Secondary air is introduced into the space formed between the outside surface of the conical frustum and the inner, cylindrical surface of the reactor shell.

The effect of this "double-fire" zone is to generate a cleaner gas than can be obtained from the conventional downdraft reactor. Theoretical aspects of the reactor design are discussed by Cruz (3) in PNOC-ERDC and University of the Philippines reports and publications.

The continuous removal of char from the bottom of the bed is provided for by a fixed slotted grate and rotating scraper. The rotating scraper shaft is cooled using air from the combustion air blower. Char falls through the grate into a container below the reactor, from which it is periodically removed through a port.

A bridge breaker is inserted through the top head of each reactor, which is agitated manually, as required. Provision is made for mechanization of both bridge breaker and ash scraper operation should this be required at a later date.

An ignition port is installed through the reactor shell, above the grate, and a spring-loaded relief valve is mounted on the sub-grate section.

Each reactor is fabricated in four flanged sections:

- Dished top head
- Fuel reservoir
- Reaction zone
- Sub-grate

Wall thickness calculations are included in Appendix 5. The reactor fabrication drawing is in Appendix I.

IX. COST & ECONOMIC ANALYSIS

Total installed cost of the gasifier system is itemized in the following table. The cost is estimated at ₱160,000, although the system could be simplified and the cost reduced to ₱100,000. An economic analysis follows the itemized cost table. Gross savings (₱/month) are computed to allow for the following variable conditions:

System outputs of 0.5, 1.0 and 1.5 Million Btu per hour.

Operating schedules of 40 and 192 hours per month.

Costs of Bunker C Fuel of 3.50 and 4.20 ₱/liter.

Operating costs, (labor and maintenance since the rice hull fuel is free) are then subtracted from gross savings to give net savings.

Under ideal conditions of system output of 1.5 MM Btu/hour (25% above design), 192 hours/month operation (8 hours/day and 24 days/month) and an avoided cost of Bunker C of ₱4.20/liter, net savings are in the order of ₱31,000/month. This will give a payback period of less than 6 months. A more realistic projection assumes an output of 1 MM Btu/hour in which case payback period will vary from 4 years to 8 months.

It can be seen from the analysis that economic feasibility is very sensitive to frequency of operation; so use of the gasifier system should be maximized.

COST OF RICE HULL GASIFIER SYSTEM

Reactors, 2 Units @ ₱15,800 each	₱31,600.00*
Combustion Air Blower	12,000.00*
Afterburner/Flare	14,000.00*
Flare Pilot System	1,500.00
Scrubber & Cooling Tank	15,500.00*
Pump & Contiguous Piping	8,000.00*
Air Condenser	5,000.00
Pipe, Pipe Fittings & Cyclones	19,000.00*
Gas Valves (4), 2 in b/Fly	9,000.00*
Air Valves (2), 3 in b/Fly	6,500.00*
Air Valves (2), 2 in b/Fly	4,500.00*
Reactor Support Frame & Walkway	5,000.00
Furnace Modifications	
Low Btu Gas Burner, Burner Control & "Gas Cracking" Pipe	20,000.00
SUBTOTAL	₱151,600.00
Installation	2,000.00
Testing Program	6,400.00
TOTAL	₱160,000.00

*These items based on quotations January 1984. Other costs are estimates.

ECONOMIC ANALYSIS FOR RICE HULL GASIFIER SYSTEM

OUTPUT from GASIFIER (MM BTU/hr)	BUNKER C (li/hr)	OPERATING schedule (hrs/day)	(hrs/mo)		COST (inflation = 20%) (₱/li)	COST (₱/hr)	COST (₱/mo)
0.5	13.15	8	192	current	3.50	46.025	8,836.80
				w/ inflation	4.20	55.23	10,604.16
		5	40	current	3.50	26.025	1,841.00
				w/ inflation	4.20	55.23	2,209.20
1.0	26.30	8	192	current	3.50	92.05	17,673.60
				w/ inflation	4.20	110.46	21,208.32
		5	40	current	3.50	92.05	3,682.00
				w/ inflation	4.20	110.46	4,418.40
1.5	39.45	8	192	current	3.50	138.075	26,510.40
				w/ inflation	4.20	165.69	31,812.48
		5	40	current	3.50	138.075	5,523.00
				w/ inflation	4.20	165.69	6,627.60

Economic Analysis (continued)

OUTPUT from GASIFIER	LABOR (P30/day)	MAINTENANCE* (P0.1 M)	MAINTENANCE* (P0.16 M)	COST of FUEL	TOTAL (P0.1 M)	TOTAL (P0.16 M)	OPERATING SCHEDULE (hrs/mo)		NET SAVINGS (P0.1 M)	NET SAVINGS (P0.16M)
0.5	720	209	334	free	929	1054	192	current	7,907.80	7,782.80
								w/ inflation	9,675.16	9,550.16
	240	209	334	free	449	574	40	current	1,392.00	1,267.00
								w/ inflation	1,760.20	1,635.20
1.0	720	209	334	free	929	1054	192	current	16,744.60	16,619.60
								w/ inflation	20,279.32	20,154.32
	240	209	334	free	449	574	40	current	3,233.00	3,108.00
								w/ inflation	3,969.40	3,844.40
1.5	720	209	334	free	929	1054	192	current	25,581.40	25,456.40
								w/ inflation	30,883.48	30,758.48
	240	209	334	free	449	574	40	current	5,074.00	4,949.00
								w/ inflation	6,178.60	6,053.60

* 2.5% of Capital Cost
(All computations are on a monthly basis)

X. IDENTIFICATION OF FURTHER NEEDS

Institutional Aspects

Both PNOC and the host industry need to reach agreement on financing fabrication of the gasification system. The proposed policy for technology transfer requires that PNOC pay 70% and the host industry 30% of the manufacturing and installation costs. Specific items of hardware and services to be supplied by each party need to be identified. After a mutually-agreed upon period of satisfactory operation of the equipment, the host industry is required to pay back to PNOC their initial contribution, i.e., pay the balance of the purchase price. "Satisfactory" operation requires demonstrable technical and economic feasibility. The extent of PNOC's involvement in operation of the plant following start-up, e.g., in the training of operating personnel, needs to be defined. A formal agreement covering these issues is required.

Technical Aspects

Conversion of the furnace to low Btu gas operation requires further work, specifically:

- Design of low-Btu gas burner and burner control system including safety shut-off valve system and selection of blower.

- A program of on-site monitoring and evaluation requires development and implementation.

XI. REFERENCES

1) P. D. GROVER, UNIDO Technical Report DP/PHI/78/022, August 1983

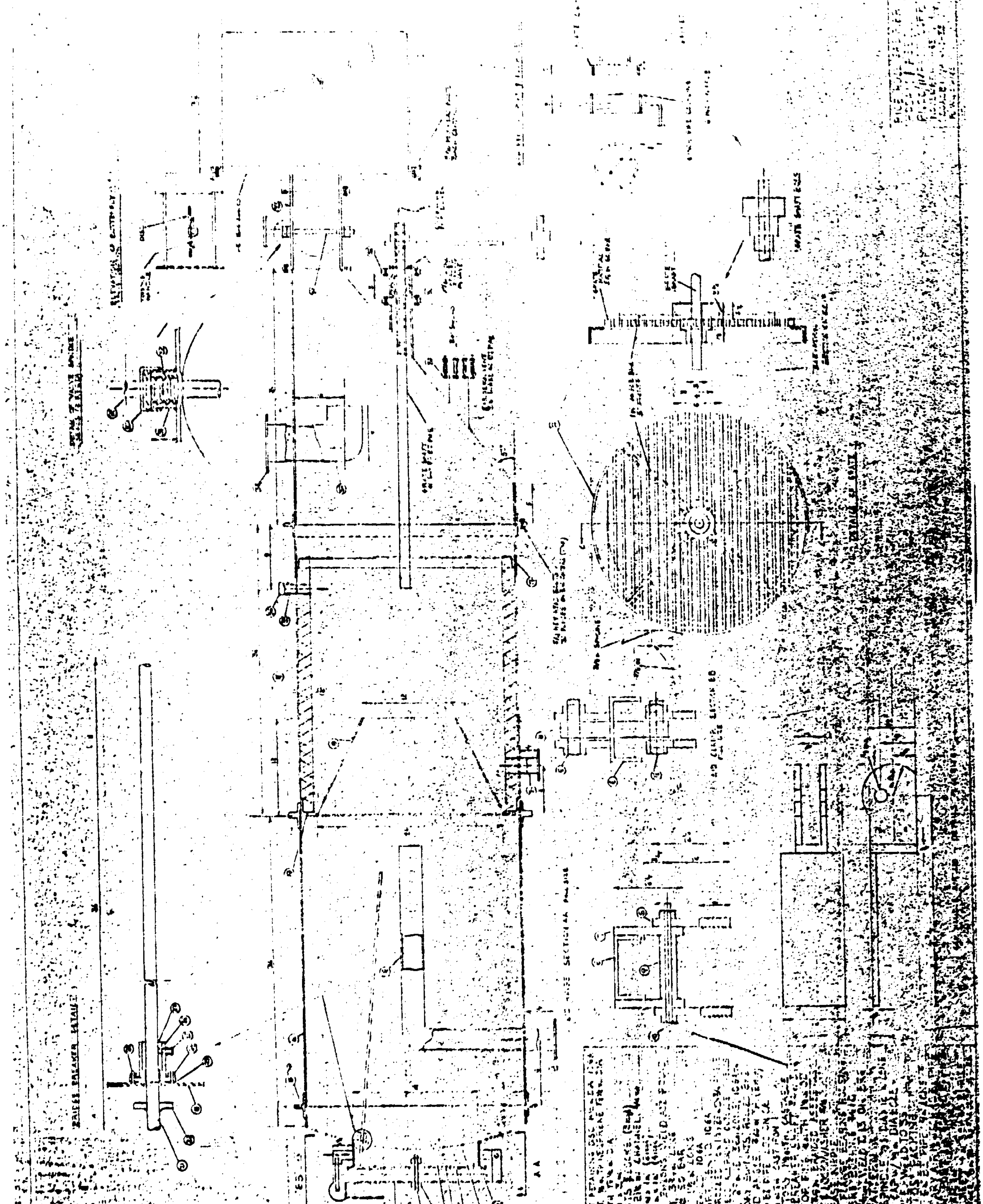
2) A. K. CHATTERJEE, UNIDO Technical Report DP/ID/SER A/397, March 1983

