FINAL REPORT

Title: A FLUID BED GASIFIER/ENGINE SYSTEM USING RICE HULLS

Grant No: USAID PDC-5542-G-SS-5080-00

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Prepared for the
United States
Agency for International Development (USAID)
Washington, D.C. 20523

June 1987

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1.0 INTRODUCTION

The University of Missouri-Rolla (UMR) Gasification Research on Wastes Project (GROW) has been working on the gasification of agricultural residues since 1978. The GROW Project has constructed several systems for use with various fuels, including wood residues, manures and rice hulls (1, 2, 3, 4). The system capacities vary from several pounds an hour to 25 tons per day. Most of the systems developed have been fluidized bed designs. However, considerable work has also been accomplished with fixed bed systems.

A pilot fluid bed gasifier/engine system using rice hull as a nonconventional energy resource has been developed by the GROW staff for this research project. The system uses a simple fluid bed design which provides the following advantages when compared with fixed bed systems:

1. The pressure and temperature can be measured and easily controlled.
2. The rapid circulation of the fuel feed and the bed material provides a constant temperature throughout the bed which results in better heat transfer between the bed material and the individual cold fuel feed particles and the air.
3. No preliminary treatment or preparation, such as grinding, pelletizing and briquetting of the feed material is required.
4. Continuous feeding of materials and removal of char and ash for long term operations makes the design more adaptable for industrial applications than the fixed bed systems.

However, the fluidized bed system has some disadvantages also, such as;

1. Increased power requirements to operate a high pressure blower, a mechanical feeding and a gas clean-up systems.
2. Dirty gas is produced because the char and ash are entrained with the gas stream.

2.0 RESEARCH OBJECTIVES

The main objective of the research project was to develop an innovative system for gasifying rice hulls and to utilize the product gas generated as fuel for a diesel and a gasoline engine.

The research project was implemented in three phases, namely, development of the fluidized bed gasifier system, development of the gas clean-up and cooling components and the test of the system on a gasoline and a diesel-engine generator set.

As part of the research project objective of transferring the technology to PADISCOR, two Filipino engineers were trained at the UMR-GROW Project test facilities on the design, fabrication and operation of a 6 inch fluidized gasifier-engine system. The two trainees were also able to pursue graduate studies in engineering at the University of Missouri-Rolla.

Consequently, design drawings and gasifier components were sent to PADISCOR for the development of a pilot commercial model in the Philippines.

3.0 SUMMARY OF REPORT

This research project has determined the design and operating parameters necessary to successfully run a fluidized bed gasifier/engine system using rice hulls.

For a 6 inch fluidized bed reactor, a rice hull feed rate of 30-32 lb/hr and an air rate of 600 SCFH were found to be the optimum conditions in maintaining a reactor temperature range of 1450-1550°F and in producing product gas heating value of 126-158 BTU/SCF.

A combination of dry cyclones, dry filter, a water-detergent recirculating counterflow scrubber, bubbler and demister was found to be adequate in cleaning and cooling the product gas for gasoline and diesel engine operations.

The operation of the gasoline engine on 100% product gas and 100% gasoline showed optimum loads of 6.7 kw and 10.4 kw at 1740 RPM and 1785 RPM, respectively. Consequently, the diesel engine operation on 100% diesel fuel oil(dfo) and dual dfo-product gas showed 8.32 kw and 8.06 kw at 1552 RPM and 1416 RPM, respectively. The gasoline engine could be run on 100% product gas while the diesel engine showed a product gas-dfo substitution rate of 35-57%. Both the gasoline and diesel engine-generator sets were capable of higher load outputs but at reduced speeds.

As part of the technology transfer objective of this research project, two Filipino engineers pursued masteral studies at the university and trained at the UMR-GROW test site facilities. To develop a pilot commercial unit, the design drawings and various fluidized bed gasifier components were supplied to PADISCOR. Mr. Candido B. Miguel, General Manager and Executive Vice-President of PADISCOR visited the GROW site in August of 1986.

4.0 GASIFIER/ENGINE SYSTEM

As shown in Figure 1, the gasifier/engine system tested in this research project was composed of the following major components:

1. A Fluidized Bed Reactor
2. A Gas Clean-Up System, and
3. A Diesel or Gasoline Engine Generating Set.

The rice hulls are fed into the reactor containing a fluidized sand bed at elevated temperatures. The combination of the high bed temperature and the fluidizing air results in the reaction of the rice hull feed to produce pyrolysis products including gas, char and tar. The product gas is piped through the gas clean-up system for the separation of char and ash particles, tar and water vapor. This clean-up system permits the product gas to be used as an alternative fuel for an internal combustion engine.

4.1 FLUIDIZED BED REACTOR

The reactor used in this project was a six inch diameter (Figure 2) fluid bed design. This design is suitable for feed rates ranging from 25 to 35 pounds per hour with gas production rates from 700 to 1000 SCF/hr and heating values ranging from 120 to 150 BTU/SCF. The pressure drop across the reactor was from 1.28-2.0 psi The reactor was made from a 12-foot six inch diameter mild steel pipe and installed in a vertical position. A 10" disengager was attached at the top of the six inch section preventing the sand bed from being carried over by the gas stream. A propane burner was provided to pre-heat the reactor during the start-up procedure.

The rice hull feeder assembly consisted of a hopper and a 3-inch diameter screw conveyor driven by a variable speed motor which can either be installed at the bottom or the middle section of the reactor. The hopper was completely sealed to prevent the air or

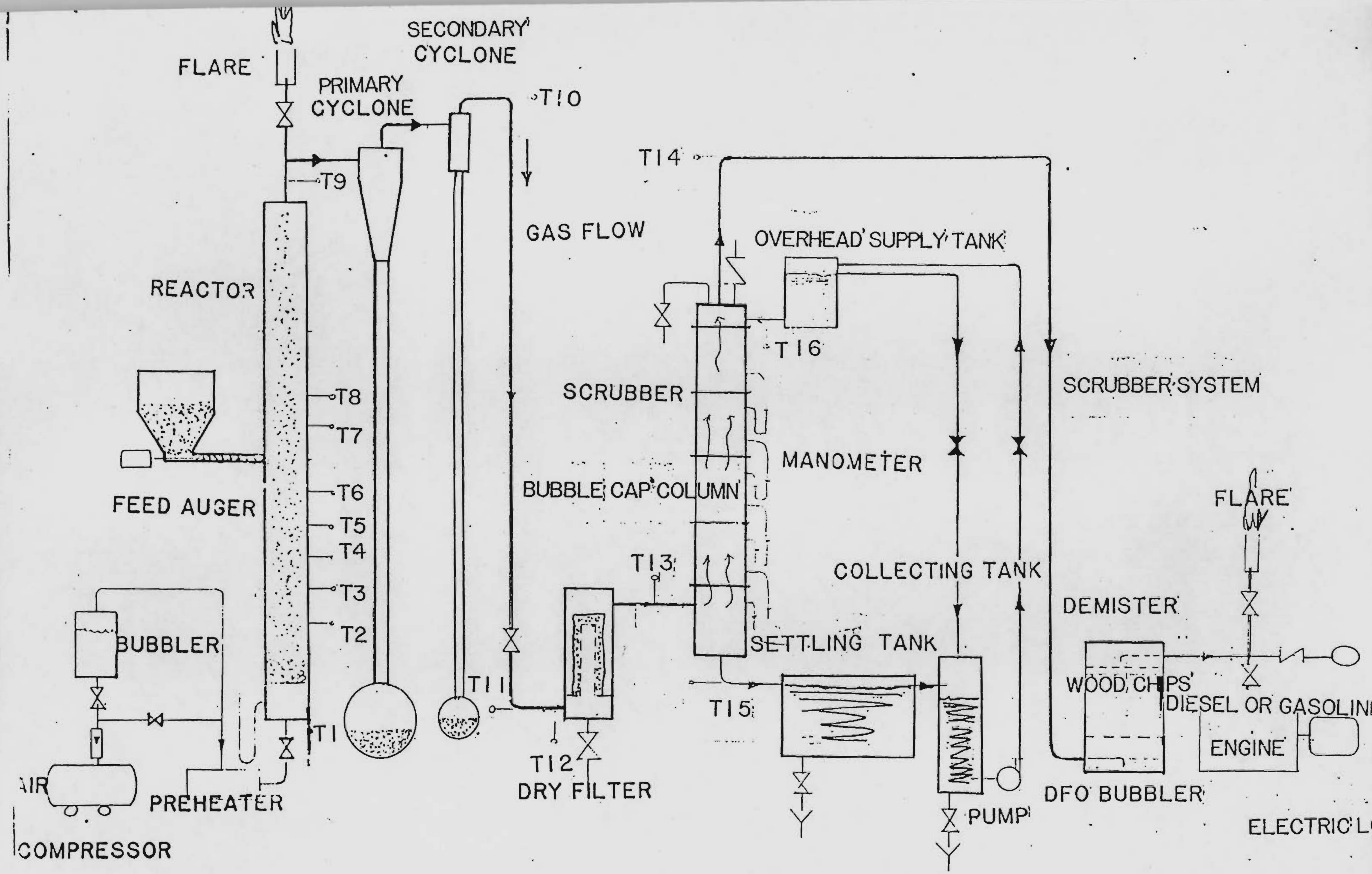

FIGURE 1: AS-BUILT SCHEMATIC DIAGRAM OF 6 IN. RICEHULL GASIFICATION-ENGINE SYSTEM

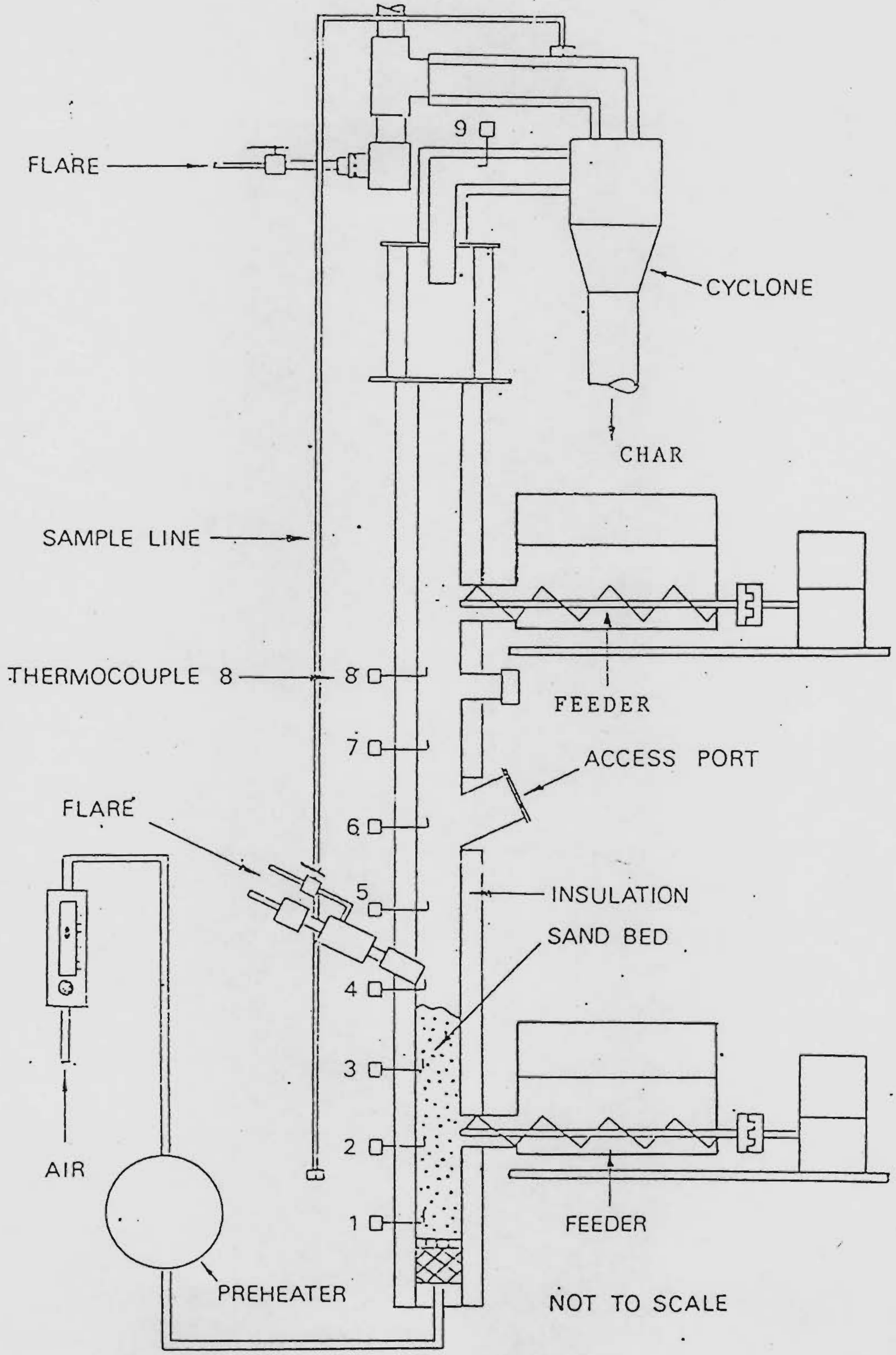

Fig:2: 6.0" Fluidized Bed Gasifier

the product gas from leaking into the rice hull storage space.

