1. PRODUCER GAS FROM INDIGENOUS SOLID FUELS
2. CONVERSION OF OIL-FIRED BOILERS TO UTILIZE SOLID FUEL

Foreword

by Edwin N. Quiros
Department of Mechanical Engineering
University of the Philippines Diliman

The following two papers by Dr. Ibarra E. Cruz describe experimental results of solid fuel gasification research conducted in the M.E. Department in the early seventies. This was a time when the effects of the Arab oil embargo and the energy crisis jolted the country into a frantic search for alternative and local sources of energy to attain some measure of energy security.

In the first paper, gasification of coconut shells, coir dust, and ipil-ipil wood chips were conducted using a gas producer design that allowed operation either as a downdraft or updraft reactor. This design feature was conveniently used to compare the performance of the updraft and downdraft gas producer in terms of operating characteristics and gas quality produced, specifically CO, CO_2, and H_2 content. Three gas producer sizes ("small", "medium", "big") of increasing grate area and fuel feed rate were built and tested. Results of the experiments indicate the updraft reactor yielded higher CO and lower CO_2 than the downdraft reactor. Higher H_2 content in the gas was obtained with the downdraft reactor. No operational difficulties from clinker formation were experienced with the small and medium size reactors. This was attributed to gasification rates being equal to or less than 40 (lbs/hr)/ft.^{2} grate area. The big gas producer operated as an upward reactor, with gasification rates of about 80 (lbs/hr)/ft.^{2} grate area, encountered heavy formation of dense and hard clinker on the grate which blocked air passage and eventually stopped operation. Saturation of the air supply with water during updraft reactor operation produced lighter clinker which was broken by occasional poking of the grate bed with a rod thus allowing uninterrupted gas production. It is believed that problems from clinker formation could be lessened by operating the gas producer as a downdraft reactor.

The second paper presents results of an attempt to convert a 100-hp oil-fired steam boiler to gaseous fuel produced from coconut shells. An updraft gas producer of 10-ft.^{2} grate area, piping, and two gas burners were built and fabricated for the purpose. Steam generated was used to drive a high-speed (1200 rpm), 3-cylinder steam engine coupled to a 50-kW electric generator with a water rheostat load. An initial run at 40 (lbs/hr)/ft.^{2} grate area gasification rate, air blast above the grate, and using one blower encountered intense burning and clinker formation at the air inlets eventually blocking air passage. High pressure drop between the gasifier and boiler furnace piping resulted to a low gas delivery and thus, a low power output (7 kW). During a second run, use of two blowers connected in series together with a increased diameter (from 4" to 6") of the gas pipe to the boiler enabled higher power output from the boiler genset. The air blast was also introduced below the grate in this run which caused clinker formation on the grate prematurely interrupting gasifier operation. A third run introduced water with the air blast under the grate resulting into a friable clinker formation. Together with vigorous manual poking of the bed during fuel charging, clinker formation became manageable enabling higher gasification rates (about 84 lbs/hr/ft.^{2} grtae area) and a steady steam engine-generator load of 35 kW. Overall, the use of gasification was partially successful. Clinker formation presents a serious problem at high gasification rates without addition of water or steam in the air blast.

PRODUCER GAS FROM INDIGENOUS SOLID FUELS

Ibarra E. Cruz

1. INTRODUCTION

This is a progress report on the research project (NSDB-NIST-UP Project 7405-En) covering the period between February 1, 1974 and January 31, 1975. The author was the director and principal investigator of the project which was undertaken at the College of Engineering, University of the Philippines with the cooperation of the National Science Development Board (NSDB) and its agency, the National Institute of Science and Technology (NIST).

The objectives of the project were (1) to investigate the feasibility of gasifying various kinds of indigenous solid fuels, in particular agricultural solid wastes, and (2) to compare the performance of the updraft gas producer with that of the downdraft reactor when using agricultural solid wastes.

Aside from an existing experimental gas producer with a grate area of 1 ft^2 (0.1 m^2), two other experimental reactors were used with grate areas of 2.4 ft^2 (0.2 m^2), and 9.6 ft^2 (0.9 m^2) respectively.

2. EXPERIMENTAL

A medium size experimental gas producer was designed and fabricated by the U.P. Industrial Research Center under the close supervision of the project director and principal investigator. This had a grate area 2.4 ft^2 (0.2 m^2) and was convertible from updraft operation to downdraft by simply interchanging the air inlet and gas outlet connections. Fig. 1 shows some design details of the convertible gas producer.