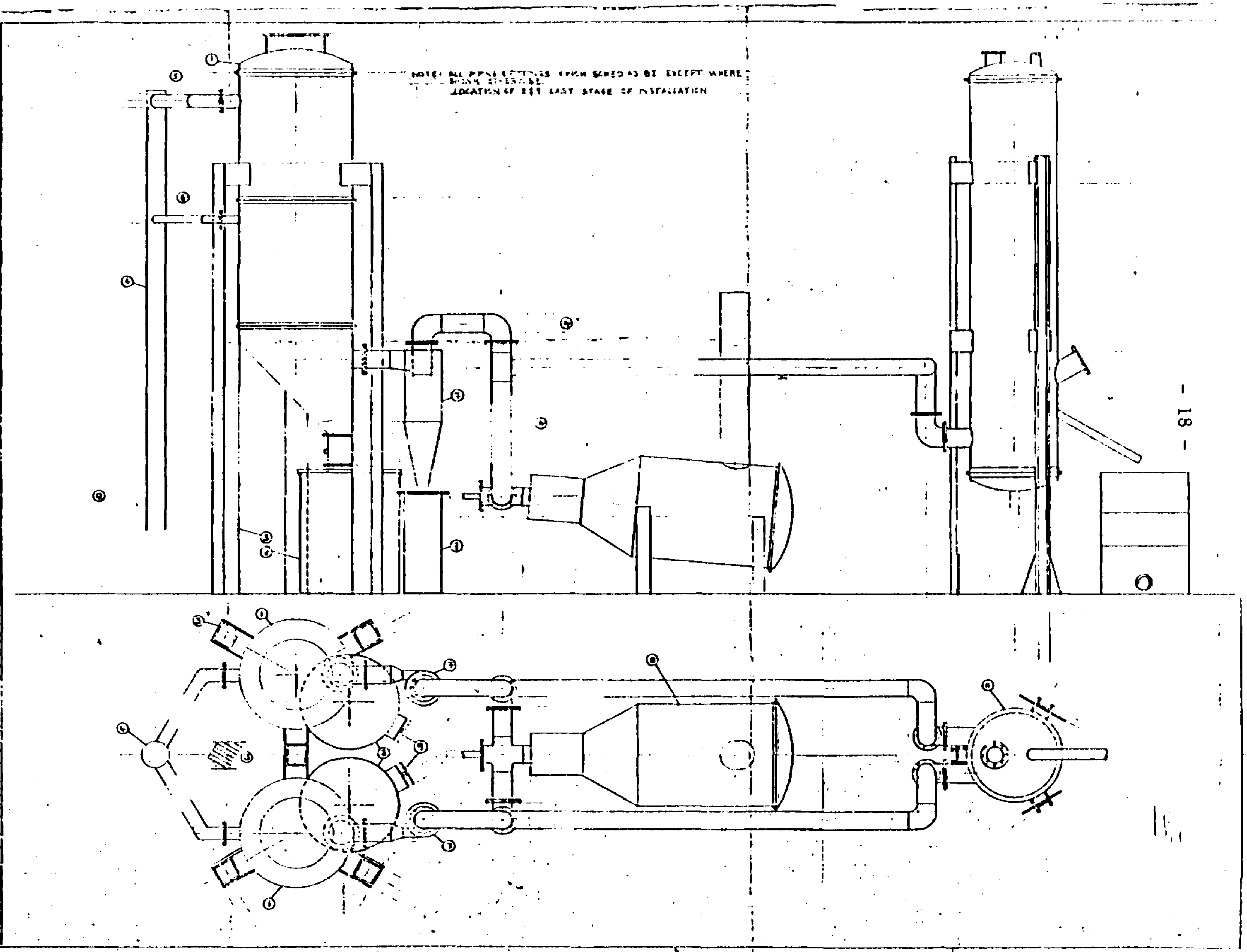
3) IBARRA E. CRUZ, Development of Rice Husk Gas Producer Systems in the Philippines PNOC-ERDC Publication, July 1983

APPENDIX I

WORKING DRAWINGS OF GASIFIER SYSTEM

(Originals of drawings are with PNOC/ERDC)



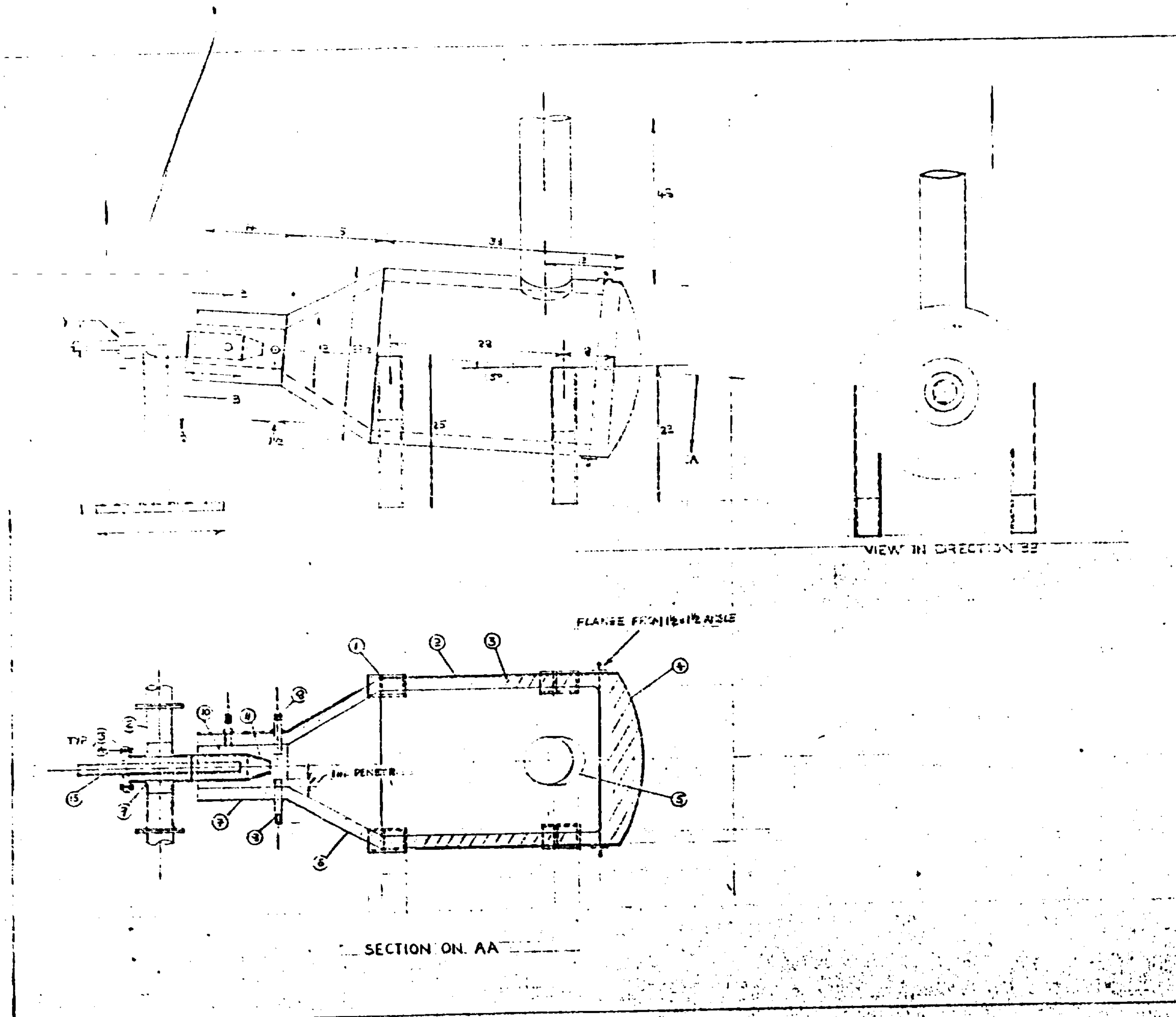


GAS FLOW CONTROL VALVES (4)	14
CHARGING PLATFORM	13
BLOWER	12
SCRUBBER TOWER	11
GAS BURNER & FLARE	10
CHAR REMOVAL PORTS	9
CYCLONE DUST CANS (2)	8
CYCLONES (2) Dc = 10 in	7
SECONDARY AIR VALVES (2)	6
PRIMARY AIR VALVES (2)	5
AIR MANIFOLD	4
REACTOR LEGS (5)	3
REACTOR CHAR CONTAINERS (2)	2
GASIFIER REACTORS (2)	1