The air from the compressor can be passed through a water bubbler and an air pre-heater before it entered a four-inch thick packing of gravel at the bottom of the reactor which served as air distributor. A rotameter rated up to 1000 SCFH was used to regulate the air that was supplied to the reactor from the compressor.

The gasifier column was also installed with an access port for inspection of the reactor internals the sand bed. A two-inch thick fiber glass wool insulation and aluminum sheet cladding were wrapped around the reactor to minimize heat loss. Thermocouples were installed along the height of the reactor to monitor the temperature profile of the column.

4.2 GAS CLEAN-UP SYSTEM

A fluidized bed gasifier system produces a highly combustible gas composed of a mixture of H2, CO2, C2H4, C2H6, N2, CH4, CO, C3+, tar vapor, water vapor and char. Not all of these constituents are suitable for utilization as fuel for internal combustion engines. The water vapor and the impurities, such as the tar and char, should be removed from the product gas stream before it can be effectively used as substitute for conventional fuels such as diesel or gasoline. Ideally, even the carbon dioxide and the nitrogen in the product gas should be removed from the gas stream for better results. However, this is a very difficult and costly process to undertake in actual operating conditions. The impurities in the gas stream were removed by taking advantage of its state at different temperature levels. With this approach, each impurity can be removed separately without affecting the removal of the others.

The separation of char and ash from the gas stream should be accomplished prior to the removal of tar and water. These particles could be collected at gas stream temperatures ranging from 600 to 1000 F. The tar and water would be separated from the gas stream at lower temperature levels where condensation occurs. This sequence should be followed to prevent "mudding-up" of the gas clean- up system which could be caused by the presence of char and ash during condensation.

A gas clean-up system was designed, fabricated and installed with the gasifier/engine system to remove the impurities in the gas streams. The following were the major components included in the system;

1. Cyclone Separators
2. Gas Filter
3. Gas Scrubber
4. Demister

The product gas clean-up system components shown in Figure 1 were arranged in such a manner as to follow the principles discussed above. The high temperature gas exiting at the top of the gasifier reactor was normally entrained with char dust and ash particles. The larger char and dust particles were separated from the gas stream by centrifugal force through two sets of cyclone separators. The finer particles escaping the cyclone separators were collected at the gas filter. The filtered gas was piped through a counterflow scrubber column for further cleaning and cooling. The exposure and contact of the gas with the scrubber liquid would result to cooling causing the tar and water vapor to condense. The condensates thus mix with the scrubbing liquid and then flow into a settling tank where it was drained periodically. The product gas then entered the dfo bubbler and demister for final removal of moisture and entrained particulates. The total pressure drop across the gas clean-up and cooling system ranged from 0.37 to 0.75 psi

4.2.1 CYCLONE SEPARATORS

A primary and a secondary cyclone separator were installed in the gas clean-up system to collect char and ash particles coming from the fluidized bed reactor. The primary cyclone separator was a 4-inch diameter cone-type cyclone. It separated the larger particulates in the gas stream. The secondary cyclone separator was a 3-inch barrel-type cyclone. It collected the finer particulates in the gas stream that escaped from the primary cyclone separator.

The cyclone separators were designed to handle gas flow rates ranging from 1,600 to 2,000 CFH at 600-1000 F. The barrel-type cyclone maximized the number of spirals traversed by the entering gas stream, thus increasing the solid particle collection efficiency. A gas entry velocity of 50-60 fps was used to attain high efficiency and prevent the tar and char from plugging the cyclone. Both cyclones were insulated to minimize heat loss and possible condensation which would reduce its efficiency.

4.2.2 GAS FILTER

A 10 in. diameter and 24 in. high gas filter was designed to prevent the finer ash particles and embers from entering the scrubber. This prevented the scrubber from "mudding-up" during the condensation of the tar and water vapor. It was packed with heat resistant fiber glass wool enclosed in a cylindrical wire mesh housing. It was installed vertically and provided with a gas inlet pipe on the bottom and an outlet pipe at the top. A clean-up door on the bottom side served as an access for inspection and collection of ash. The top cover can be quickly opened and closed to facilitate the changing of the fiber glass wool packing.

4.2.3 GAS SCRUBBER

The counterflow gas scrubber was used to allow for an efficient contact between the gas and the scrubber liquid for the removal of tar and water vapor from the gas stream. Under this process, the tar and water vapor condenses and then carried away by the scrubber liquid.

The gas from the filter was piped to the bottom section of the scrubber. It flowed upward through the risers into the tunnel caps. It then passed through the annular section between the riser and the cap by depressing the liquid level and bubbling into the liquid through the cap slots. Interfacial areas were created between the gas and the scrubbing liquid as the bubbles were dispersed into the tray. These interfacial areas allowed for effective heat and mass transfer between the gas and the scrubbing liquid. The scrubber was tested using pure tap water, tap water with a heavy duty detergent (trisodium phosphate or TSP) and tap water with TSP and diesel fuel oil. The use of tap water without TSP was found to be impractical because of tar build-up on the bubble caps, scrubber plates and column surfaces. The TSP mixed with water prevented the tar from adhering on the metal surface of the bubble caps, scrubber plates and column. The addition of diesel fuel oil to the solution of the scrubber liquid showed no additional advantage. For this reason, the tap water with the TSP detergent was used for subsequent test runs.

The gas scrubbing system was composed of the following components;

1. Bubble Cap Column
2. Settling tank
3. Collecting Tank
4. Overhead Supply Tank

Bubble Cap Column

The 8 in. diameter scrubber column was composed of three sections consisting of a three part 8 in. mid section, a 12 in. top a 12 bottom section. Installed on each of the form trays or plates were three tunnel-type bubble caps.

Settling Tank

A simple gravity settling tank was provided to separate the scrubber liquid from the yellow-brown colored condensate and the small amounts of ash and char particulates collected from the column. The tank was a 55 gallon barrel installed horizontally with effluent inlet on the center of one end and clean liquid outlet on the top side of the other end. A drain was also provided to flush out the dirty condensate accumulation at the bottom of the tank. Baffles were installed inside the tank to ensure laminar flow and to reduce the distance through which the dispersed phase could settle, thus, reducing settling time. The settling tank was designed to operate at a liquid flow rate of 15-30 gallons per hour and a settling time of about 100-200 minutes.

Collecting Tank

The clean liquid from the settling tank was discharged to a 15 gallon collecting tank. This served as a buffer that balances the liquid flow that was being recirculated through the system. The tank was cylindrical in shape, 12" in diameter and 36" in height. A pump was installed to draw liquid from the bottom of the collecting tank for recirculation through the scrubber system.

Overhead Supply Tank

To insure a steady flow of scrubbing liquid through the scrubber, a 12 in. diameter and 14 in. high overhead supply tank was installed on the top of the scrubber column.

It was installed with a flow meter, regulating valves and an overflow pipe. The overflow pipe was used to prevent non-uniform liquid flow and to maintain the operating pressure. It also facilitated flow calibration without overloading of the pump motor.

4.2.4 DEMISTER

The demister was used to separate the entrained scrubber liquid and water vapor from the gas before it is used as fuel for the internal combustion engines. The demister was made from a 55.0 gallon barrel installed vertically. The bottom of the demister was provided with a diesel fuel oil reservoir and the mid-section was packed with 12" thick layer of wood chips. The diesel fuel oil bath was used to strip condensates from the gas stream while the layer of wood chips was used to absorb entrained scrubber liquid and water vapor from the gas.

The demister also safeguarded the engine from sucking scrubber liquid in case of uneven flow or level build up in the scrubber column.

4.3 DIESEL AND GASOLINE ENGINE/GENERATOR SETS

The diesel and gasoline engine/generator sets used in this research project were Army surpluses. The specifications are listed below;

Gasoline Engine & Generator Set Specifications.*

1. Engine: 4 cylinders, 1800 rpm.
2. Generator Set: 12.5 kw, 1800 rpm, 0.8 pf, 60 cps, 125 or 250 VAC 50-100 A, 2 phase, 2 wire, SN 149 ON 38203 - PHLA 53-31.

Diesel Engine-Generator Set Specifications.*

1. Diesel Engine Specification: 3 cylinders, 1800 rpm, 18 hp, Monarch Engine Corporation SN CSR 320 1897 MOI.
2. Diesel Engine-Generator Set: 10 kw, 1800 rpm, 0.8 pf, 60 cps, 35 amps, 120/208 v, 3 phase, 4 wire, SN PU-669 A/G, Consolidated Diesel Electric Co.

5.0 TEST RUN CONDITIONS AND DATA ANALYSIS FOR THE GASIFIER

5.1 TEST RUN CONDITIONS AND DATA ANALYSIS

The temperature profile of the reactor is shown in Table 1. The air rate, fuel feed rate, air/fuel ratio and average gasification temperature for each test run are also included in the table.

The air/fuel ratio, the average gasification temperature and the product gas heating value gas are shown in Table 2. These values were taken for each gas sample during the various test runs. These data were valuable in determining the operating parameters to attain desirable operating conditions.

The gas composition and the heating value of the individual gas samples taken during the test runs are indicated in Table 3. These values were obtained using a Carle gas chromatograph.

For test runs 1 through 5, the fuel feeder was located at the mid-section of the reactor or six (6) feet above the bottom of the sand bed. The height of the sand bed was 36". This allowed the feeding of the rice hull into the top of the fluidizing bed. The air supplied to the reactor was passed through a water bubbler and an air pre-heater. The bubbler was used to entrain water molecules with the gasifying and fluidizing air to increase the hydrogen content of the product gas. The air preheater, set at 800°F was used to help maintain the gasification temperature in the reactor.

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From Table 2, it can be seen that the air/fuel ratio used in these test runs was varied from 13.8 to 20.0 SCF air per pound of rice hull. This resulted to gasification temperatures ranging from 1,139 to 1,364°F and product gas heating values from 93 to 154 BTU/SCF. The heating value of the product gas for these test runs were relatively high for air gasification, particularly for test run no. 5. However, the product gas contained excessive amounts of tar and water which caused clogging of the gas lines. Frequent cleaning and maintenance of the pipes and gas clean-up system were necessary for continuous operation of the gasifier system.

These undesirable results were attributed to the excess moisture supplied by the bubbler to the reactor and the relatively low average gas temperature. Another reason was that due to feeding on top of the fluidizing bed, most of the moisture and tar released from the rice hulls immediately exited the reactor before undergoing further reaction.

To eliminate these problems, test runs 6 through 12 were conducted without using the bubbler. The sand level was also increased from 36" to 60". The sand level was increased in order to feed the rice hulls into the fluidizing bed.

This condition resulted to relatively higher gasification temperatures, but no substantial decrease in tar was achieved. Clogging of the gas lines with tar and char was not eliminated. The increase in the height of the sand bed resulted to the problem of supplying the desired air/fuel ratio and maintaining uniform fluidization. Higher air/fuel ratio was required to fluidized the sand bed. Air/fuel ratios varying from 17.3 to 33.3 SCF air per pound of rice hull were used for these test runs. The excessive amount of air supplied to the reactor resulted to lower product gas heating value. Consequently, the increase in the level of sand in the reactor increased the pressure drop through the gasifier system.

For test run no. 13, the fuel feeder was installed at the bottom section of the reactor, 18" above the bottom of the sand bed. The sand level was reduced from 60" down to 36 inches. This set-up allowed the fuel to be fed into the fluidizing bed.

However, the height of the sand bed resulted to the development of a high pressure at the feed point. This caused the sand to be blown out of the reactor into the rice hull feeder screw conveyor.

Starting test run no. 14, all the test runs were conducted with the rice hull feeder installed at the bottom section of the reactor. The sand level was reduced to 18" to eliminate the problem stated above. The use of the air pre-heater was also discontinued to reduce energy input into the gasifier system.

This set-up resulted to improved control of the gasification temperature and a substantial decrease in tar on the gas stream. However, occasional bridging of the rice hull in the feeder and non-uniform feeding rate were observed. These problems were solved by completely sealing the rice hull feed hopper, thereby preventing the fluidizing air from escaping through the feeder.

Various test runs were conducted using different air rates and fuel feed rates for this set-up. The gasification temperature was also maintained at different levels to observe its effect on the quality of the product gas.

The relation between the air/fuel ratio and the product gas heating value is shown in Figure 3. The data used in this figure were gathered from Table 2. The general least squares fit interpolation technique was used to approximate the behavior of the curve for these values. This technique was also used for figures 4 & 5. The curve shows that the air/fuel ratio ranging from 19 to 20 SCF air per pound rice hull resulted to product gas heating values from 140 to 150 BTU/SCF for this gasifier system. Air/fuel ratios less than 19 and more than 20 SCF/LB produced gas with lower heating values.