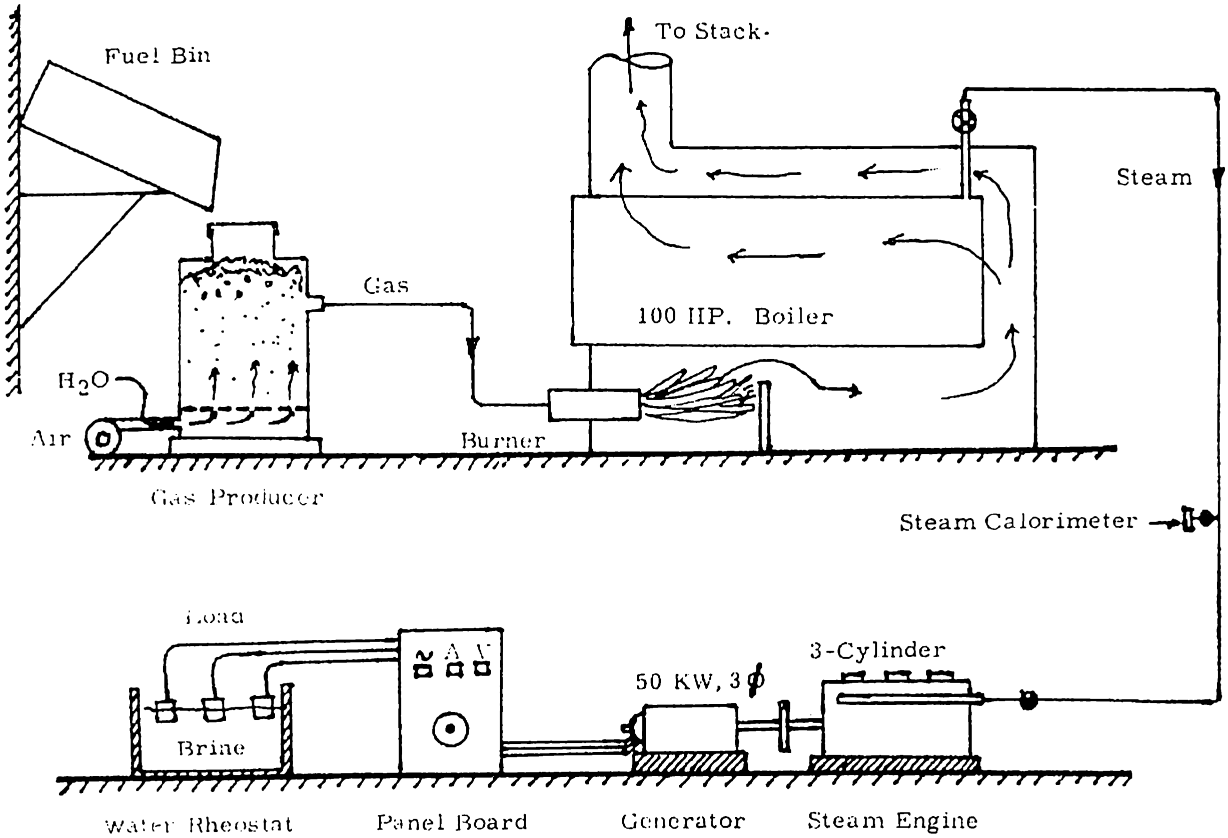

Fig. 1. Experimental lay-out in the conversion of an oil-fired boiler to producer gas-fired.

To compare the performance of an up-draft reactor with that of a down-draft reactor, the same fuel (ipil-ipil chips) [1] was used when operating

Dr. Ibarra E. Cruz is a Professor of Mechanical Engineering and Director of Graduate Studies, College of Engineering, University of the Philippines.

[1] In the case of downdraft operation some coconut shells were mixed with ipil-ipil but the results would not have been significantly if only one kind of either fuel had been used.

either in downdraft or updraft flows. Gas samples were analyzed, temperatures of the gas taken, and fuel feed rates measured. Data were evaluated in order to obtain a quantitative comparison between the performances of an updraft and a downdraft reactor.

When enough satisfactory experimental runs were made using the gas producer with a 2.4 sq.ft. grate area, a larger reactor was designed and fabricated. The grate area of the large gas producer is 9.6 sq. ft. Fuel used in initial experimental runs was coconut shells. Again gas samples were taken and analyzed and fuel rates measured. Evaluation of performance included the observation of any formation of clinker on the grate with and without saturating the air blast with moisture.

3. RESULTS AND DISCUSSIONS

Fig. 2 shows in graphical form the results of gas analyses and temperature measurements comparing the performance of the gas producer as an updraft reactor with the performance in a downdraft operation. The measurements in each case were carried out over a period of approximately 4 hours, from the time the reactor was charged full of fuel to the time when it was nearly empty at a fuel rate of 20 to 25 lbs./hr./ft.^{2}. As predicted by theory, the gas quality in the updraft operation was better than that of the downdraft. This is indicated in Fig. 2 by a higher CO content and a lower percentage CO_2 in the updraft compared with the downdraft. Also the temperature variation in the time between fuel chargings tended to be more pronounced in the downdraft operation compared with that of the updraft operation.