RICE HULL GASIFIER SYSTEM
LAYOUT OF MAJOR COMPONENTS

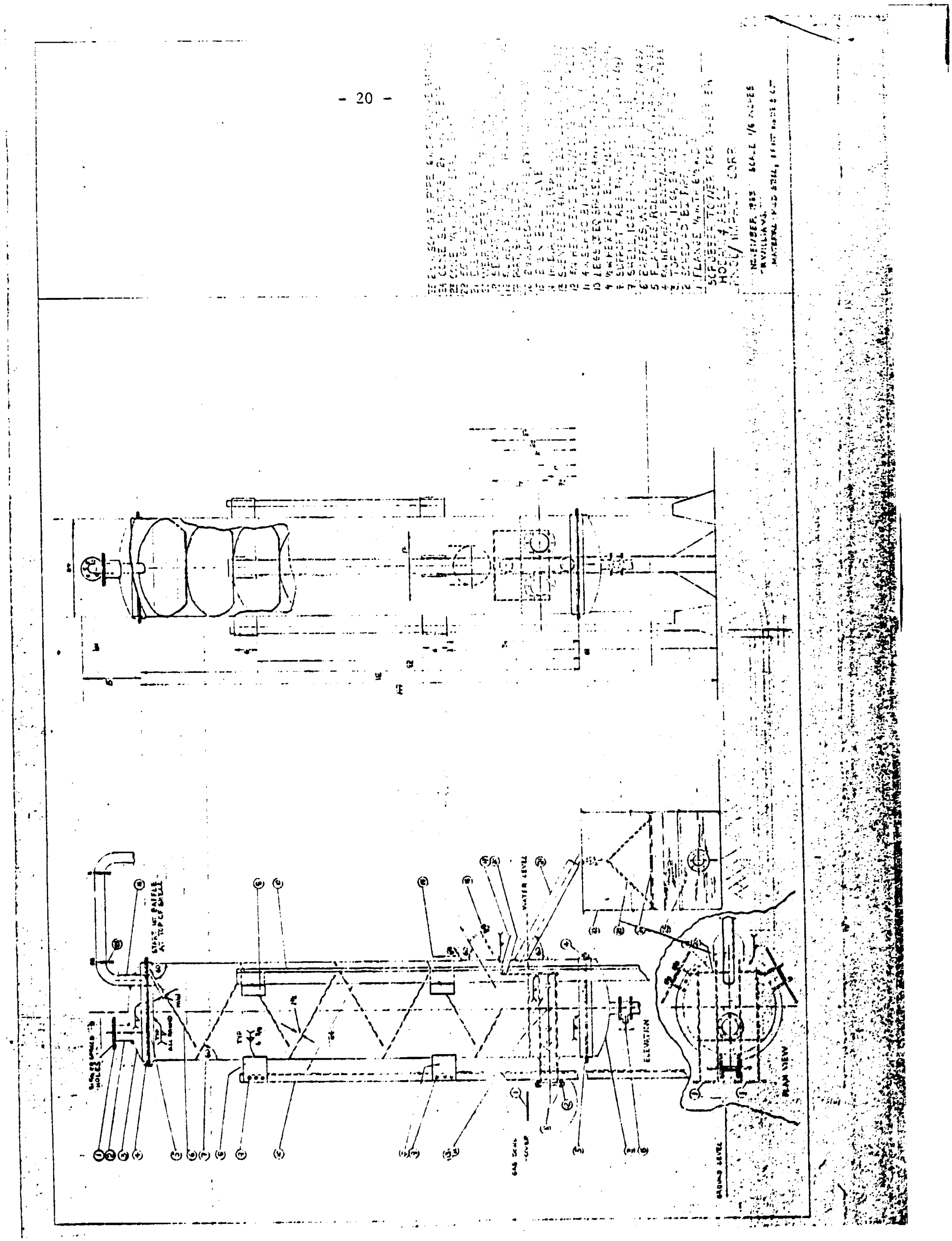
EDDAM & ASSOCIATES
FOR: FNOC/IMPACT CORP.

R. WILLIAMS DEC 1983 SCALE: 1/16



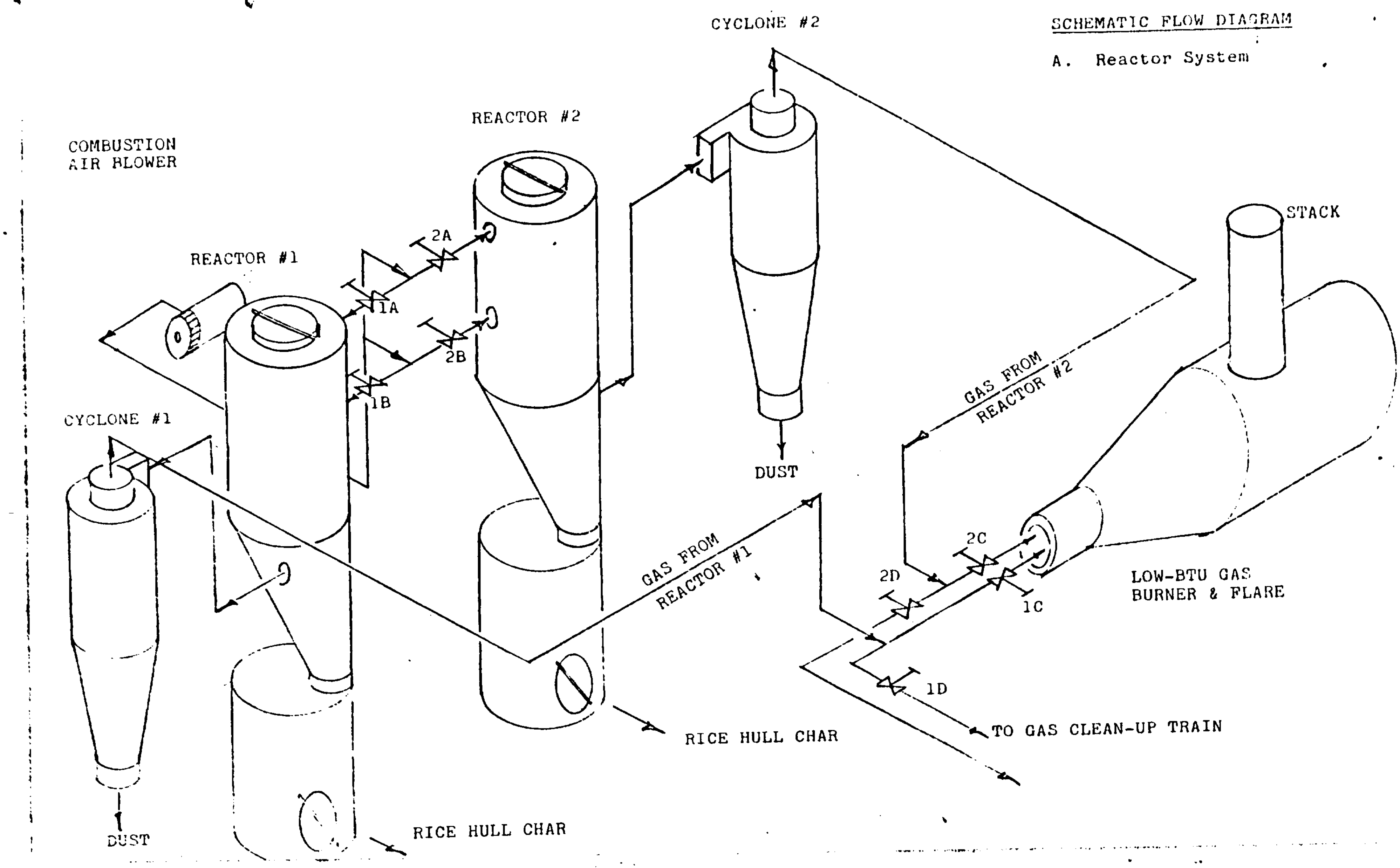
15	2in SCHED 40 BI PIPE
14	5/8 HEX BOLTS/LOCKS/FLATS, 8 /OC TYP
13	FLANGES, 6½in DIA, ¼in TH
12	4in SCHED 40 BI PIPE, 10in LONG
11	4in TO 2in STND BI CON REDUCER
10	4in SCH 40 PIPE, 12in LONG AT 5° to HORIZ
9	4in STND BI CROSS
8	IGNITION PORT, 1in SCH 40 BI PIPE NIPPLE
7	ROLL-UP (or weld case) 14in LONG × 12in DIA
6	CONE 23½ × 12 × 15in × 10 GA
5	STACK, 8in DIA, 14 GA 43in LONG
4	HEAD, 10 GA 28½in OD, FLANGED
3	CASTABLE REFRACTORY TH
2	SHELL, 28½in OD × 39in LONG × 10 GA
1	LEGS, (4 req'd) FABRICATE BOX FROM 2 PCS 4in CHANNEL, CUT TO FIT SHELL