The effect of the air/fuel ratio to the average gasification temperature is shown in Figure 4. The data in Table 2 were used to plot the relationship between these two parameters.

It can be observed that increasing temperatures were attained for air/fuel ratios up to 23. Beyond this point, the gasification temperature began to decline. The increasing temperature values for air/fuel ratios from 13 to 23 was attributed to the increasing supply of oxygen into the reactor, thus increasing combustion reactions. The additional air also had a cooling effect on the reactor.

The Table 4 shows the average gasification temperature, the product gas heating value, cold gas efficiency and the gas composition for test runs 30 through 36. For these test runs, the operating problems in feeding the rice hulls, non-uniform fluidization, low and uneven gasification temperature ranges, excessive tar on the gas stream and clogging

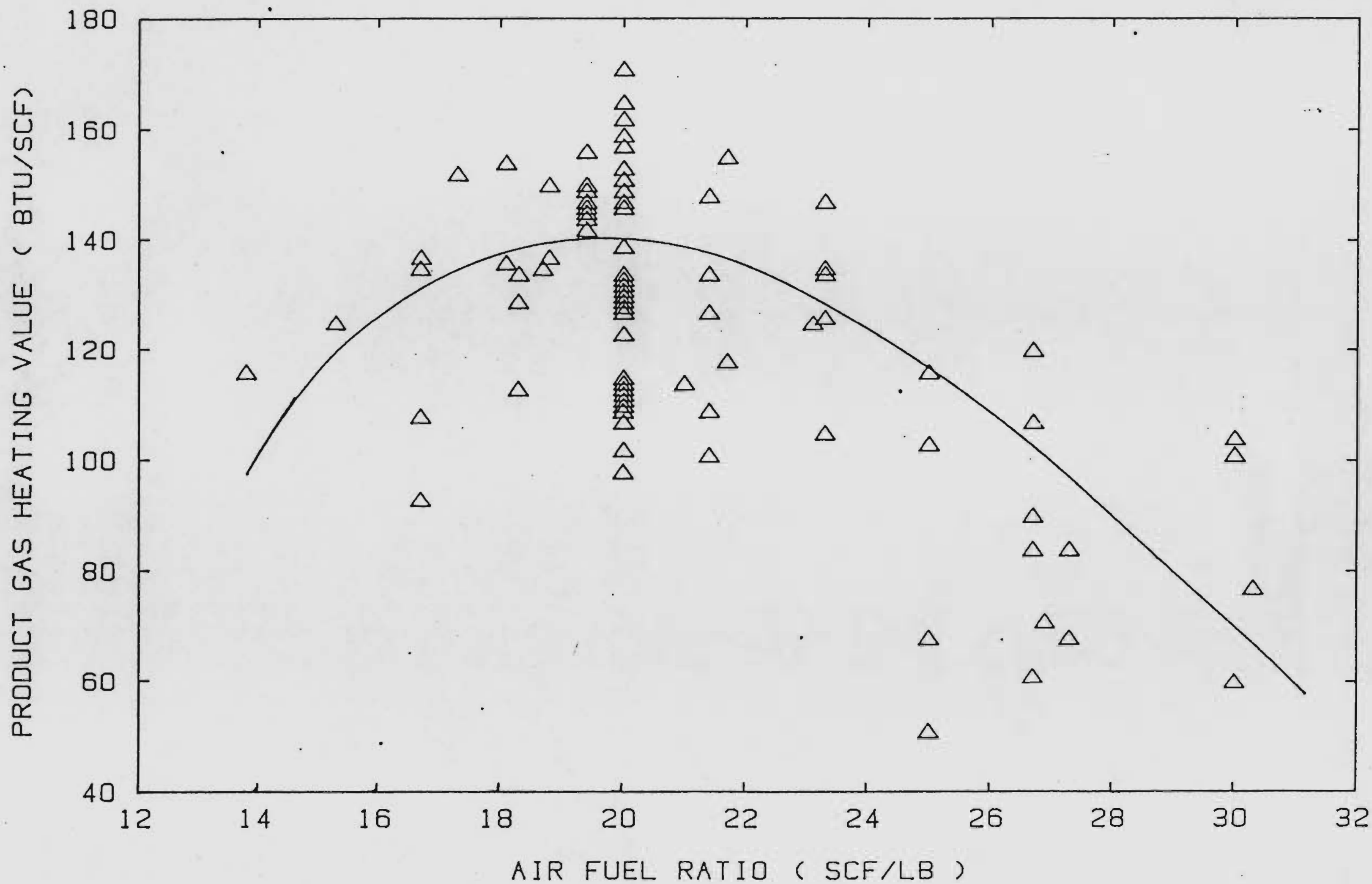

FIG. 3 : PLOT OF AIR/FUEL RATIO VS. HEATING VALUE

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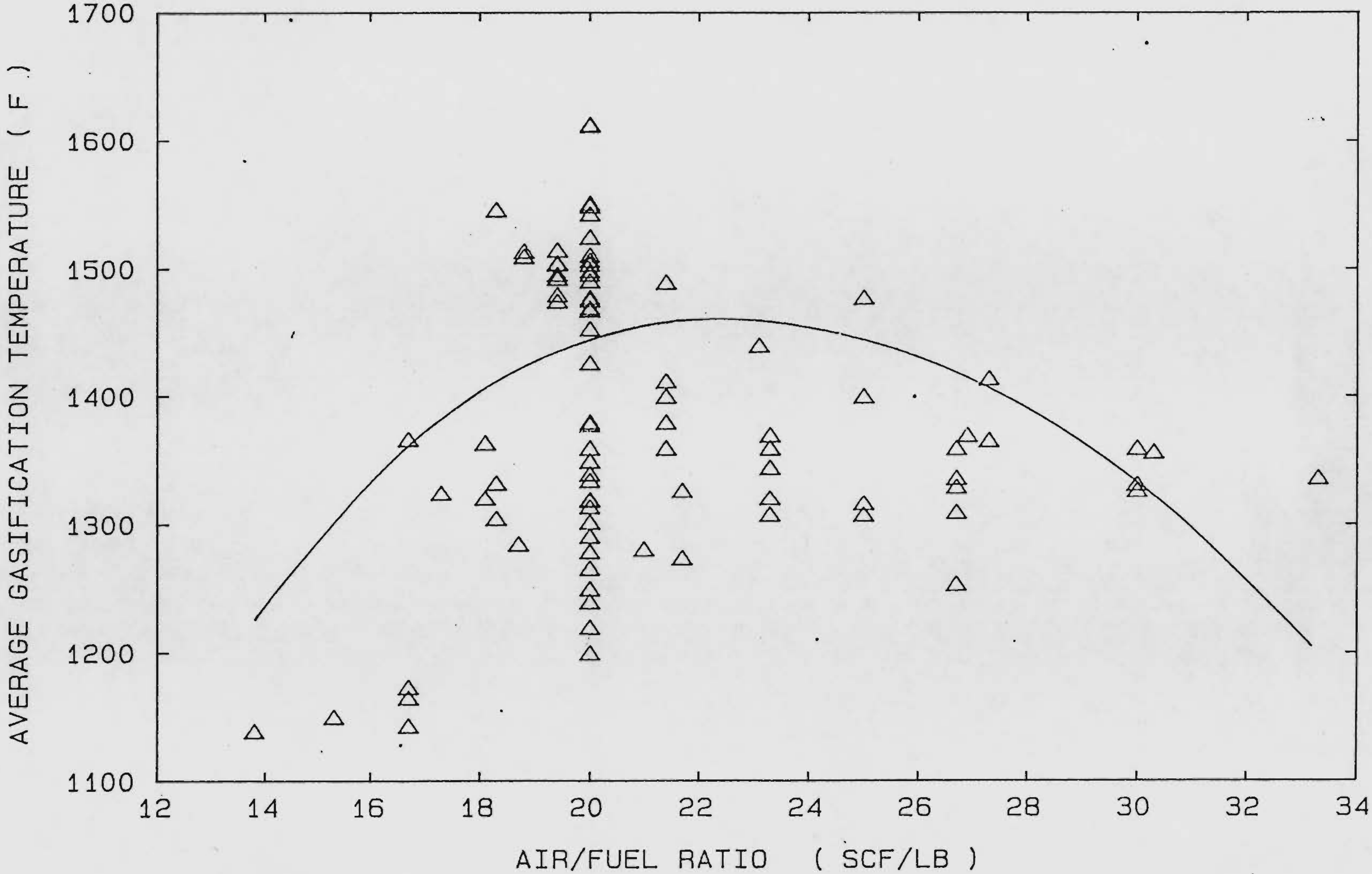

FIG. 4 : PLOT OF AIR/FUEL RATIO VS. AVERAGE GASIFICATION TEMPERATURE

of the gas lines were eliminated.

Product gas heating values varying from 128 to 156 BTU/SCF were obtained using air/fuel ratios of 19.4 and 20.0 SCF/LB. The gasification temperature ranged from 1,453 to 1,551°F. An average product gas heating value of 143 BTU/SCF was generated through these test runs at an average gasification temperature of 1,495°F and air/fuel ratio of 19.7 SCF/LB. The average cold gas efficiency for these test runs was 66.4%.

The relation between the gasification temperature and the heating value of the product gas is shown in Fig. 5. The decrease in the heating value for increasing temperatures was attributed to further reaction shift to combustion.

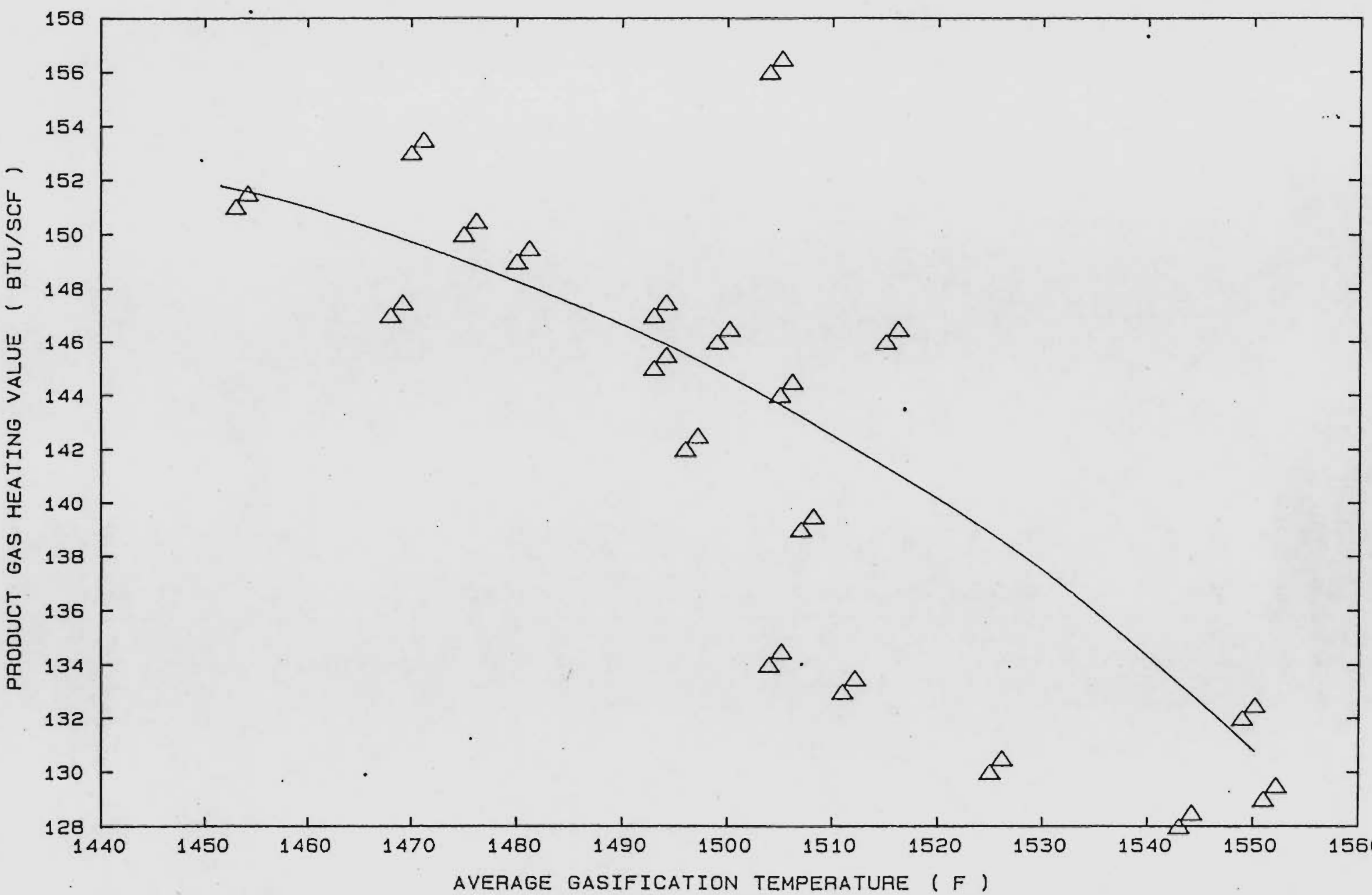

FIG. 5 : PLOT OF AVERAGE GASIFICATION TEMPERATURE VS. PRODUCT GAS HEATING VALUE

5.2 RICE HULL AND CHAR PROPERTIES

Rice hulls are a by-product of rice milling operation. Its calorific value is approximately 6,000 BTU per pound. The ash content is relatively high, at about 20% by weight and contains 90 to 95 % silica. The moisture content is usually less than 10%. The high silica content of the rice hull makes it one of the most difficult fuel to gasify. Formation of a glass-like barrier of silica occurs at temperatures above 1,700°F. Gasification temperatures therefore, should be maintained below 1,700°F to prevent clogging in the reactor due to slag and clinker formation.