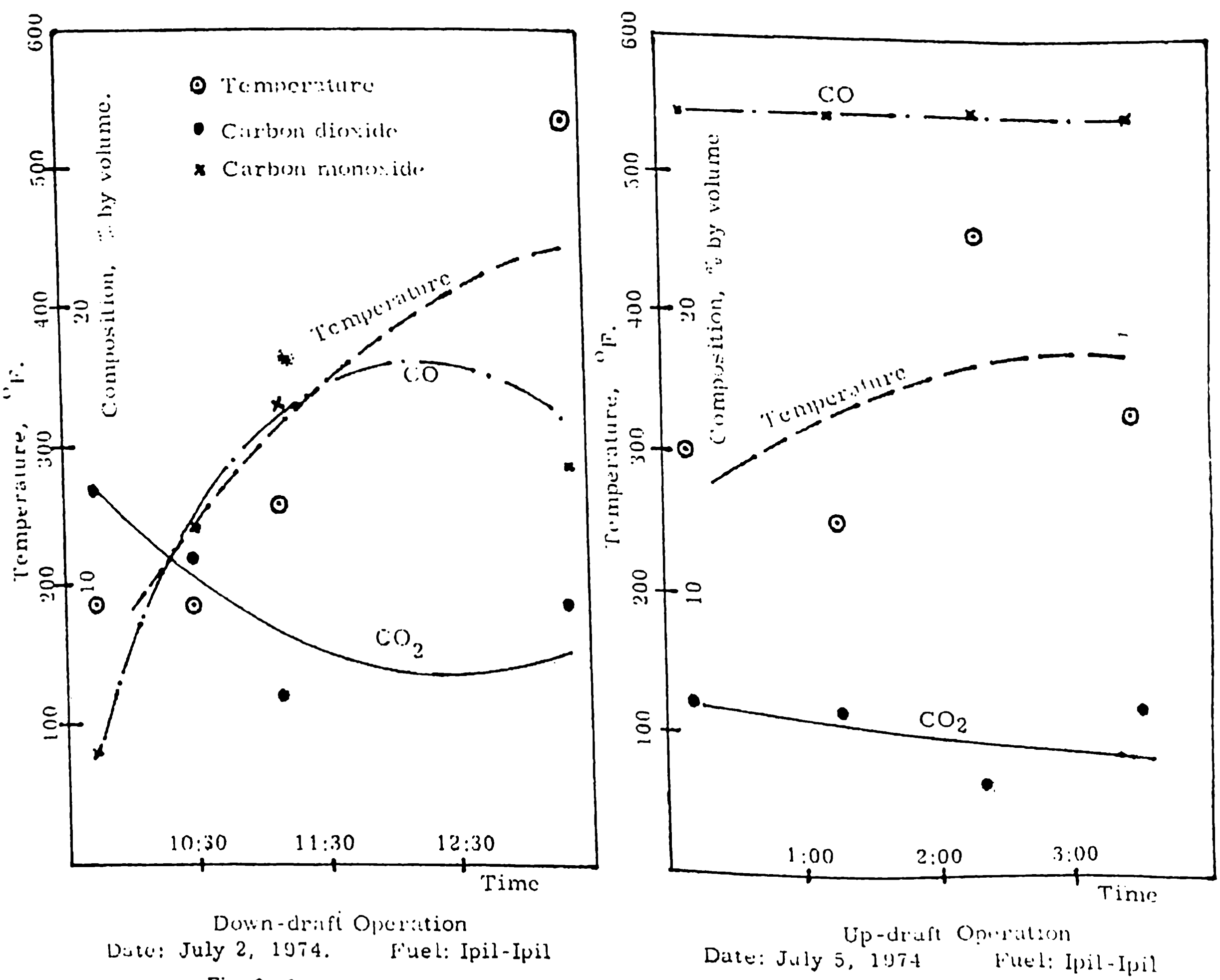

Fig. 2. Comparison between down-draft and up-drapt producer gas composition and temperature.

Fig. 3 shows the schematic diagram of the fuel bed in an updraft reactor compared with that in a downdraft producer.

Conventionally, the producer gas fuel bed is divided into three zones aside from the ash zone which is immediately adjacent to the grate: (a) the combustion zone where the oxygen of the air is depleted as it reacts with carbon; (b) the reduction zone where the CO_2 is reduced to carbon monoxide in the Boudouard reaction; and (c) the distillation zone where the volatile products of the raw fuel which includes tar and liquor (mostly H_2O) are distilled off.

In the updraft operation, the distillation zone is at the uppermost portion of the fuel bed and hence the distillation products including H_2O are passed up and out of the reactor without further reacting with the fuel.

In the downdraft reactor, the distillation zone is still in the uppermost portion of the bed, but located above and adjacent to the combustion zone which establishes itself in the immediate vicinity of the inlet air. Since the gases are in a downdraft flow, the distillation products have the opportunity to react further with the rest of the fuel bed. Thus the H_2O can be reduced to form CO and H_2 in the reduction zone. This can also serve the purpose of controlling clinker formation instead of introducing steam with the air. Too much H_2O however, passing through the combustion and reduction zones can chill the bed and hence retard completion of the desirable reactions.