LOW-Btu GAS BURNER & FLARE
HODAM & ASSOC.
PNOC/IMPACT CORP
DECEMBER 1983. R WILLIAMS. SCALE 1/8 INS
MATERIAL: MILD STEEL


WATER LEVEL
ELEVATION
PLAN VIEW
GROUND LEVEL

APPENDIX 2

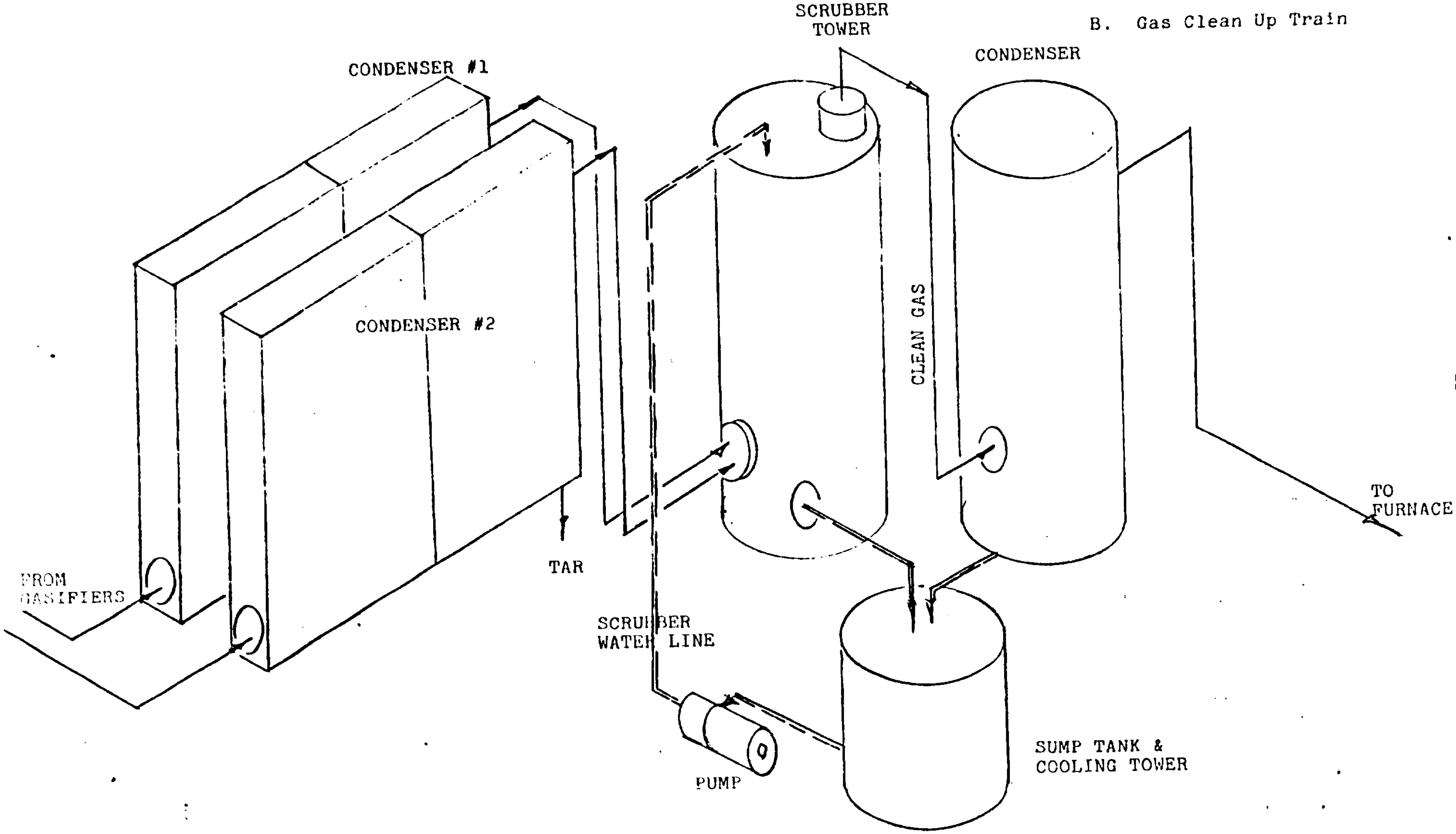
SCHEMATIC LAYOUT OF
GASIFIER SYSTEM



SCHEMATIC FLOW DIAGRAM
A. Reactor System
CYCLONE #2
REACTOR #2
COMBUSTION AIR BLOWER
STACK
REACTOR #1
2A
1A
2B
1B
CYCLONE #1
GAS FROM REACTOR #2
DUST
2C
2D
1C
GAS FROM REACTOR #1
LOW-BTU GAS BURNER & FLARE
1D
TO GAS CLEAN-UP TRAIN
RICE HULL CHAR
DUST
RICE HULL CHAR

SCHEMATIC FLOW DIAGRAM

B. Gas Clean Up Train



APPENDIX 3

OPERATING INSTRUMENTATION

OPERATING INSTRUMENTATION

A. PRESSURES

Pressure differentials across major components in the system will be indicated by "Dwyer" Magnehelic pressure gauges (about US$35 each) or an equivalent gauge.

The following pressure differentials will be measured:

P1A
: Pressure Drop across Reactor #1

P2A
: Pressure Drop across Reactor #2

P1B
: Pressure Drop across Condenser #1

P2C
: Pressure Drop across Condenser #2

P1C
: Pressure Drop across Scrubber Tower

P2D
: Pressure Drop across Scrubber Tower

P3
: Pressure Drop across Condenser

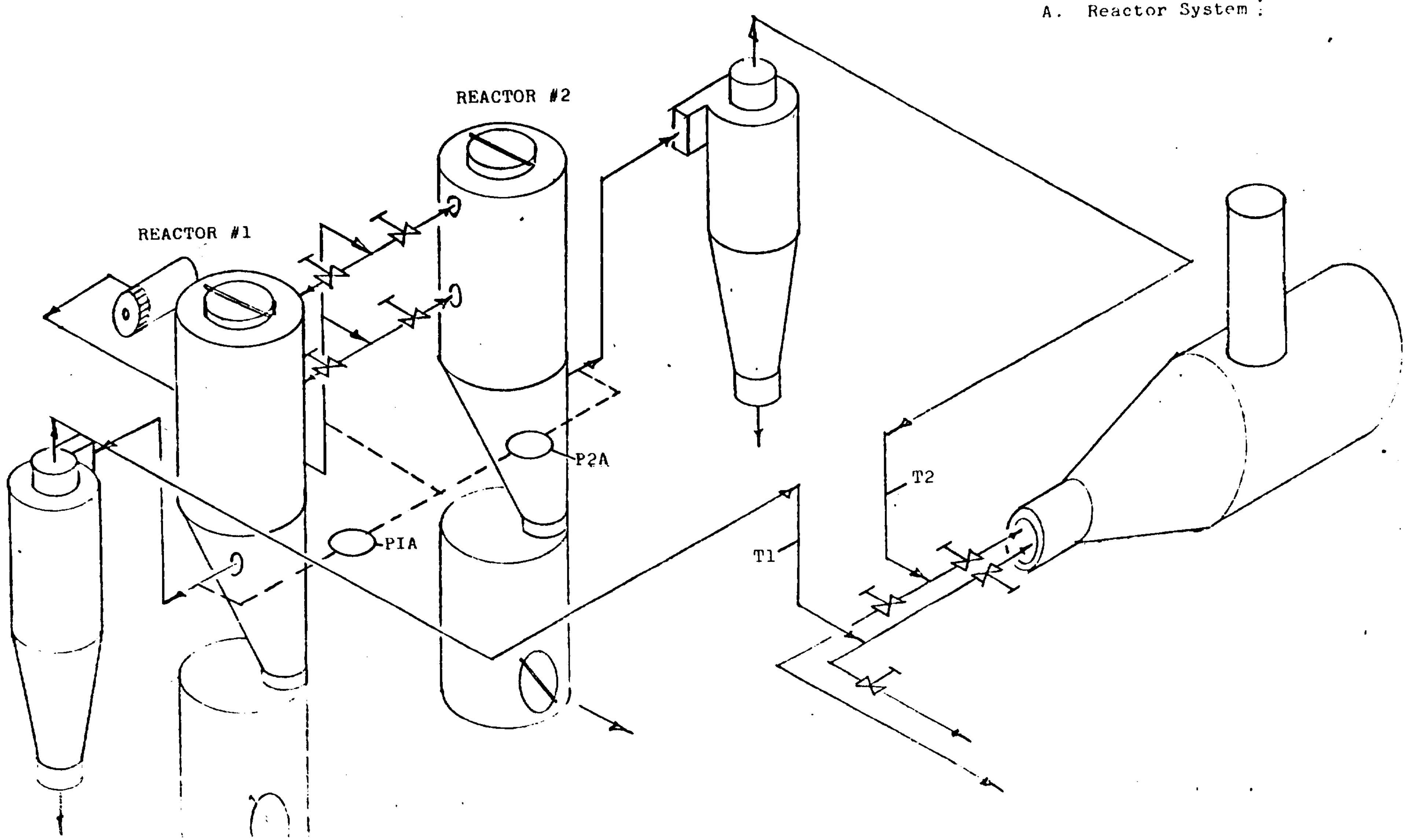
B. TEMPERATURES

Temperatures (T3, T4 and T5) are recorded using bi-metallic "Dial" gauges inserted into the gas pipe.

Temperatures T1 and T2 are measured using Type K, (0 to 2500°F) thermocouples with compensating analogue meters.

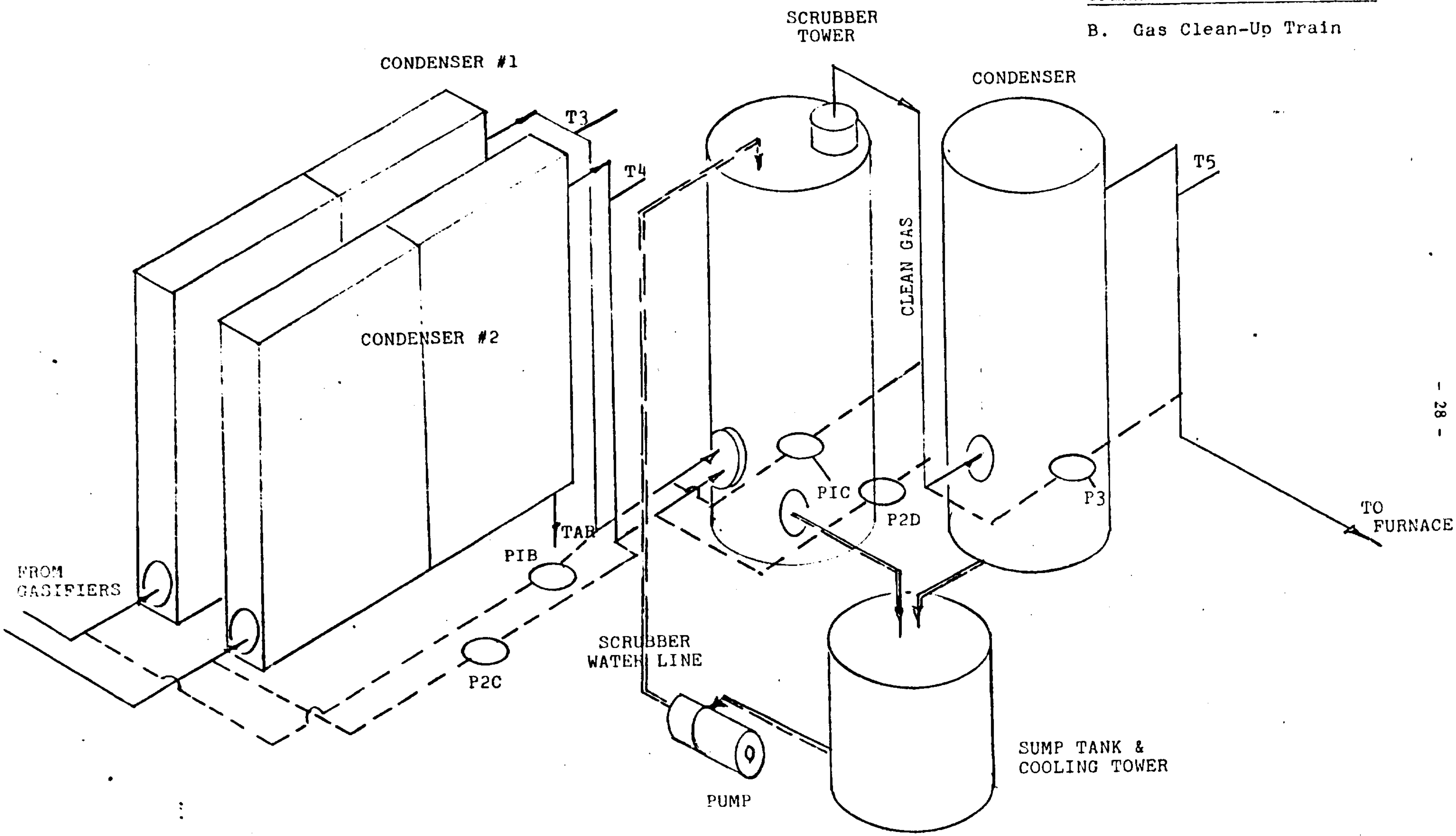
OPERATING INSTRUMENTATION

A. Reactor System :



OPERATING INSTRUMENTATION

B. Gas Clean-Up Train



APPENDIX 4

ABRIDGED OPERATING & MAINTENANCE INSTRUCTIONS

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A. GENERAL

1. Specifications and Capacity

Each gasifier reactor has a 60 cm. diameter grate section, and is capable of delivering 650 MJ per hour of hot gas.

Fuel consumption for this output is 92 kg/hr.

The system can be turned down to 25% of the maximum rated output with minor loss in overall thermal efficiency.

2. General Function and Mode of Operation

In a gasifier, fuel (rice hulls) is converted to low-Btu gas (heat of combustion 160 Btu/scf dry gas basis). The gas is used as fuel in the furnace.

Combustion air for the gasifier is provided by means of a fan. Poor quality gas is flared in the after-burner. At this time, the reactor is under pressure. When the reactor is hot and combustible gas is being delivered to the flare, gas flow is diverted to the furnace. In the furnace, low-Btu gas replaces Bunker C fuel for the provision of heat to melt the aluminium metal.

The reactor is of the fixed-bed, downdraft (co-current) type.

Combustion air is introduced into a bed of fuel through a central distribution pipe. The fuel bed is supported on a grate which is periodically agitated. Low-Btu gas exits the bed through the grate and leaves the reactor below the grate.

Fuel is added through a lid on top of the reactor. A suitable head of fuel is maintained above the combustion zone. Ash is removed through a port at the base of the ash can.

A port giving direct access to the fuel bed is provided for ignition purposes. (This is to be open only when the reactor is cold).

A flare is provided to burn the gas during start-up operations, and provide a visual qualitative analysis of the gas quality.

3. Function of the System

After exiting the gasifier reactor, hot gas is cleaned, cooled and delivered to the furnace. Tar is first removed in a condenser, then the gas is cleaned by direct contact with water. The gas is passed through a distributor pipe below the water surface in the scrubber tower, then it ascends the tower countercurrent to a water cascade. Warm gas exiting the scrubber can is passed to a gas/ambient air condenser. Condensate is returned to the scrubber sump tank.

Cool gas leaving the condenser is delivered to the furnace.

4. Safety and Health Issues

Low-Btu gas is both poisonous and explosive. Its major components are carbon monoxide, hydrogen, carbon dioxide and nitrogen. When ignited in the presence of an appropriate quantity of air, it burns rapidly (air:gas ratio of 1.4:1). Inside a sealed vessel, such as the reactor or scrubber, it can explode. Accumulations of gas/air mixture in the furnace will also explode if ignited. Low-Btu gas explosions can be of sufficient violence to cause severe damage if they occur in a closed space.

Methods of Starting Reactor:

Do not use any liquid fuels such as gasoline, diesel or alcohol as an aid to igniting the reactor.

Occurrence of Minor "Blowback":

The major risk of blowback occurs during start-up when the gas is ignited at the flare. At this point, air from the start-up fan may pass through the fuel bed with much of its oxygen not being consumed in the reaction. An explosive mixture can exist inside the reactor, flare and connecting pipe. If gas velocity at the flare is less than the velocity of the explosion flame front, flame will propagate back down the flare into the reactor. There is no danger since the excess pressure is immediately vented to atmosphere through the flare. A jet of smoke and occasionally ash is blown out of the flare. The flame is usually extinguished. Wait until the gas quality has had a chance to improve before attempting to light the flare again.