The rice hull used in this research normally contains 7.0% moisture and 17.0% ash. After gasification the char contained 5.0% moisture and 80.0% ash.

FINAL MODIFICATIONS AND ADJUSTMENTS

1. The height of the sand bed was maintained at 18 inches.
2. The feeder was located at the bottom section of the reactor
3. The rice hull feed rate was set at 30-32 pounds per hour
4. The air rate was maintained at 600 SCFH.
5. The bubbler and the air pre-heater were bypassed.
6. The rice hull feeder hopper was provided with an inclined and vertical chute siding and completely sealed.

RESULTS OF THE MODIFICATIONS AND ADJUSTMENTS

1. The bridging of the rice hull at the fuel hopper was totally eliminated.
2. The excessive pressure build-up at the reactor was no longer a problem.
3. The gasification temperature can be easily controlled and maintained from 1,450 to 1,550°F range.
4. The clogging of the gas pipes was eliminated.
5. The uniform fluidization due to improved feeding resulted to a more consistent gas quality.
6. An average cold gas efficiency of 66.4% was obtained
7. The product gas heating value ranged from 128 to 156 BTU/ SCF.

6.0 FLUIDIZED BED GASIFIER - GASOLINE ENGINE/GENERATOR SET RETROFITTING SCHEME AND PERFORMANCE.

6.1 GASOLINE ENGINE AND GENERATOR SET SPECIFICATIONS

1. Engine: 4 cylinders, 1800 rpm.
2. Generator Set: 12.5 kw, 1800 rpm, 0.8 pf, 60 cps, 125 or 250 VAC 50-100 A, 2 phase, 2 wire, SN 149 ON 38203 - PHLA 53-31.

* The engine and generator set were Army surpluses.

6.2 GASOLINE ENGINE/GENERATOR SET RETROFITTING SCHEME FOR PRODUCT GAS OPERATION

As shown in Figure 6, the product gas from the reactor, the gas cleaning, cooling and demisting equipment was mixed with ambient air by means of experimentally determined valve settings. The mixture flowed to the carburetor thru the top air intake port by means of a hose connected to the product gas- mixture pipe. The flow of the air-product gas mixture into the engine was attained by the normal suction of the engine and by the positive pressure at the reactor. Five valves were provided at the intake piping so that the proper air-product gas mixture could be attained and gas could be flared prior to engine switch over to product gas operation. The engine was always run on gasoline prior to product gas operation.

The retrofitting scheme in the test set-up was done simply by installing a hose to convey the product gas-air mixture atop the carburetor where the normal air hose and air filter housing were connected. No adjustments were made on the carburetor or the speed governor.

The engine was normally started on gasoline at no load. Once the speed, voltage, current and frequency of the generator were stabilized, the operation of the gasoline engine was shifted to the product gas. The shift to product gas was accomplished by shutting off the gasoline pump supplying the carburetor. While the engine was consuming the remaining fuel at the carburetor cup reservoir, valves B, G, C and A were opened and

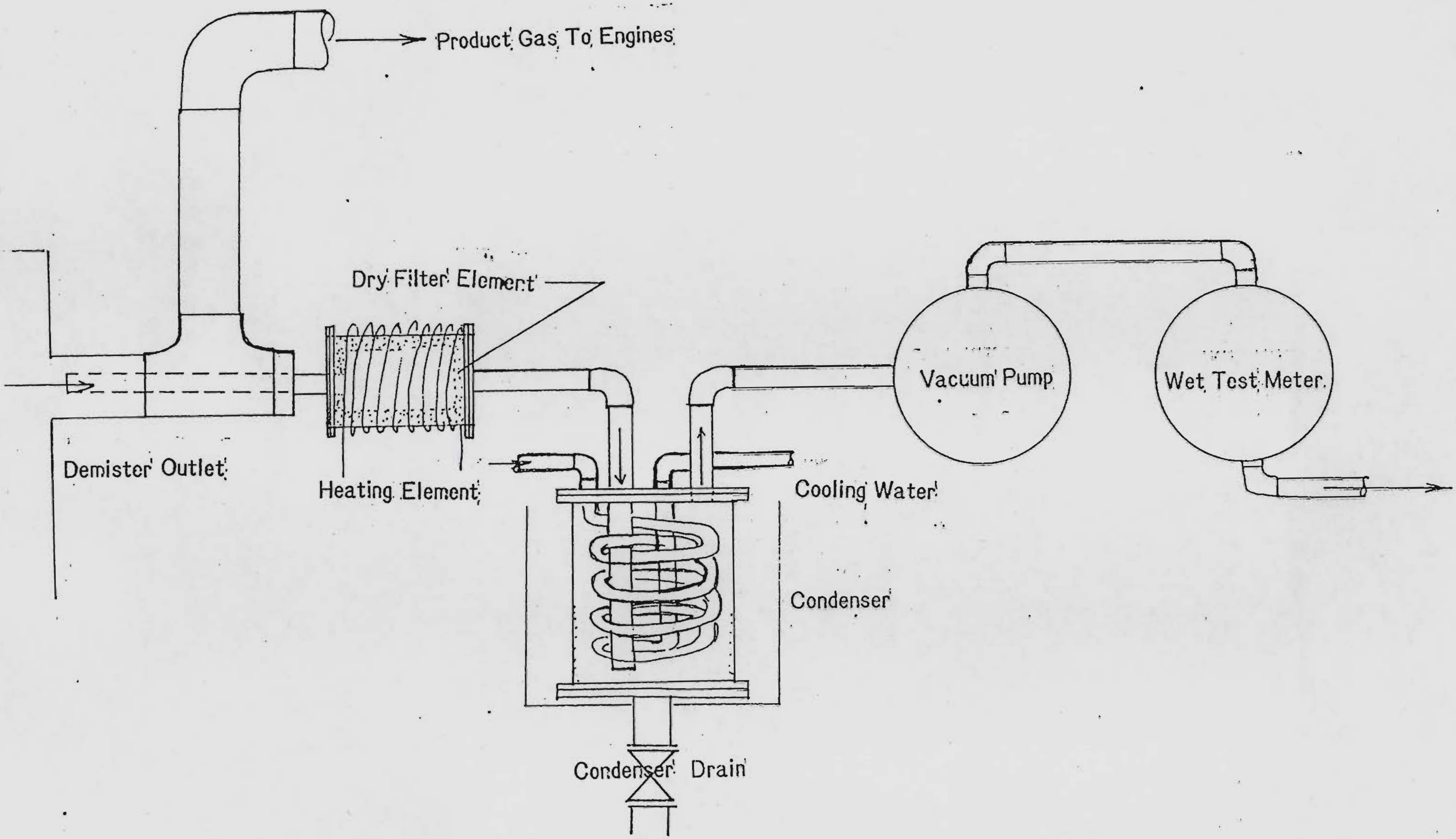

FIGURE 18 ISOKINETIC SAMPLER

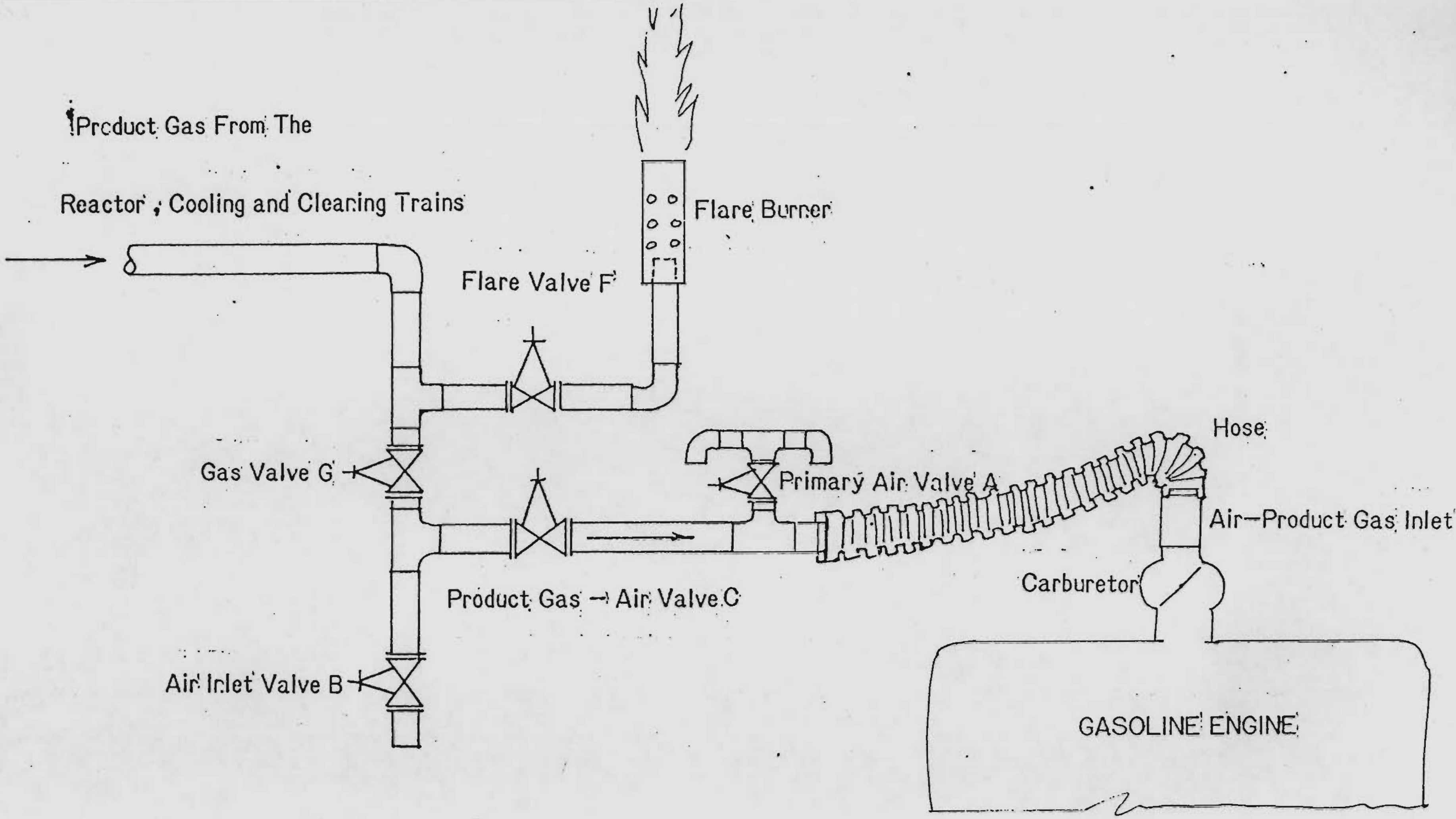

FIGURE 6 GASOLINE ENGINE–PRODUCT GAS RETROFITTING SCHEME

adjusted and the flare valve F shut off. Finer adjustments were done on valve A while air valve B was finally closed. When the speed on product gas operation had stabilized, the generator resistive electrical loads (heaters) were turned on and increased gradually to approximate 1/4, 1/2, 3/4 and full load of the rated kw capacity based on 100% gasoline fuel operation. Various operating parameters were gathered to compare the operation of the engine-generator set on 100% gasoline and 100% product gas as shown in Tables 5, 6, 7 and Figures 7 and 8a, 8b, 8c, 9, 10a and 10b.

Two run modes were tried on the gasoline engine run on 100% product gas. First, the engine was run with its pre-set spark advance. The data are shown in Table 7. A relatively low rpm, frequency, voltage, amperage and kw outputs were attained. The engine was also running at variable pulsating speed. Much improvement in the engine performance was attained when air valve A was added and the spark advance advanced by 8-10 degrees. These results are shown in Table 6 and Figures 10a and 10b.