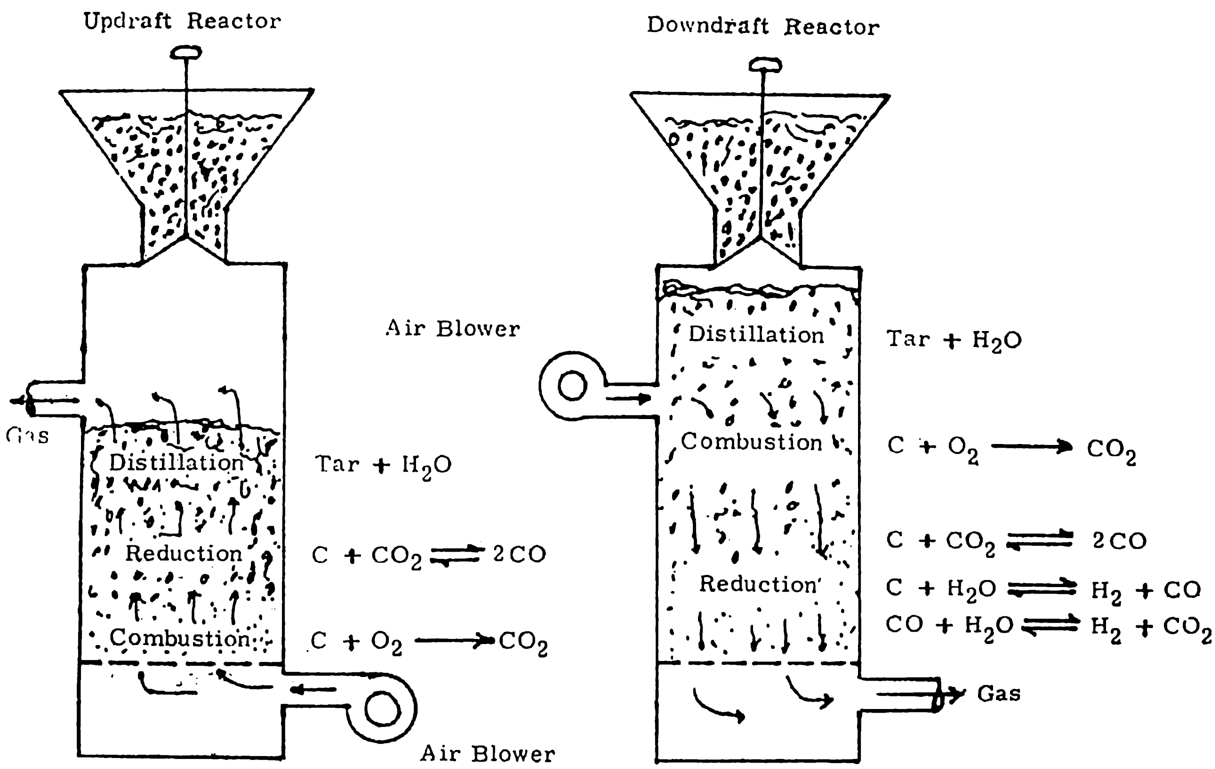

Fig. 3. Two types of gas producers.

Table 1 shows typical analyses of producer gas sample taken during some experimental runs conducted during 1974. It shows comparative performances of three different gas producers (in effect four different reactors) using several kinds of fuel or blends. Again, it would appear that the updraft reactor produces somewhat better quality gas than the downdraft reactor considering that the CO content in the updraft was always above 20% and the CO_2 less than 10%, while in the downdraft reactor the CO was less than 20% and the CO_2 more than 10% in most cases. It must be noted however that, generally, the H_2 content in the downdraft operation was higher compared to the updraft operation, which was to be expected since more H_2O was being reduced to form H_2 in the case of the downdraft reactor.

TABLE I

Typical Gas Analyses of Samples Taken During Some Experimental Runs.

Date	*Type of Producer**	*Fuel*	*Dry Gas Analyses, %* CO_2	O_2	CO	H_2	CH_4	*Fuel Rate* *kg/hr.*	*lb/ft²/hr*
2/26/74	SUD	Coal	12	1	14	19	1		
3/6/74	MDD	Coco	6	3	17	7	1		
5/14/74	MDD	Coco	20	2	8	5	3		
5/24/74	MDD	Ipil	9	1	19	12	—		
5/29/74	MDD	Ipil	9	4	15	6	—		
6/10/74	MDD	Coco	12	2	12	9	—	40	36
6/13/74	MDD	Coco	17	2	8	14	—	30	29
6/17/74	MDD	Ipil-Coco	14	1	7	23	—	40	37
6/19/74	MDD	Ipil	13	1	14	18	—	20	19
7/2/74	MDD	Ipil-Coco	9	3	14	7	—	23	21
7/5/74	MUD	Ipil	6	2	27	5	—	26	24
7/6/74	MUD	Coir-Dust-Coco	9	5	16	7	—	20	18
7/27/74	MUD	Ipil	7	3	24	8	—	24	22
8/16/74	MDD	Ipil	10	3	12	5	—	36	33
8/27/74	MDD	Ipil	13	0	14	6	—		
11/22/74	BUD	Coco	8	0	27	13	1	176	40
12/17/74	BUD	Coco	7	0	26	11	1	339	78
12/27/74	BUD	Coco	3.6	0.4	22	7.6	0.1	366	84

* SUD — small updraft producer, 1.1 ft² grate area
MUD — medium updraft producer, 2.4 ft² grate area
MDD — medium downdraft producer, 2.4 ft² grate area
BUD — big updraft producer, 9.6 ft² grate area

In all operations of the small and medium size gas producers, no trouble was encountered as far as clinker formation was concerned even without the introduction of steam with the air blast.[2]

The fact that gasification rates were not too high, seldom nearing 40 lbs/hr/sq.ft. of grate area, might explain this clinker-free operation. The big gas producer, operating as an updraft reactor at gasification rates of about 80 lbs/hr/sq.ft., exhibited heavy clinker formation on the grate. This eventually blocked the air passages in the grate and stopped production of gas. The clinker formed was dense and hard to break.

In a subsequent experimental run, water was introduced with the air blast to saturate it with moisture. Heavy clinker was still encountered although this was lighter and could be broken when the bed was poked with a rod. This made possible the passage of air through the grate after breaking up the clinker and thus gas production was mostly uninterrupted during a whole-day experimental run.

Better control of clinker formation, can be achieved by addition of steam in the air blast. It is the opinion of the author, however, that operation of the gas producer as a downdraft reactor will satisfactorily control clinker formation even without the addition of steam. This remains to be seen in future experimental runs.

4. CONCLUSIONS:

1. The updraft gas producer appear to produce better quality gas than the downdraft reactor.
2. In the medium size gas producer (2 sq. ft. grate area), there was no observable clinker formation when gasifying coconut shells or ipil-ipil chips at rates of less than 40 lbs/hr/sq.ft. of grate area, even without addition of steam to the air blast.
3. In the big updraft gas producer (10 sq. ft. grate area) the problem of ash clinkering was serious.
4. Solution to the problem of clinker formation is addition of steam to the air blast but better results might be achieved by operating the gas producer as a downdraft reactor.

5. ACKNOWLEDGEMENT.

The author acknowledges the support given by the National Science Development Board in the form of a research grant for this project.

6. REFERENCE.

"Producer Gas From Coconut Shells and from Coir Dust"—by I.E. Cruz, E.P. Dimagiba, and E.B. Garcia, U.P. Engineering Research Journal, July, 1972, Vol. I, Nos. 1 & 2, pp. 1-10.