Carbon Monoxide

20 to 25 percent of low-Btu gas is carbon monoxide. This gas is poisonous. Under no circumstances inhale the smoke or gas from a gasifier system. The gasifier should always be installed outside with an open-sided cover (pole barn) for protection from the elements. In such a location, there should be no risk of toxic levels of carbon monoxide. If the gasifier must be installed in a confined space, adequate ventilation from fans is essential.

Health Hazards

Tars and acids formed in the upper part of the reactor as a result of pyrolysis of the fuel will condense around the lid. If an operator gets tar on his hands, e.g., during refuelling, he should wash it off immediately. The use of protective gloves is recommended. The tars are known to contain carcinogens. With time, the scrubber water will become contaminated with soot and this will require disposal. Care should be taken when handling and disposing of this material.

High Temperatures

The lower part of the reactor and contiguous piping from reactor to scrubber will become hot during operation. Operating personnel should keep well clear of these components. Removal of the ash door on a hot reactor should only be undertaken with protective gloves.

Open Ports

It is good practice not to open any part on the reactor while it is hot, other than the lid for refueling purposes. When opening the lid for refueling, it is important to stand clear of the opening for a few seconds and to avoid looking directly inside. In particular, eyes should always be kept clear of any open port. The ash door, and any other port should only be opened on a cold reactor. If it is essential to open the ash door on a hot reactor, the operator should stand to one side since a minor blowback may occur when the hot gas is exposed to air.

B. OPERATION

1. Reactor Fuel

Rice hull fuel for the gasifier must be free of dirt and other contamination. No minerals, soil, metal or other foreign substances may be present. These will all form blockage in the oxidation-reduction zones of the reactor. High moisture content fuel will cause a reduced thermal efficiency and a possible overload of accumulated condensate in the scrubber.

2. Fueling Reactor

The reactor is isolated before refueling. Open the fuel port, keeping well back from the opening, pour fuel into the reactor, and close the fuel port as soon as possible.

During the start-up and occasionally while running, the fuel should be "poked" down using the bridge-breaker. A -radual drop in gas quality manifested by sluggish persormance at the gas burner will indicate a bridging problem with the fuel and the reactor should be "poked down".

Fueling will be required about every 20 minutes at full output, and somewhat less for lower loads. If the reactor is not refueled in a timely manner, the gas quality will drop.

3. Starting Reactor

The "fire" is started through the side port. Remove the cap. Using a hand held torch, ignite the fuel in the reactor. Refer to the valve control sequence for proper valve setting, etc. Hot char may also be added through the port to fire the reactor. Another method to use requires a red hot metal rod to be inserted for a few minutes, then removed prior to starting the blower. Do not use flares or any other incendiary device. The ashes from these will cause blockage and slagging internally in the reactor.

4. Ash Removal

Ash can only be removed when there is no gas flow. The blower must be off. Remove the ash port lid by turning counter-clockwise. The grate should be turned occasionally to assist in the removal of ash from the upper zones. Gas flow and gravity also contribute to the removal of ash. Generally, the upper zone should be kept as clear as possible of ash. If too much is allowed to accumulate, a reduction in performance is caused by ash blockage which restricts gas flow. The pressure drop across the reactor should not exceed 2" of water column.

5. Gas Clean Up

After the cyclones and air condenser (tar removal), hot gas is bubbled through water to both cool and clean it. Gas entering the scrubber will be as hot as 500°F. The exiting gas will be below 200°F. Leaving the water, the gas passes through a demisting tower. In this column, the packing picks up carry over mist from the water bath. Some carbon is also deposited. The packing can be easily removed and replaced. In the scrubber, the water level must be maintained within certain limits to insure both proper cleaning of the gas (low limit) and to prevent an excessive pressure drop in the scrubber (high limit). The level is set by the location of the discharge pipe.

C. MAINTENANCE

1. Reactor

Rotation of the grate should be periodically checked. There should be adequate clearance between the wiper bar and the grate bed. The following seals should be periodically checked for possible leakage:

- Grate Shaft
- Bridge-breaker Shaft
- Butterfly Ash Control Valve Shaft

2. Gas Clean-Up

The cyclone should be detached and cleaned every six months.

Tar discharge ports from the air condensers should be cleaned every day.

The scrubber water has to be drained from the scrubber tower and the sumptank and replaced every week.

The flare burner may require occasional cleaning.

3. Furnace Conversion

Each day, prior to start up, ensure correct operation of the safety shut-off and gas modulation valve.

4. Valves

The gas and air control valves should be checked daily for correct operation. In particular, they should be checked for correct sealing when closed.

D. CHECKLIST

1. Start-Up

- Ensure that valve control sequence (Section E) has been followed.
- Before ignition of one reactor ensure that gas is diverted to the flare and the flare pilot is on.

- Follow the "reactor starting" procedure, close the ignition port and start the combustion air blower. Gas is now being delivered to the flare.

- Prior to diverting gas to the furnace, turn the scrubber water pump on and check that the scrubber water is flowing.

- To divert gas to the furnace, follow the valve control sequence.

2. Start-Up of Hot Reactor

- Provided that a bed of hot char remains inside the gasifier after refueling with fresh rice hulls, the reactor can be started without ignition.

3. Shut Down

- Follow valve control sequence (Section E)

- Isolate reactor(s) from the combustion air blower.

- During the "post-gassing" period, ensure that residual gas can escape into the flare.

E. VALVE CONTROL SEQUENCE (see Appendix 2 for valve numbers)

Starting with Gasifier #1 supplying gas to the furnace and with Unit #2 being filled with rice hulls. Under these conditions:

1A		2A		2C	open
1B	open	2B	closed	1C	closed
1D		2D			

When Reactor #2 is ready for ignition (or restarting). Valves 2A and 2B are opened in appropriate proportions determined by operator experience. Reactor #2 will now delivér gas to the flare.

When the gas from #2 is clear as determined from visual observation of the flare, Valve 2C is closed and Valve 2D opened simultaneously.

At this stage, both Reactors are delivering gas to the furnace. The valve situation is:

1A, 1B, 2A, 2B, 1D, 2D } open

1C, 2C } closed

When Reactor #1 exhausts its fuel, the following sequence is followed.

Closed ID, open 1C simultaneously (gas to flare) close 1A and 1B. Reactor #1 will cool down can be refilled.

The Valve situation is now:

1A, 1B, 1D } closed

2A, 2B, 2D } open

1C open

2C closed

Primary and Secondary Air Valves

Setting and primary and secondary air valves determines the relative quantities of combustion air delivered to the two combustion zones. The settings are a matter of operator experience. Adjustment of the valves is made while observing combustion of the gas at the flare.

APPENDIX 5

DESIGN CALCULATIONS

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A. Reactor Sizing

Internal diameter (at grate level) of UP rice hull gasifiers is 44 cm., area is 1520.5 sq.cm., (0.15 sq.m.)

Potential fuel consumption rate is 50 kg/hour.

Specific fuel rate = 50/0.15 or 330 kg. per hour & sq.m.

Heat combustion of loose rice hull is 5470 Btu/lb. at 9.3% moisture. This is 12.72 MJ/kg.

The aluminium melting furnace has a capacity of 100 liters of Bunker Fuel per hour.

Heat of combustion of Bunker Fuel is 40.5 MJ/liter consequently energy consumption is 4050 MJ/hour.

Let efficiency (to hot gas) of gasifier be 55%. Required input to gasifier capable of meeting furnace demand will be 4050/0.55 MJ/hour.

Fuel consumption will be 4050/0.55 x 1/12.72.

Required grate area: $\frac{4050}{0.55} \times \frac{1}{12.72} \times \frac{1}{330} = 1.75$ sq.m.

Diameter of such a reactor would be $\sqrt{\frac{4 \times 1.75}{\pi}}$ or 1.5 meters, (150 cm)

NOTE: It would be prudent to build the first generation or reactors using the UP design and reactor only slightly larger.

Use of reactor of 60 cm. ID   area = 0.28 sq.m.

Potential cut put as hot raw gas from such a reactor:

$$0.28\ (m^2) \times 330\ \frac{kg.}{hr\text{-}m^2} \times 12.72\ MJ/kg. \times 0.55$$

= 652.76 MJ/hour or about 15% of furnace requirements. Seven such reactors would be required to completely replace the furnace oil consumption.

Two reactors together will generate about 1300 MJ/hour (1.2 Million Btu per hour).

Rice hull fuel consumption by two reactors:

$$2 \times 0.28\ (m^2) \times 330\ \frac{kg}{hr\text{-}m^2} = 185\ kg/hour$$

Rice hull fuel consumption for one reactor will be 92 kg/hour.

Bulk density of rice hulls = 122 kg/cu.m.

Volumetric consumption = 92/122 = 0.75 cu.m./hour

For a reactor of ID 60 cm., cross sectional area 0.28 m^2, length of internal fuel reservoir will be 1.36 m or 136 cm.