6.3 DISCUSSION OF RESULTS

As the rice hull feed at 30-32 lb/hr and the air fuel rate at 600 SCFH were maintained, the resulting temperature in the reactor ranged from 1450 to 1550 F and the heating value of the gas at 128-156 BTU/SCF. In Figure 7, the rice hull fuel specific consumption in lb-f/kw-hr is shown to decrease as the electric load is increased. Since the production of product gas was fairly constant, some of it was flared on loads lower than 4.76 kw to avoid a very rich air-product gas mixture. At 100% product gas the engine-generator load showed an optimum rating of 6.7 kw at 95 v, 70.5 amps, 50 hz at 1740 rpm. Higher total kw outputs, however, were observed to be attainable but at lower rpm, voltage, amperage and frequency. For shaft power applications (water pumping, rice milling, etc.) where broader rpm ranges are tolerable, the operation of the gasifier-engine system may have a broader range of applications.

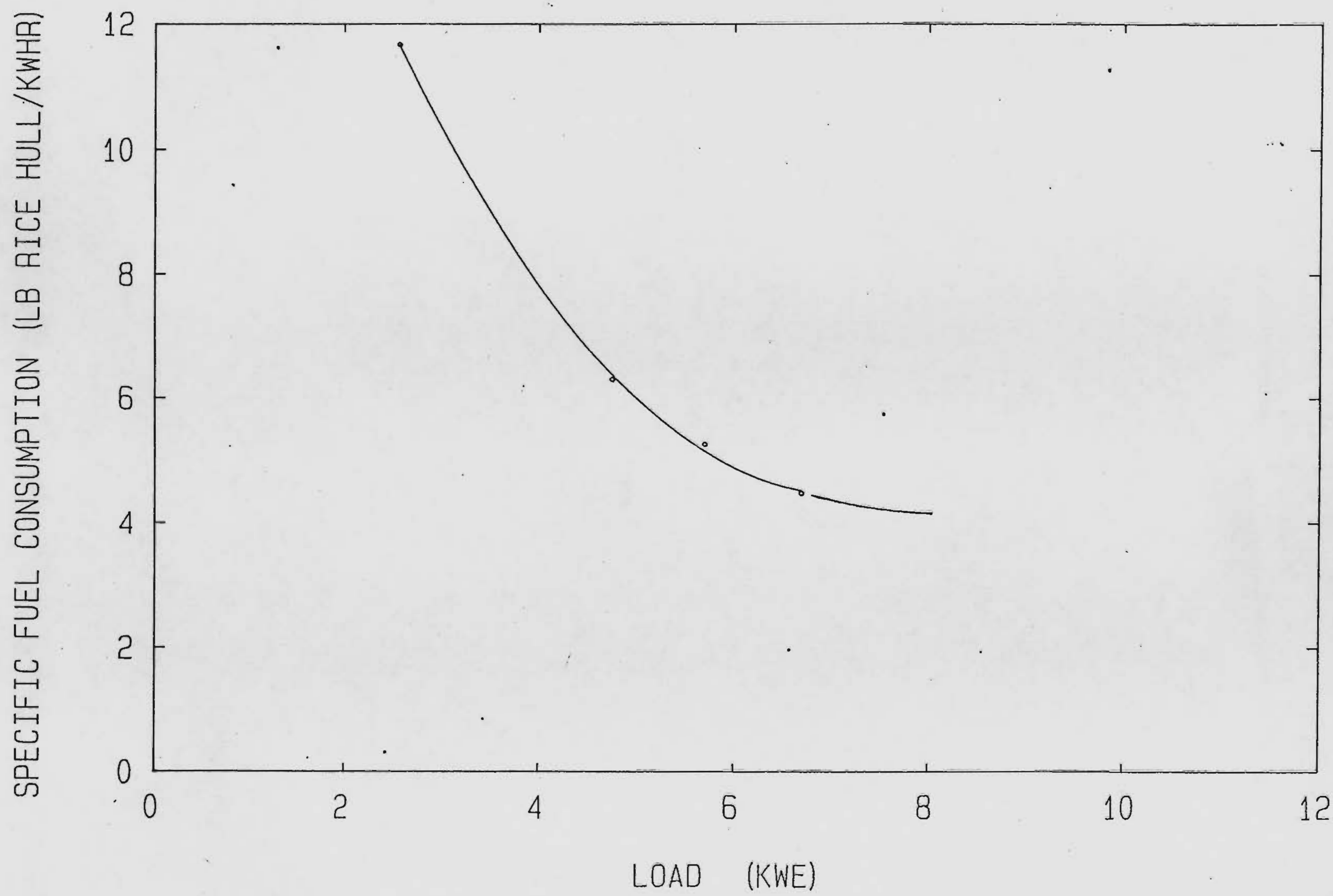

FIG. 7: Plot of Electric Load VS. SFC on 100% Product Gas and 8-10° Advanced Spark Advan

Figures 8a, 8b, 8c and 9 and Table 5 show the operation of the system on 100% gasoline in terms of specific fuel consumption (li/kw-hr), rpm, voltage and thermal efficiency as plotted versus the electric load. It was observed that the engine at its normal run on 100% gasoline delivered decreasing rpm, voltage and frequency at increasing loads. The decrease, however, were more pronounced on the gasifier operation. Figure 10a and 10b and Table 6 show the operating parameters and the load on 100% product gas mode. The total gasoline savings at a rice hull feed rate of 30 lbf/hr at various electric loads could be obtained from the Figure 8a and from Table 5. The thermal efficiencies on both modes at various loads were shown in Tables 5 and 6 and Figure 9. It is interesting to note to note that with an 8-10 advance of the spark advance and a 15-60 rpm reduction, the thermal efficiencies on 100% product gas operation was higher than that of 100% gasoline operation at loads higher than 4 kw. This could be probably due to a more complete combustion of the product gas when the spark advance setting was earlier than when it was operating on gasoline. Consequently, at above 4 kw most of the product gas was being sucked by the engine instead of a portion being lost during flaring.

Observations on the engine oil pressure and cooling water temperature showed no marked difference on the two modes of operation.

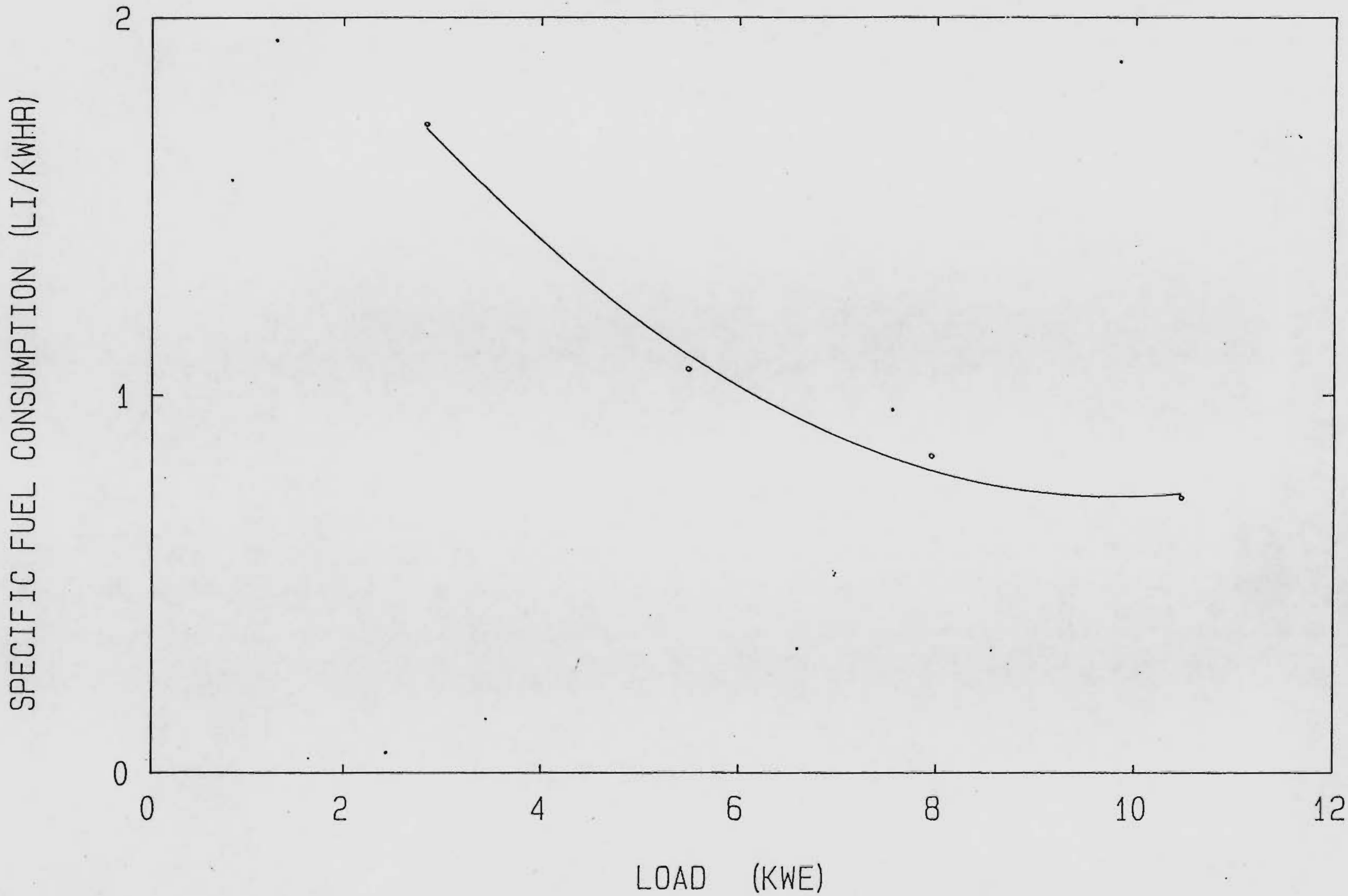

FIG. 8a: Plot of Electric Load VS. SFC on 100% Gasoline at Normal Engine Settings