[2] Only when coal was used was steam mixed with the air blast. In cases when steam was not introduced, heavy clinker formed on the grate.

CONVERSION OF OIL-FIRED BOILERS TO UTILIZE SOLID FUEL

Ibarra E. Cruz*

1. *Introduction.*

This study has been made with the objective of establishing the feasibility of converting oil-fired boilers to utilize indigenous solid fuels and to accumulate boiler operation data using these substitute fuels for oil.

There were two approaches considered: (1) the design and fabrication of a powdered fuel burner to burn powdered fuel (e. g. coir dust) directly in the boiler furnace, and (2) gasify the solid fuel in a gas producer, then pipe and burn the gas in the boiler furnace.

The latter scheme was chosen since it involved the least physical change that must be made in the boiler furnace and the least damage to the boiler in case the study proved unsuccessful.

The project (NSDB-NIST-UP Project 7408 En) was supported by the National Science Development Board and was undertaken at the College of Engineering, University of the Philippines. The project director was Dr. Ruben A. Garcia, the project leader and principal investigator was the author. The 100-hp steam boiler of the Department of Mechanical Engineering was used in this project.

This progress report covers the period from February 1, 1974 to January 31, 1975.

2. *Experimental.*

The technique adopted in converting a 100-hp, oil-fired steam boiler (Gabriel horizontal fire-tube boiler) to utilize indigenous solid fuel was to gasify the solid first in a gas producer and then to release the heat by combustion through two gas burners installed in the boiler furnace.

An updraft gas producer of 10 sq. ft. grate area and two gas burners were designed and fabricated by the U.P. Industrial Research Center under the close supervision of the Project leader and principal investigator. When initial tests showed that the updraft reactor could produce good quality gas and that the locally designed and fabricated burners could burn the gas successfully, three experimental runs, each lasting the greater part of a working day were made.

The experimental run consisted of producing gas in the updraft reactor using coconut shell as fuel, weighing the fuel as it was charged into the reactor. The producer gas was conducted through approximately 80 feet of 6-inch pipes with 8 corner bends to the two gas burners installed at the boiler, where the gas was burned by a pilot flame of ignited pieces of wood inside the furnace. Steam was raised to a pressure of 80 to 100 psig and this was used to run a 3-cylinder, high-speed (1200 RPM) Spillingwerk steam engine, directly coupled to a 50 kilowatt, 3-phase electric generator. Load on the generator was provided by dissipating energy in a water rheostat.

Fig. 1 shows a schematic diagram of the experimental lay-out. Fig. 2 is the schematic diagram of the producer gas burner. (The burner uses high velocity air to induce the fuel gas and additional primary air for combustion). During the runs samples of producer gas and boiler stack gas were taken and analyzed, temperatures measured, and voltage, and current supplied to the water reheostat

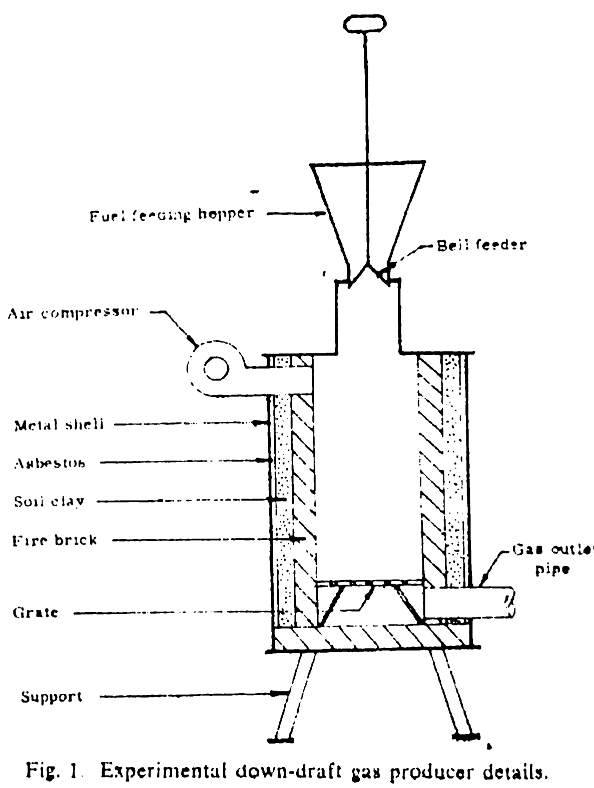

Fig. 1 Experimental down-draft gas producer details.

* Professor of Mechanical Engineering and Director of Graduate Studies, College of Engineering, University of the Philippines.