The entire reactor will be about 4 meters (13 feet) high. This is too high. Problems of refueling.

Rather than reduce the capacity of the reactor, assume it will be fueled every 20 min.

Required capacity of internal fuel reservoir is now 0.75/3 or 0.25 cu.m.

Length of internal fuel reservoir will be 0.89 m. or 90 cm.

Summary

The proposed 60 cm. ID reactor (0.28 sq.m) will have an internal fuel reservoir capacity of 0.25 cu.m). Distance from reactor top to beginning of inverted cone is 90 cm. Rice hull fuel consumption will be 92 kg/hour (bulk density of hulls is 120 kg/cu.m). The reactor will require fueling every 20 minutes when 0.25 cu.m or 30 kg. of hull will have to be delivered to the reactor.

B. Gasifier Chemistry Calculations

Gas composition for low-Btu gas from hulls (% by volume):

CO	:	23.4
CO_2	:	8.9
H_2	:	13.2
N_2	:	48.9
CH_2	:	5.6

Carbon content of dry hulls: 39.26%

Carbon content as fired (10% moisture content) will be about 35%.

Calculation of Gas Production:

	Per 100 lb-mol Gas	lb-atom Carbon	lb-mol Hydrogen	lb-mol Oxygen
CO_2	8.9	8.9	-	8.9
CO	23.4	23.4	-	11.7
CH_4	5.6	5.6	11.2	-
H_2	13.2	-	13.2	-
H_2	48.9	-	-	-
N_2	48.9	-	-	-
TOTAL	100.00	37.9	24.4	20.6

100 lb-mol gas contains 37.9 lb-atom C

Carbon gasified per hour:

Loose hulls fired to gasifier: 92 kg/hr (for one reactor)

200 kg/hr. at 35% carbon (this is the feed rate for one of the two proposed gasifiers)

Carbon to gasifier: $\frac{0.35 \times 200}{12}$ = 5.9 lb-atom

Carbon withdrawn in char (from UP test data)

Carbon content of char: 35%

Char production: 30% of feed rate

$$\frac{0.3 \times 200 \times 9.35}{12} = 1.75 \text{ lb-atom}$$

Carbon content of low-Btu gas and tars:
5.9 - 1.75 = 4.08 lb-atom

Carbon in tar fraction (from UP test data)

Tar production: 10% of feed rate

Carbon content of tar: 80%

$$\frac{0.1 \times 200 \times 0.8}{12} = 1.33 \text{ lb-atom}$$

Carbon content of low-Btu gas: 4.08 - 1.33 = 2.75 lb-atom

Dry gas made per hour $\frac{2.75 \times 100}{37.9} = 7.25$ lb-mol

385 x 7.25 = 2790 scfh. or 46 scfm. per reactor

Calculation of combustion air required by one reactor (nitrogen balance):

Nitrogen in gas per hour: $\frac{7.25 \times 48.9 \text{ lb-mol}}{100}$

Dry air supplied per hour: $\frac{7.25 \times 48.9 \times 385}{100 \times 0.79} = 1728$ scfh.

= 30 scfm. per reactor

NOTE: Selection of gasifier combustion air blower:

Theoretically, a blower of capacity 60 scfm would be sufficient. Purchase one of capacity 100 scfm. and 1 psi.

C. Cyclone Design

Gas flow into cyclone: 46 scfm.

Conditions at cyclone entry: 800°F and 20 inches w.g. (0.7 psig)

Converting gas flow to acfm (V2)

$$V2 = \frac{1260}{520} \text{ (°R)} \times \frac{14.7}{15.1} \text{ (psia)} \times 46 = 108 \text{ acfm}$$

Using a cyclone of 10 inches diameter, the inlet area of cross section of 0.087 ft^2

$$\text{Inlet velocity} = 108 \text{ ft}^3/\text{min.} \times \frac{1}{0.087 \text{ (ft}^2\text{)}} \times \frac{1}{60} = 20 \text{ ft/sec.}$$

D. Steel Selection and Wall Thickness Calculations

i) Pressure

A design pressure of 15 psig will be used, and the reactor vessel will be designed to meet ASME Section VIII specifications.

ii) Temperatures

The lower portion of the reactor shell is lined, internally, with refractory. The upper portion of the shell and the section below the grate are not lined but will not be exposed to the temperature extremes of the reaction zone around the air inlet. The shell has ambient air on its outside skin. A design temperature of 650°F will be used.

iii) Material Selection

Use medium carbon steel pressure vessel plate, SA 285 Grade C, 515 or 516 Grade 70 (40345/lb.)

iv) Wall Thickness Calculations

For design pressure, corroded condition

$$t = \frac{PRi}{SE - 0.6\ P} \quad \text{where}$$

$$P = 15\ \text{psi}$$

Design Temperature: 650°F

Diameter, D: 28 inches

Material (SA515/516) S = 17500 psi (at 650°F) E = 0.7

Corrosion Allowance: 0.075 inches

$$t = \frac{15 \times 14}{(17{,}500 \times 0.7)} - (10.6 \times 15) + 0.075$$

t min. = 0.0921 inches (use 10 gauge material 0.1345 inches th.)

Maximum allowable working pressure for 10 gauge material:

$$P = \frac{SE\ t}{Ri + 0.6\ t}$$

$$P = \frac{17{,}500 \times 0.7 \times 0.0345}{14 + (0.6 \times 0.1345)} = 117 \text{ psig}$$ (limited by flange joints)

Minimum thickness for a temperature excursion to 900°F at 900°F, S = 6,500 psi

$$t = \frac{15 \times 14}{(6{,}500 \times 0.7)} - (0.6 \times 15) + 0.075$$

t min. = 0.121 inches (we are using 10 gauge of thickness 0.1345 inches which incorporates a substantial FOS)

E. Selection of Bolts & Bolt Circles for Flanges

Top Head

$$\text{Area} = \frac{D^2}{4} = \frac{\times 28 \times 28}{4} = 615.75 \text{ in}^2$$

Internal Design Pressure: 15 psig

Force on Top Head: 15 x 615.75 = 9236 lb.

Stress Allowable for Standard Bolts: 5000 lb/in^2

Total Bolting Area Required: $9236 \times \frac{1}{5000} = 1.85\ in^2$

Perimeter Distance on Flange: 90 inches

Using 3 inch center, 30 bolts are required.

For 5/16 inch bolts:

$$\text{Bolting area} = 30\ \frac{(\pi \times (5/16)^2}{4} = 2.3\ in^2$$

A similar bolt pattern can be used for the intermediate and bottom flanges.

Gaskets: 1/4" thick soft asbestos x 3/4" wide.

F. Low-Btu Gas Burner Combustion Calculations

GAS COMPONENT	% BY VOLUME	S.G. OF COMPONENT	% OF S.G.	NET HHV OF COMPONENT	COMPONENT'S CONTRIBUTION
CO	23.4	0.0670	0.2263	321	75.11
CO_2	8.9	1.5194	0.1352	-	-
H_2	13.2	0.0696	0.0092	273	36.04
O_2	-	1.1047	-	-	-
N_2	48.9	0.9672	0.4730	-	-
CH_4	5.6	0.555	0.0310	911	51.02
					162.2

Specific gravity of low-Btu gas: 0.8747

Net heat of combustion: 162.2 Btu per cuft.

Net heat of combustion of air/fuel mixture:

$$\frac{162.17}{1 + 1.41} = 67.3 \text{ Btu per cuft.}$$

Air: Fuel ratio by volume for perfect combustion is 1.41:1)

Gas Density (Dg) = 0.8747 x 0.0764
= 0.0668 lb. per cu.ft.

Density of air/fuel mixture:

$$\frac{(1.41 \times 0.0764) + (1.0 \times 0.0668)}{2.41} = 0.0724 \text{ lb. per cu.ft.}$$

Converting air/fuel ratio by volume to air/fuel ratio by weight:

$$\frac{1.41 \times 0.0764}{0.0668} = 1.61$$

CORRECTION FACTOR FOR SATURATED GAS (F)
(gas exiting scrubber tower)

$$F = \frac{520}{460\ t} \times \frac{P - Wp}{30 - Pt}$$

t = gas temperature = 90°F

P = total gas pressure, assume a value of 0.5 psig
= 30.95 inches Hg. (abs.)

Wp = water vapor pressure for saturated gas at 80°F
= 1.422 inches Hg.