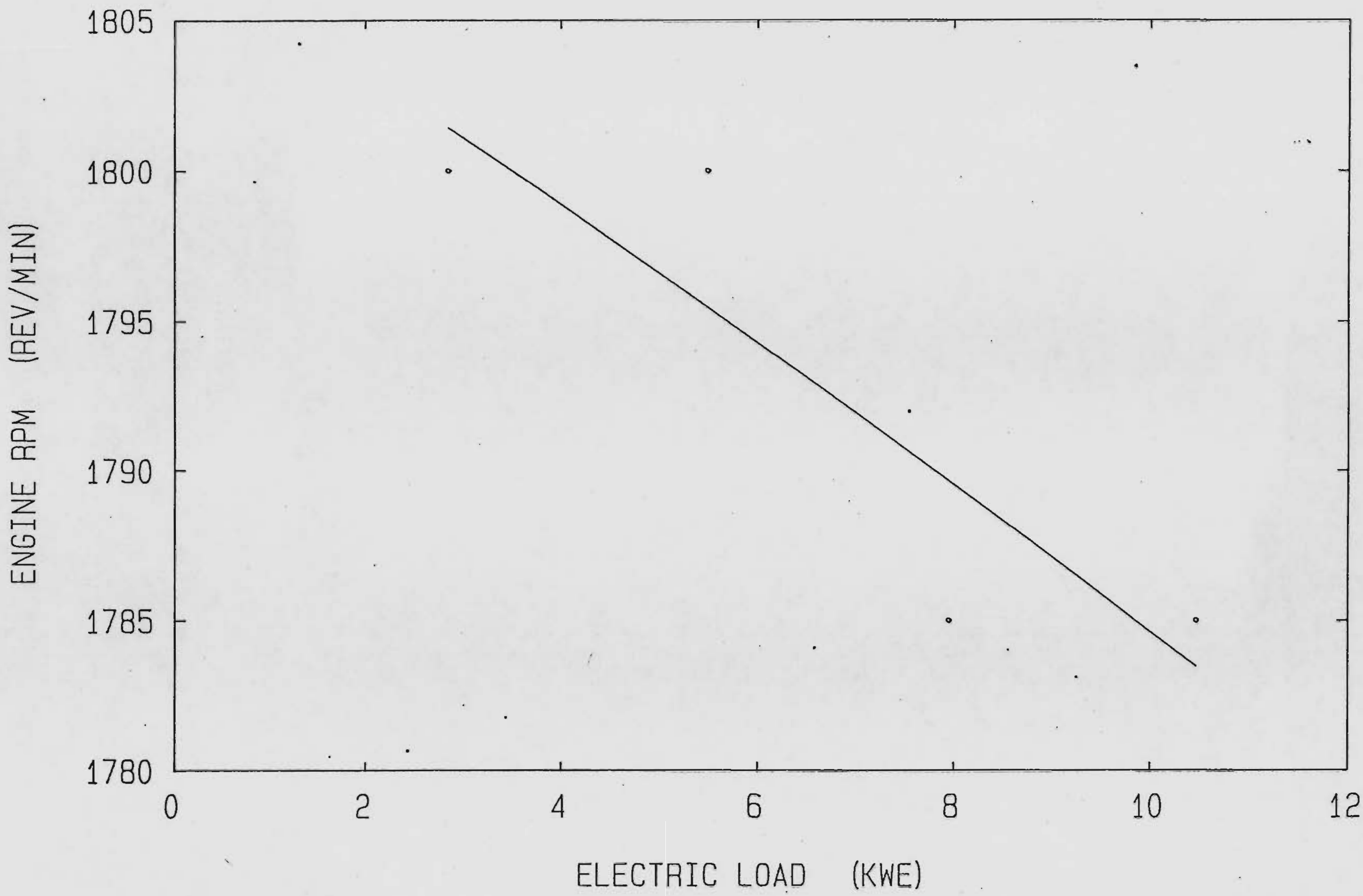

FIG. 8b: Plot of Load VS. RPM on 100% Gasoline at Normal Engine Settings

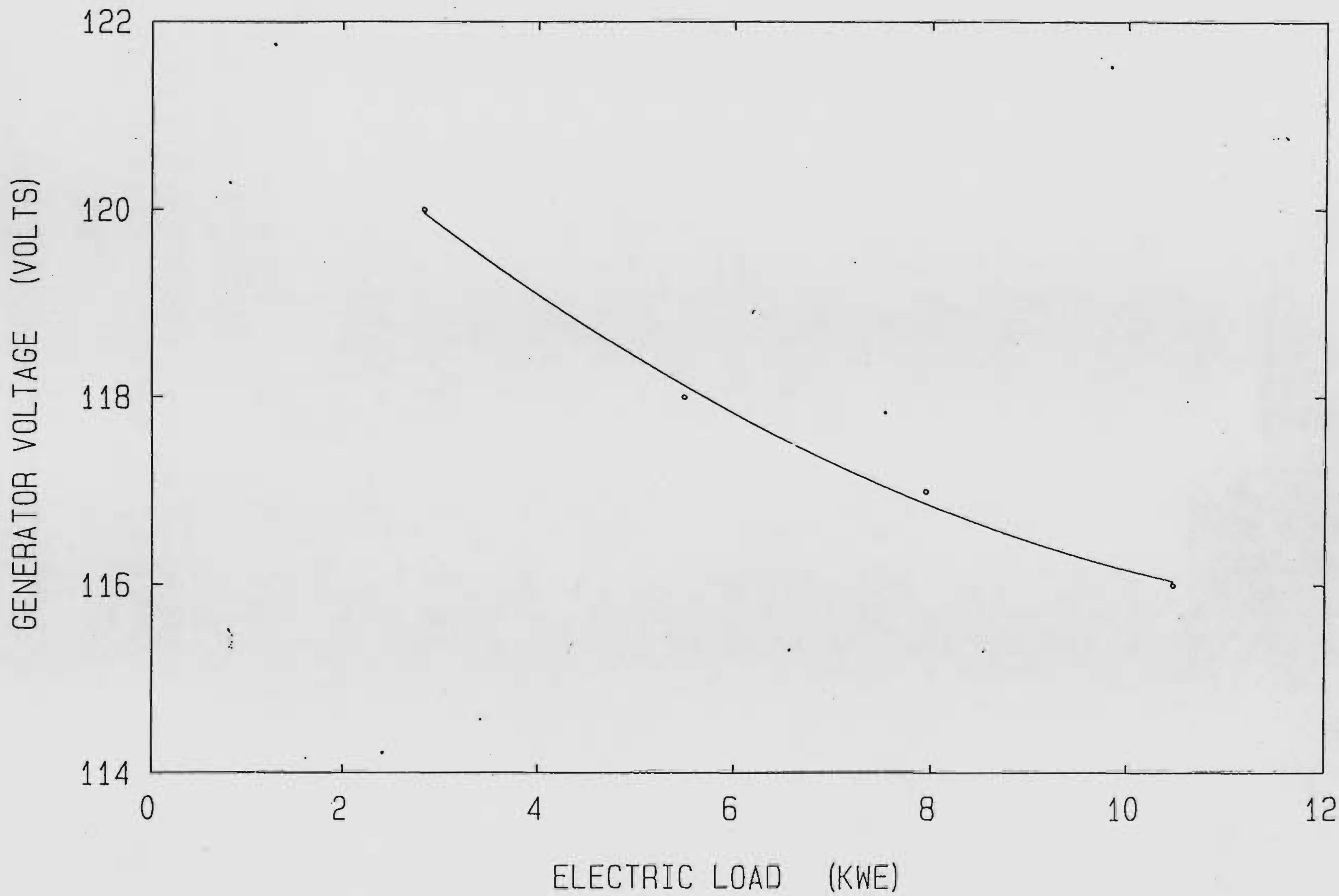

FIG. 8c: Plot of Load VS. Voltage on 100% Gasoline at Normal Engine Settings

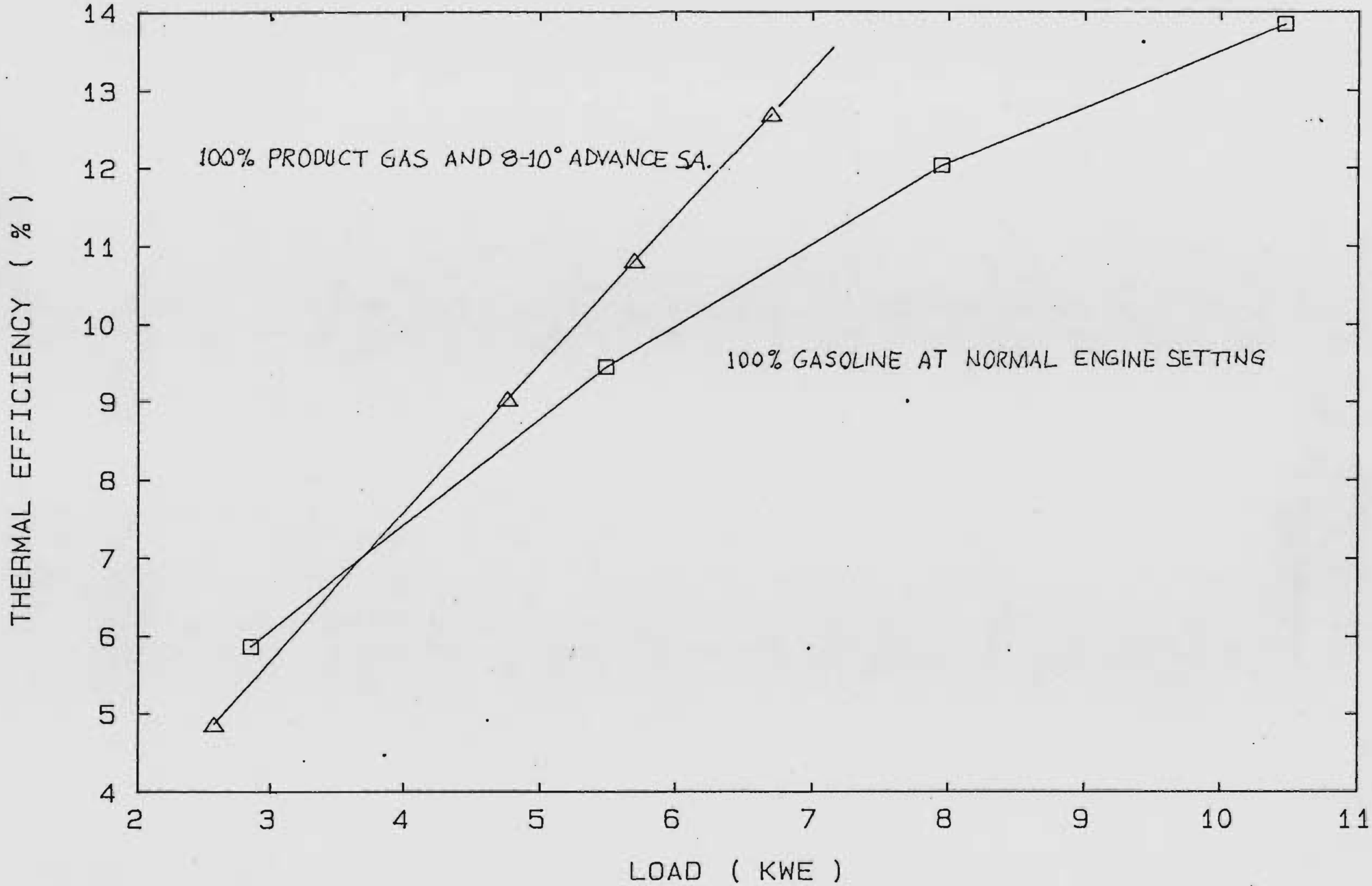

FIG. 9 : PLOT OF ELECTRIC LOAD VS. THERMAL EFFICIENCY

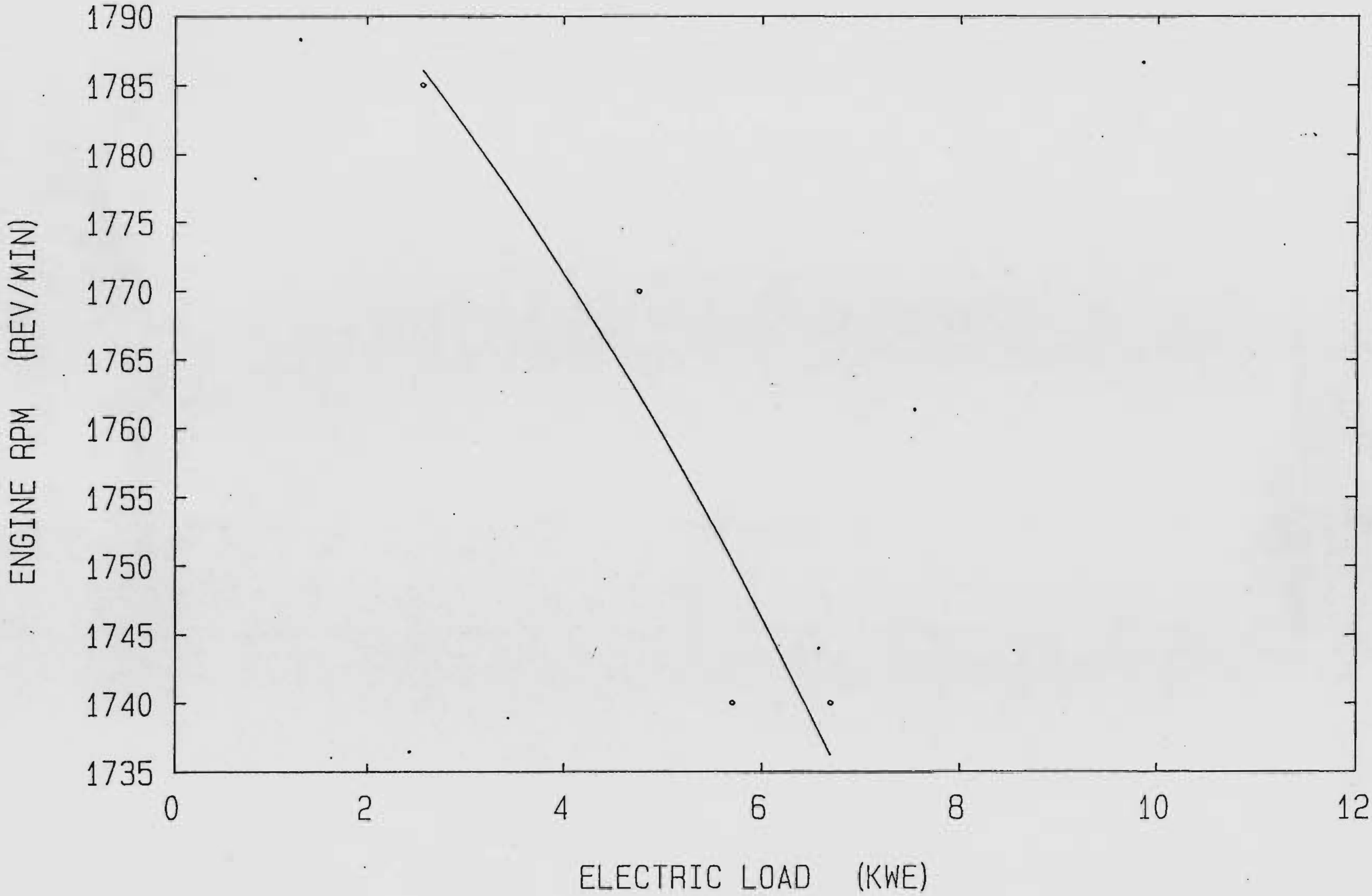

FIG. 10a· Plot of Load VS. RPM on 100% P. Gas and 8-10 Advanced Spark Advance

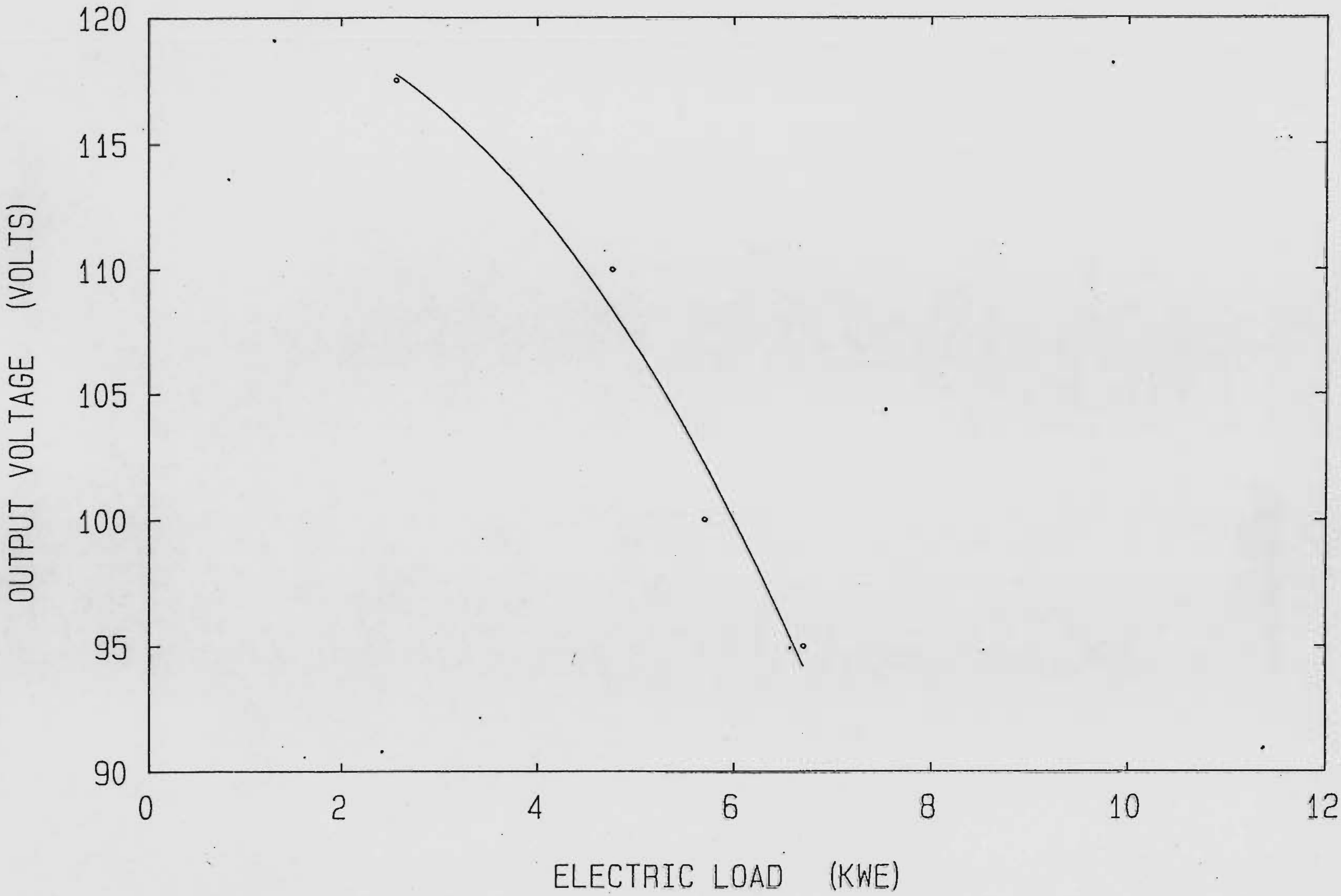

FIG. 10b Plot of Load VS. Voltage on 100% P. Gas and 8-10° Advanced Spark Advance

7.0 FLUIDIZED BED GASIFIER - DIESEL ENGINE/GENERATOR SET RETROFITTING SCHEME AND PERFORMANCE.

7.1 DIESEL ENGINE AND GENERATOR SET SPECIFICATION

1. Engine: 3 cylinders, 1800 rpm, 18 hp, Monarch Engine Corporation SN CSR 320 1897 MOI.
2. Diesel Engine-Generator Set: 10 kw, 1800 rpm, 0.8 pf, 60 cps, 35 amps, 120/208 v, 3 phase, wire SN PU-669 A/G Consolidated Diesel Electric Co.

   * The engine and generator set were Army surpluses.

7.2 DIESEL ENGINE/GENERATOR SET RETROFITTING SCHEME.

As in the gasoline engine, the cooled and cleaned gas was introduced to the diesel engine thru the air intake line and manifold as shown in Figure 11.

The diesel engine was started up and run on its normal diesel fuel oil run mode while the product gas was being flared through valve F. As the speed stabilized, the gas valve was gradually opened while the air valve (A) and the flare valve (F) were gradually closed. Consequently, the engine reeved up and to set it to its original rpm of 1800, the diesel fuel oil throttle valve was adjusted to lower the dfo supply to the injector. As the electric loads were increased, the opening of the product gas valve was increased to allow for more gas into the engine. At lower loads, however, a fraction of the product gas was flared to obtain the right air gas mixture. The entry of the product gas in the engine and the subsequent reduction in the throttle valve setting to reduce the flow of dfo to the injector resulted in the reduction of dfo consumption.