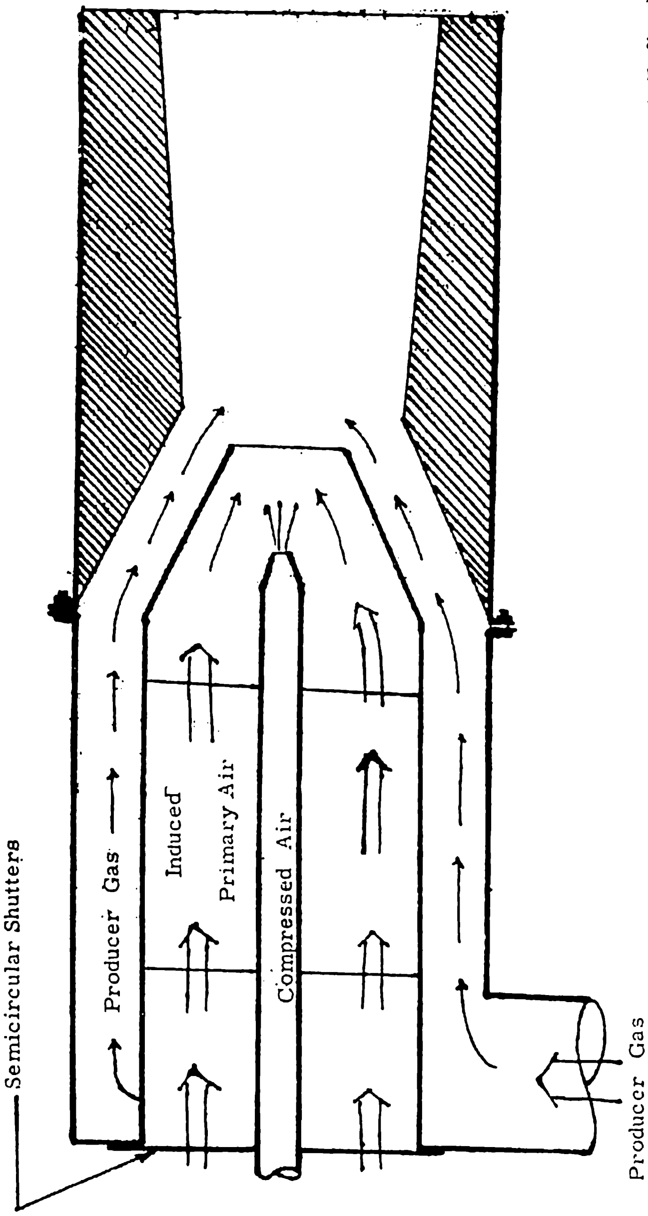

Fig. 2. Schematic diagram of producer gas burner.

recorded. After each run, the grate was examined for any formation of clinker. Three experimental runs were conducted respectively on November 22, December 17, and December 27, 1974.

3. *Results and Discussion*

Appendices 1, 2, and 3 summarize the data obtained during Runs (1), (2), and (3) on November 22, December 17, and December 27, 1974 respectively.

A comparison of the fuel feed rates shows that Run (3) was conducted at the highest gasification rate (84 lbs/hr/sq. ft.) followed by Run (2) at 78 lbs/hr/sq. ft. Run (1) at 40 lbs/hr/sq. ft. had a rate half as much as Runs (2) and (3). These rates are consistent with the time (measured in each run) required to raise steam from cold feedwater to dry saturated at 90 psig. Thus, it took 142 minutes to raise steam to 90 psig in Run (1), 85 minutes in Run (2), and 78 minutes in Run (3). The measured time included only the period during which gas was being burned in the furnace and did not include the time spent for charging fuel into the producer, during which gas production was temporarily stopped in order to make charging more convenient.

Only one blower of low static pressure was used in Run (1). Although the blower was rated at about 1000 CFM, the high pressure drop in the pipe lines between the producer and the gas burners at the boiler prevented the blower from delivering its rated capacity. As a consequence, only enough gas was produced to sustain a steady load of about 7 kw.

To counteract the high pressure drop in the pipe lines, a two-stage blower was improvised in which the low pressure blower was connected to supply air to the inlet of a second high pressure blower. This improvisation worked fairly well as shown in the results of the succeding two runs, since enough gas was produced for a steady load of about 25 to 35 kilowatts.

Computations show that the 100 hp boiler should be able to raise enough steam to drive the steam engine-generator set at the rated capacity of 50 KW, with the present gas producer, if enough air can be supplied to the reactor for it to produce about 700 CFM of gas. This corresponds to an airblast of about 500 CFM and a gasification rate of 100 lbs/hr/sq. ft. grate area.

In Run (1), the airblast was introduced several inches above the grate for the reason that this would not subject the grate to very severe temperature if a layer of non-burning fuel could separate it from the combustion zone. What happened however was that intense burning occurred right at the mouth of the airblast inlets (there were four inlets) and clinker formed and adhered to the inlets, eventually blocking the passage of air. Furthermore, channeling in the fuel bed occurred frequently.

In Run (2), the grate was raised above the airblast inlets so that air now passed under the grate and up through the reactor bed in a more uniform distribution. When the grate was examined after this run was terminated prematurely in the afternoon of December 17, 1974, heavy clinker formation was found on the grate which blocked the passage of air. The clinkers formed were hard, dense and cannot be easily broken.

Clinker formation in gas producers can be controlled by the addition of steam in the airblast. Water, however may also be used to saturate the airblast with moisture, and since this was more convenient to do compared with installing a steam line, Run (3) was conducted with water injected with the airblast under the grate. Thus, the experimental Run (3) on December 27, 1974, from 8:00 A.M. to 4:00 P.M., was not interrupted by clinker trouble. As a further precaution however, the fuel bed was poked vigorously by a steel rod during every fuel charging operation, so that whatever clinker might have formed would be broken up. When the run was over and the grate was later examined, clinker formation was still found to be present but the clinker this time was friable and easily broken up.

A very likely way of effectively controlling clinker formation is by operating the gas producer as a downdraft reactor In a downdraft reactor, the uppermost section of the fuel bed is the distillation zone, next in the descending order is the combustion zone which fixes itself in the vicinity of the airblasts followed by the reduction zone, and finally the ash zone on the grate. Since the ash zone is far removed from the combustion zone (unlike in an updraft reactor where the ash zone is adjacent to the combustion zone) it stands to reason that clinkering will be less likely to occur. Furthermore, since the volatile matter, including tar and liquor, passes down from the distillation zone to the combustion zone, this can effectively lower the temperature in the latter zone and thus help control clinker formation without depending on steam in the airblast.