Pt = water vapor pressure for saturated air at 60°F
= 0.53 inches Hg.

$$F = \frac{520}{460 + 90} \times \frac{30.95 - 1.422}{30 - 0.53}$$

$$F = 0.98$$

Air/fuel ratio by weight corrected for saturated gas:

$$0.98 \times 1.61 = 1.58$$

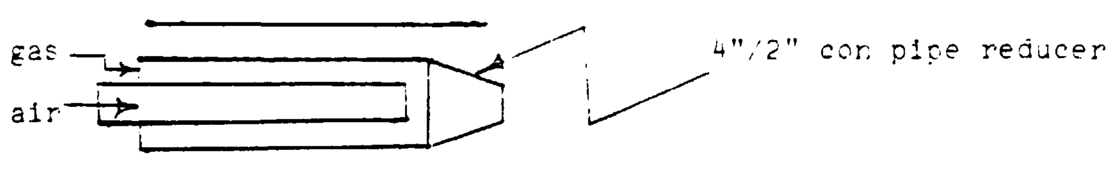
From fluid flow considerations, the air/fuel ratio by weight is connected to the cross sectional areas of the air and fuel orifices by the following formula:

$$1.58 = \frac{A\ (air)}{A\ (gas)} \quad \frac{D\ (air)}{D\ (gas)}$$

D (air) = 0.0764 lb. per cu.ft.

D (gas) = 0.0668 lb. per cu.ft.

A (air) = 1.6 A (gas)



Gas Orifice Nozzle: 2 inches diameter BI pipe
(OD = 2.375, ID = 2.067)

Outside Cross Sectional Area: $\frac{\pi D^2}{4}$ $\frac{(2.375)^2}{4}$

$= 4.43 \text{ inches}^2$

Inside Cross Sectional Area: $\frac{\pi D^2}{4}$ $\frac{(2.067)^2}{4}$

$= 3.36 \text{ inches}^2$

AREA OF AIR ANNULUS:

OD 7", area $\frac{D^2}{4}$, $\frac{49}{4}$ = 38.48 inches^2

ID (2" pipe) 4.43 inches^2

Effective area 28.48 - 4.43 = 34.05 inches^2
(excludes pre-mixed air from center 2 inch pipe)

Minimum required area for air inlet is:
1.6 x area of gas orifice = 1.6 x 3.36
= 5.38 inches^2

We have an effective air annulus area of 34 inches^2!!!

Proposed gas flow to furnace: 46 scfm per reactor,
total of 92 scfm.

Conditions at gas burner: 90°F and 4 inches w.g. (estimate)

Converting gas flow to acfm (V2)

$$V2 = \frac{550}{520} \times \frac{14.7}{14.9} \times 92 = 96 \text{ acfm}$$

Required air supply to burner (perfect combustion)

1.41 x 96 = 136 acfm
(use 15% excess air, 150 acfm)

Estimate of energy delivered to the furnace:

92 scfm x 60 x 162.2 (Btu per cu.ft.)
= 900×10^3 Btu/hr.

APPENDIX 6

ADDITIONAL DUTIES

The following additional tasks were undertaken by the consultant:

- Design of Feeder for a Pyrolysis Reactor

A feeder screw auger was designed for use with a rice hull pyrolysis reactor currently being tested at PNOC-ERDC. The feeder uses the principle of a tube auger in which the pitch of the flights is progressively reduced from the feed to the discharge end. This causes the feed (rice hulls) to form a "plug" inside the auger preventing back-flushing of gas from inside the reactor out to atmosphere.

- Investigation of Rice Hull Briquettor

During a demonstration of the briquettor, two sacks of rice husks were converted to briquettes. The operators experienced some difficulties starting the machine - a matter of waiting for the temperature of the heating element to stabilize.

The machine employs a screw auger to subject the husks to high pressures and elevated temperature (a result of friction). Under these conditions, the lignin solubilized, the husks loose their structure and fuse together in a homogenious mass. Moisture content plays a key role in this fusion and needs to be within carefully controlled limits. During the demonstration, rice husks from an alternative source would not briquet due to incorrect moisture content. A layer of about 1/16 inch thickness around the outside of the briquetted materials is charred by the application of heat to the die following discharge from the auger. This increases the strength of the briquette and promotes discharge by reducing friction between the outer surface of the briquette and the die walls.

The machine capacity is 100 to 110 kg/hr. (about 240 lb/hr.). If used for a gasifier-engine-generator application, such a quantity of fuel, has the potential to deliver 125 HP at the engine shaft. (Using a figure of 7050 Btu/lb for the husk briquettes as reported in the company literature). The briquettor will, itself, consume 10 to 15% of this quantity of power.

For combustion application, (furnace or boiler), if all the product from the briquettor is fired, this could potentially generate 1.4 million Btu/hr. Energy consumed by the briquettor, itself, is equivalent to 50,000 Btu/hr. (3.6%).

In the following table, the cost of briquetted rice hulls is compared with conventional fuels using the common unit of US$/Million Btu. All prices are for delivered fuel. Information was obtained from the following sources:

Fuel Oil:	PNOC Pandacan Laboratory
Coal:	PNOC Coal Corporation
Wood and Charcoal:	Price available to the public in Manila

Due to problems with ignition and odors generated during combustion. The briquetted hulls will not compete with wood or charcoal in the domestic market. An industrial consumer might be able to obtain wood and charcoal at prices lower than those quoted.

Cost of the briquetted hulls was determined from the economic analysis. Selling price for the briquettes assumes that the manufacturer only covers his operating cost. No profit or overhead is included.

	COST	HEATING VALUE	$/MILLION BTU
Bunker fuel*	P3.5/liter	18,000 BTU/lb	6.57
Coal	P800/MT	10,000 BTU/lb	2.60
Wood	P3/kg	6,800 BTU/lb	14.32
Charcoal	P5/kg	11,786 BTU/lb	13.77
Briquetted ricehulls	P0.34/kg	6,181 BTU/lb	1.79

*bunker C

specific gravity = 0.9529 - 0.9652
price on site = ₱ 3.404/liter
warfage = 0.009/liter
delivery charge = 0.0418/liter
with pump = 0.01/liter

₱ 3.4648/liter

Minimum delivery of 10,000 liters costs ₱34,572

ECONOMIC ANALYSIS: BRIQUETTED RICEHULLS

I. CAPITAL COST

A. Equipment cost (C) = ₱67,500

₱67,500 may be obtained through loan from commercial and industrial banks extending big loans for industrial purposes.

B. Interest rate (i) = Prime rate + 5%

Interest rate for short term loans is 18% (prime rate) + 4%.
Interest rate for long term loans is 18% (prime rate) + 5%.

C. Term (n) = 5 years

Short term loans are payable in one year. Long term loans are payable in more than one year to 15 years (maximum).

D. Monthly amortization (MA)

$$MA = \frac{C * (i/12)}{1 - (1 + i/12)^{-(n * 12)}}$$

$$= \frac{₱67,500 * (0.23/12)}{1 - (1 + 0.23/12)^{-(5 * 12)}}$$

$$= ₱1,902.86/month$$

II. POWER CONSUMPTION

A. Motor

Specifications: Size = 15 hp
Efficiency = 90%

Number of operating hours: 8 hours/day, 22 days/month
Cost of electricity: ₱1.075/kwh

$$15\ hp * 0.746 \frac{kw}{hp} * \frac{1}{0.90\ (eff)} * \frac{8\ hr}{day} * 22\ \frac{days}{month} * \frac{P1.07}{kwh}$$

= ₱2,352.40/month

B. Heater

Specifications: Size = 4 kva
Power factor: 0.8
Number of operating hours: 8 hours/day, 22 days/month
Cost of electricity: ₱1.075/kwh

4 kva * 0.8 = 3.2 kw

$$3.2\ kw * \frac{8\ hours}{day} * \frac{22\ days}{month} * \frac{₱1.075}{kwh}$$

= ₱605.44/month

III. MAINTENANCE COST

Maintenance costs about US$0.1744/100 kgs. Equipment operates at a maximum capacity of 110 kgs/hour. However, assumption is such that equipment actually operates at 100 kgs/hour.

$$\frac{US\$0.1744}{100\ kg} * \frac{100\ kg}{hr} * \frac{8\ hours}{day} * \frac{22\ days}{month} * \frac{P14}{\$}$$

= ₱429.72/month

IV. LABOR COST

Minimum wage for semi-skilled laborers is P30/day.
Number of days of operation = 22 days/month

$$\frac{₱30}{day} * \frac{22\ days}{month}$$

= ₱660/month

V. FUEL COST

Unit will be installed on-site (ricemill), therefore fuel is to be obtained free of charge.

COST AND PROFITABILITY STUDY

I. COST OF PROJECT PER MONTH

A.	Monthly amortization	₱ 1,902.86
B.	Power cost =	2,957.84
C.	Maintenance cost =	429.72
D.	Labor cost =	660.00
E.	Fuel cost =	-
		₱ 5,950.42

II. NOTES AND ASSUMPTIONS TO PROFIT AND LOSS ANALYSIS

BREAK-EVEN POINT

1. At average capacity of 100 kg/hr (operating at a rate of 8 hours/day, 22 days/month), a total of 17,600 kg briquetted rice hulls can be produced.

$$\text{Selling price} = \frac{₱\ 5950.42}{17,600\ kg}$$

$$= ₱\ 0.34/kg$$

Other tasks included delivering a lecture on the commercial application of gasifier technology, particularly retrofit of steam boilers, and advise on the conversion of diesel engines to dual fuel operation.