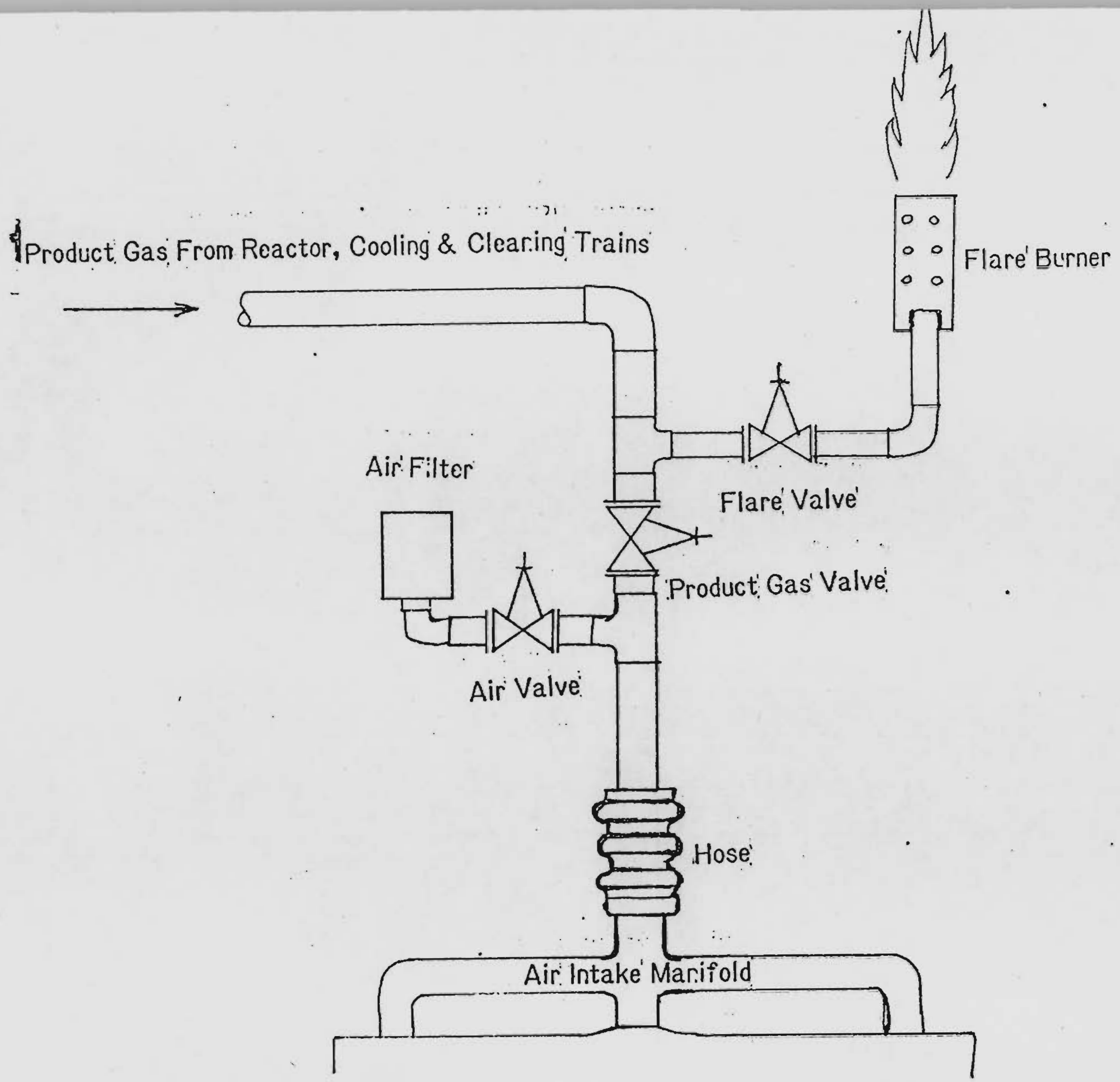

FIGURE 11 DIESEL ENGINE TO PRODUCT GAS RETROFITTING SCHEME

7.3 DISCUSSION OF RESULTS

In Figure 12, the specific dfo consumption on dual (dfo-product gas) runs showed a range of dfo percentage substitution of 35-57% at various loads. The highest substitution percentage rate was obtained at a load of 5.81 kw at 1747 rpm. A maximum of 8.06 kw load was attained at 1416 rpm, 105 v and 80.8 amperes. Although higher loads were observed to be attainable, the engine run at lower rpms and voltages which were not suited for frequency and voltage sensitive loads. Tables 8 and 12 show an average of 50% thermal efficiency difference between the dual mode and 100% dfo mode runs. Figure 13 compares the thermal efficiencies on both modes.

On dual fuel run mode Figures 14 and 15 and Table 8 show that at approximately up to more than half the load, the rpm and voltage can be easily maintained at desired levels to maintain desired frequencies. However, at higher loads, both the dual and diesel modes showed increasing need for more supply of dfo. Although the electric load could still be increased, the rpms and voltages cannot be maintained. At the specified rating of 1800 rpm, it was noted that the percentage dfo substitution and voltages increased as the loads approached 5.81 kw then decreased as the loads were increased passed 5.81 kw.

Figure 16 shows the specific dfo consumption on both modes. The difference between the two curves can be seen to be fairly constant up to about 6.0 kw then narrows down above it. This can be explained by the need to increase the dfo supply to maintain the rpm as the engine takes in more load. The rice hull specific consumption on dual runs are shown in Figure 17. Just like the operation of the gasoline engine, the rice hulls feed rate was fixed at 30-32 lb/hr and 600 SCFH air rate.