Succeeding experimental runs will aim at finding out whether this theory will hold.

4. *Conclusions*

(1) The conversion of a 100-hp boiler to utilize producer gas from a reactor of 10 sq. ft. grate area is a partial success in that a steady steam engine-generator load of 35 KW was maintained for some 5 hours of operation.

(2) Clinker formation on the grate was a serious problem at a gasification rate of 80 lbs/hr/sq. ft. grate area, with airblast alone (without steam) as the gasification medium.

(3) Clinker control was partially successful by saturating the airblast with moisture, since the clinkers formed were friable and could be broken up by rodding the fuel bed down to the grate.

(4) Theory predicts that a more likely way of controlling clinker formation is by downdraft operation of the gas producer; however this must yet be experimentally demonstrated.

5. *Acknowledgment*

The author acknowledges the support given by the National Science Development Board in the form of a research grant for this project.

Appendix 1

EXPERIMENTAL RUN (1) ON NOVEMBER 22, 1974

I. *System Conditions*:

A. One blower was used connected to an air blast duct of four inches diameter.

B. The grate was located about 6 inches below the air inlet ports thus introducing the air blast above the grate.

C. Feeding of fuel (coconut shell) was manual.

D. Gas feeding at the boiler was controlled by means of separate valves for each burner.

E. Furnace air inlet ports were kept fully open at start-up and reduced gradually as the furnace heated up.

F. Steam pressure was allowed to build up to 90 psig in 142 minutes (from the moment gas was ignited in the furnace) before steam engine start-up.

G. Fuel feed rate (coconut shell) into the gasproducer was on the average 176 kg/hr/sq. ft. or 40 lbs/hr/sq ft. of grate area.

II. *Producer Gas Analysis and Temperature:*

Time	%CO_2	%O_2	%CO	%H_2	%CH_4	Temp. °F
9:02 A.M.	13.2	1.2	22.0	11.2	0.2	155
9:27 "	9.6	0.2	24.4	13.8	1.1	210
9:37 "	8.6	0.0	25.4	13.0	1.2	250
10:24 "	9.8	0.0	26.0	13.0	0.9	270
10:53 "	8.2	0.0	26.6	13.4	1.2	220
11:20 "	7.6	0.2	26.8	13.4	1.3	320
11:47 "	4.8	0.2	25.8	8.8	0.9	460
12:10 P.M.	8.6	0.0	25.8	5.4	0.7	200

EXPERIMENTAL RUN (1) ON NOVEMBER 22, 1974

III. *Boiler Stack Gas Analysis and Temperature*

Time	%CO_2	%O_2	%CO	%H_2	%CH_4	Temp. °F
9:34 A.M.	13.6	5.8	1.0	—	0.0	446
10:30 "	6.8	13.2	1.2	0.0	0.0	395
11:00 "	9.2	10.4	0.4	0.0	0.0	419
11:30 "	8.4	11.2	0.0	0.0	0.0	415
11:44 "	4.6	15.6	0.4	0.0	0.0	354
12:23 P.M.	2.6	12.4	2.4	0.0	0.0	400

IV. *Steam and Engine Load Conditions*

Time	Steam Conditions Press. psig	Steam Conditions % Quality	Inlet Temp.	Generator Load Conditions RPM	Amps	Volts	KW
10:45 A.M.	92	98	163	1120	80	232	32
10:56 "	70	99	155	1000	53	143	13
11:00 "	68	99	147	960	48	129	11
11:13 "	75	99	134	1050	36	121	8
11:25 "	80	98	132	1050	38	128	8
11:46 "	80	99	135	1050	35	116	7
12:18 P.M.*	72	99	132	985	36	120	7
12:33 "	73	98	133	1030	36	120	7
12:58 "	78	99	139	1060	40	129	9
1:15 "	71	99	135	970	36	117	7
1:56* "	85	98	136	990	34	115	7
2:21 "	80	100	139	1080	35	116	7
2:46 "	75	99	136	1025	35	117	7
3:01 "	65	99	133	975	30	102	5
3:06 "	55	99	132	990	0	0	0
3:09 "	Time shut down						

Appendix 2

EXPERIMENTAL RUN (2) ON DECEMBER 17, 1974

I. *System Conditions:*

A. Two blowers were used in series, and the air blast duct diameter increased to six inches from four.

* Batch feeding of fuel into the gas producer had just been completed at about the indicated time.

Appendix 2 (Continued)

B. The grate was raised two inches above the air inlet ports or a total of 3.5 inches above the air inlet port center line thus introducing the air blast below the grate for more uniform distribution.

C. Feeding was manual, aided by an overhead fuel hopper.

D. Gas feeding at the boiler was controlled by means of separate valves for each gas burner.

E. Furnace air inlet ports were kept fully open at start-up and reduced gradually as the furnace was heated up.

F. Steam pressure was allowed to build up to 90 psig in 85 minutes (from the moment gas was ignited and remained burning in the furnace) before engine start-up.

G. Fuel feed rate (coconut shells) into the producer was on the average 339 kg/hr or 78 lbs/hr/sq.ft. of grate area.

II. *Producer Gas Analysis and Temperature*:

Time	*%CO_2*	*%O_2*	*%CO*	*%H_2*	*%CH_4*	*Temp. °F*
10:50 A.M.	7.2	0.0	25.3	11.0	0.8	300
11:20 "	7.8	0.2	24.8	14.0	0.8	270
1:02 P.M.	8.6	0.0	25.0	7.2	0.4	200
1:25 "	4.4	0.0	14.4	5.8	0.8	210
1:40 "	4.6	0.0	26.8	12.4	0.0	350

III. *Boiler Stack Gas Analysis and Temperature*:

Time	*%CO_2*	*%O_2*	*%CO*	*%H_2*	*%CH_4*	*Temp. °F*
10:55 A.M	16.0	3.7	0.4	0.0	0.0	400
11:30 "	15.6	4.4	0.6	0.0	0.2	515
1:05 P.M.	13.2	7.2	—	—	—	450
1:30 "	16.4	3.8	0.4	0.0	0.0	470

EXPERIMENTAL RUN (2) ON DECEMBER 17, 1974

IV. *Steam and Engine Load Conditions*:

	Steam Conditions			*Generator Load Conditions*			
Time	*Press. psig*	*% Quality*	*Inlet Temp. °C*	*RPM*	*Amps*	*Volts*	*KW*
11:17 A.M.	95	99	161	1200	95	223	37
11:23 "	84	99	164	1200	111	219	42
11:28 "	71	100	165	1180	112	204	40
11:31 "	65	100	161	1150	105	190	35
11:37 "*	60	100	161	420	0	0	0
1:14 P.M.	74	99	160	1130	104	197	35
1:17 "	70	99	160	1120	98	181	31
1:22 "	58	99	155	1100	92	166	26
1:27 "	53	99	154	1100	94	163	27
1:32 "	50	99	153	1100	84	144	21
1:35 "**	50	99	151	1130	0	0	0
1:40 "	Engine shut down						

* Experimental run was stopped shortly after the indicated time and was resumed shortly after 1:00 P.M.

** Run was discontinued due to serious clinker build up on the grate which prevented free passage of the air blast.

Appendix 3

EXPERIMENTAL RUN (3) ON DECEMBER 27, 1974

I. *System Conditions*:

A. Two blowers were used in series, with an air blast duct diameter at six inches.

B. Water was added to the air blast in the gas producer by means of two 1/4" dia. injection tubes, each inserted into a separate air inlet port, controlled by water flow regulator.

C. The grate was kept at 3.5 inches above the air inlet port centerline, thus introducing the air blast below the grate.

D. Feeding was manual, aided by the overhead fuel hopper.

E. Clinkering was controlled by manual poking of the fuel bed in the vicinity of the combustion zone each charging time.

F. Gas feeding at the boiler was controlled by means of separate valves for each gas burner.

G. Furnace air inlet ports were kept fully open at start-up and reduced gradually as the furnace heated up.

H. Steam pressure was allowed to build up to 90 psig in 78 minutes (from the moment gas was burned in furnace) before engine start-up.

I. Fuel feedrate (coconut shells) into the producer was on the average 366 kg/hr or 84 lb/hr/sq. ft. of grate area.

II. *Producer Gas Analysis and Temperature*:

Time	% CO_2	% O_2	% CO	% H_2	% CH_4	*Temp.* °F
10:23 A.M.	8.6	0.0	11.6	27.2	0.0	628
10:43 "	1.6	0.0	7.6	28.8	0.75	240
11:21 "	8.8	0.2	11.6	29.4	0.13	735
11:38 "	3.6	0.4	7.6	22.0	0.1	800
2:08 P.M.	8.8	0.0	10.8	27.2	0.4	490
2:23 "	2.4	0.0	13.2	16.4	0.0	772
2:43 "	1.6	0.0	9.6	30.4	0.0	280
3:27 "	7.8	0.2	11.0	30.6	0.0	496
3:43 "	5.6	0.2	12.2	28.8	0.13	780
3:58 "	1.8	0.0	13.0	25.4	0.47	900

EXPERIMENTAL RUN (3) ON DECEMBER 27, 1974

III. *Boiler Stack Gas Analysis and Temperature*:

Time	% CO_2	% O_2	% CO	% H_2	% CH_4	*Temp.* °F
10:18 A.M.	17.0	2.4	1.2	0.0	—	480
10:46 "	14.0	5.6	0.4	0.0	—	465
11:16 "	18.8	0.8	1.2	0.4	—	493
11:41 "	14.4	4.4	2.4	0.0	—	465
2:03 P.M.	15.6	4.8	0.0	0.0	—	485
2:18 "	13.2	5.8	2.0	0.0	—	450
2:38 "	9.0	11.0	0.0	0.0	—	363
3:23 "	17.4	2.0	0.4	0.0	—	505
3:38 "	17.6	2.0	0.8	0.0	—	470
3:53 "	10.0	10.0	1.6	0.0	—	420

Appendix 3 (Continued)

V. *Steam and Engine Load Conditions*:

Time	*Steam Conditions* Press. psig	% Quality	*Inlet Temp. °C*	*RPM*	*Generator Load Conditions* Amps	Volts	KW
11:08 A.M. ([1])	90	100	162	1150	80	215	30
11:20 "	70	99	160	1100	85	206	30
11:25 " ([2])	55	99	160	1040	0	0	0
1:52 P.M. ([1])	110	99	147	1150	108	217	41
2:00 "	91	99	162	1100	108	205	38
2:12 "	60	100	160	1080	105	190	35
2:17 "	55	99	158	1100	92	187	30
3:03 " ([1])	97	99	160	1200	108	215	40
3:10 "	83	99	158	1090	103	195	35
3:25 "	74	99	162	1100	116	195	39
3:40 "	66	100	150	1130	82	125	18
3:43 "	67	100	—	—	0	0	0
4:02 "	Engine shut down						

[1] Gas producer was charged full of fuel shortly before the indicated time.

[2] Experimental run was stopped shortly after the indicated time and resumed at 1:00 P.M.