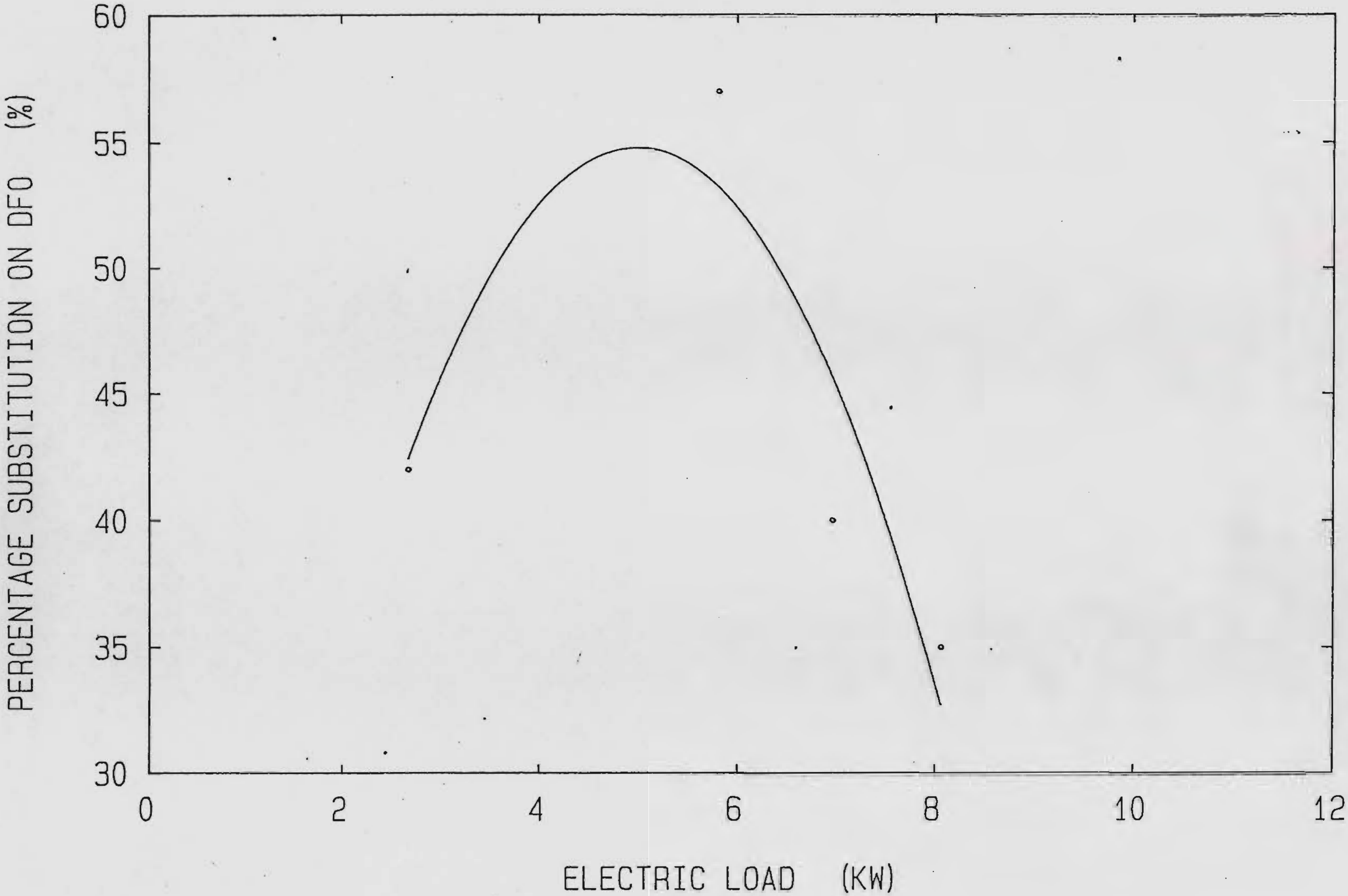

FIG. 12 Plot of Load VS.%Substitution on Dual Runs

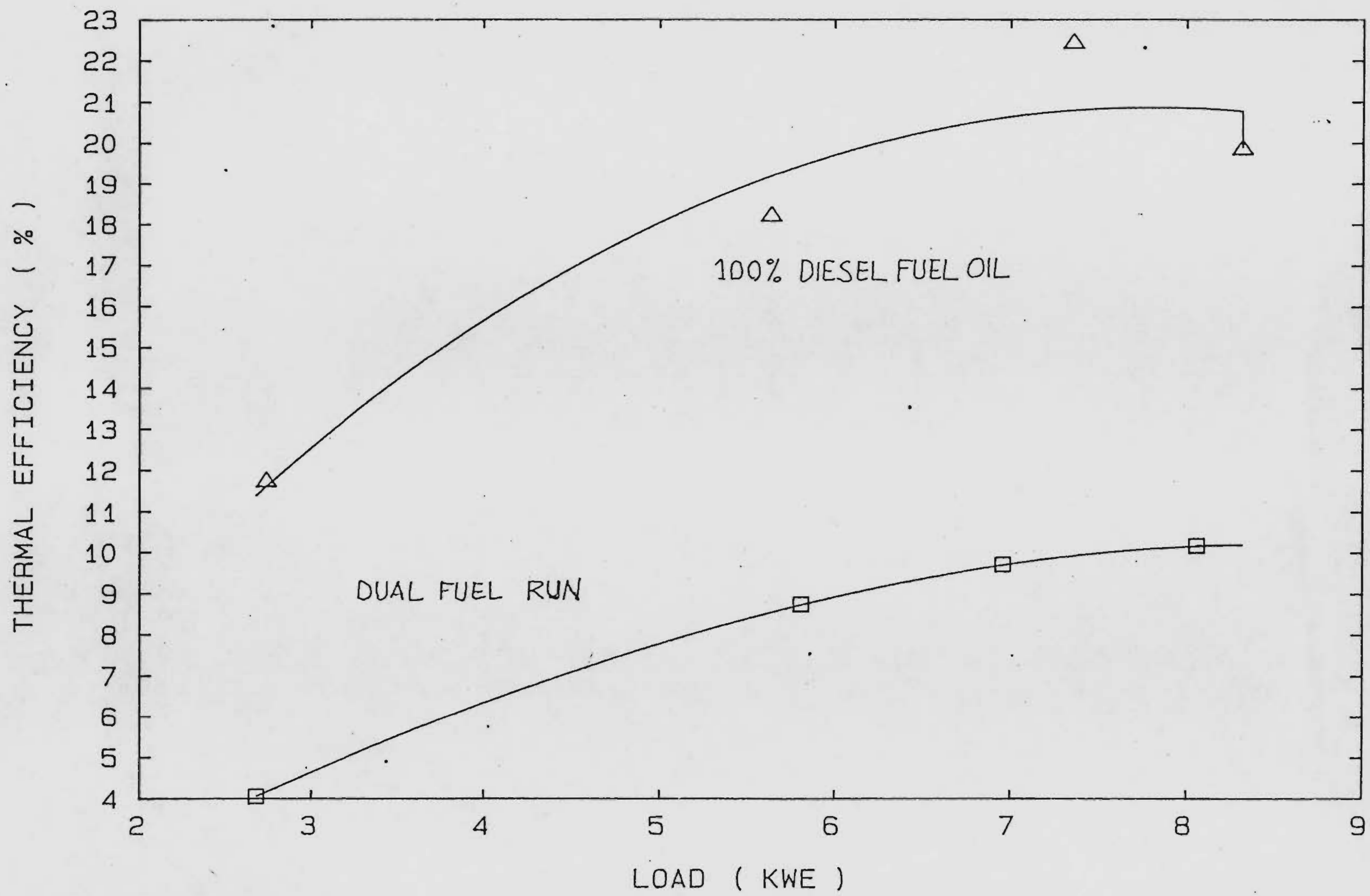

FIG. 13 : PLOT OF ELECTRIC LOAD VS. THERMAL EFFICIENCY

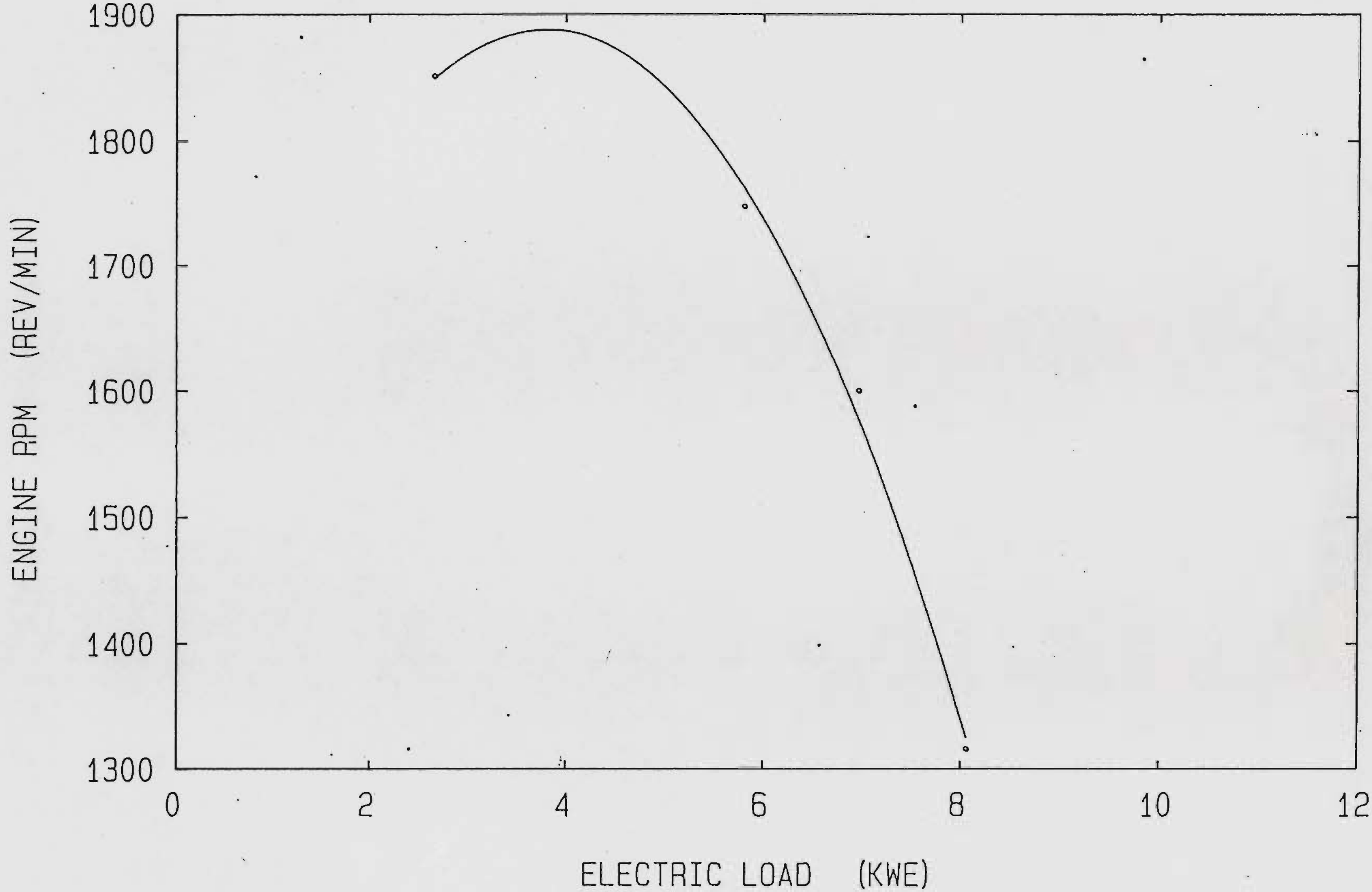

FIG. 14 Plot of Load VS. Engine RPM on Dual Fuel Runs

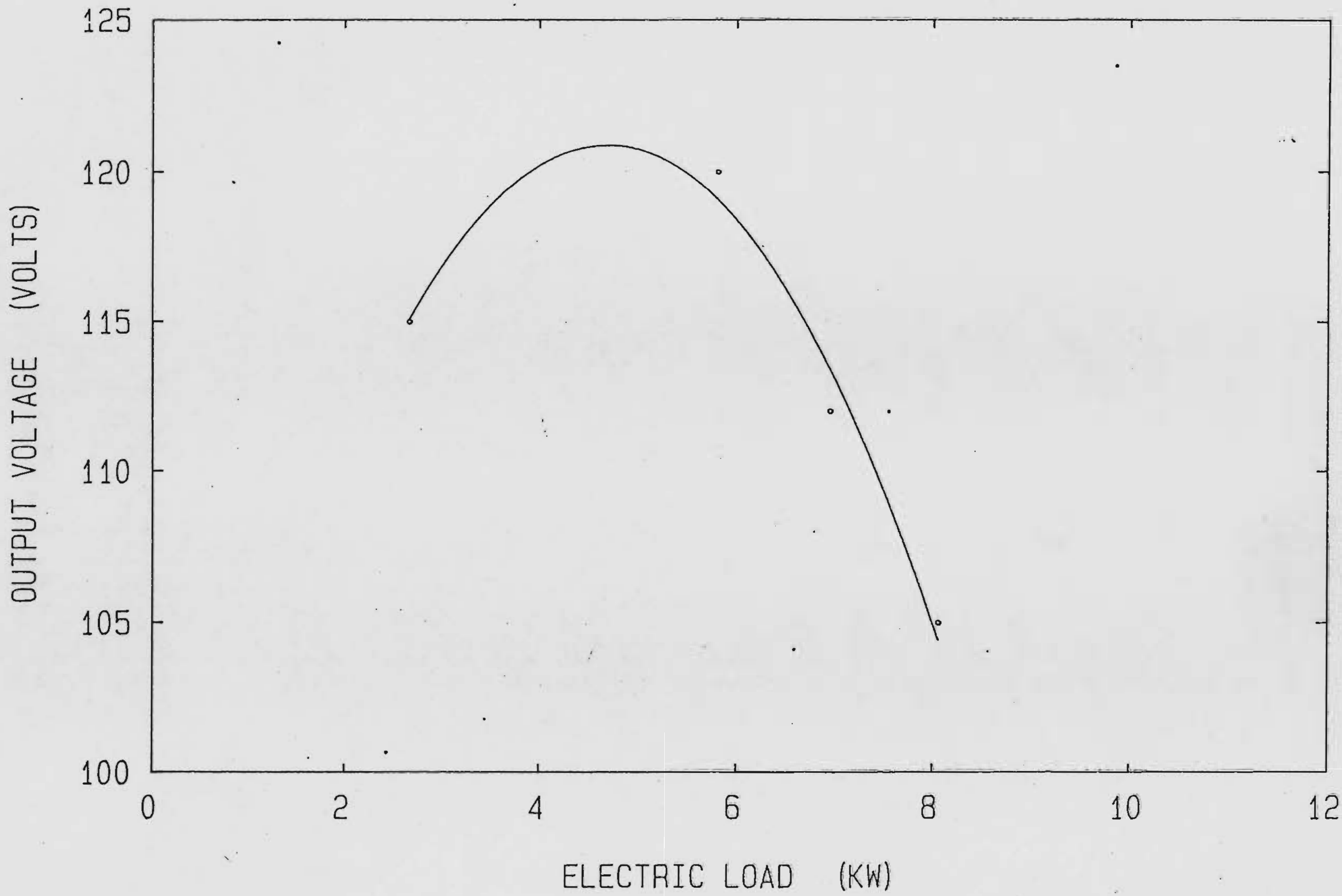

FIG. 15: Plot of Load VS. Generator Voltage on Dual Fuel Runs

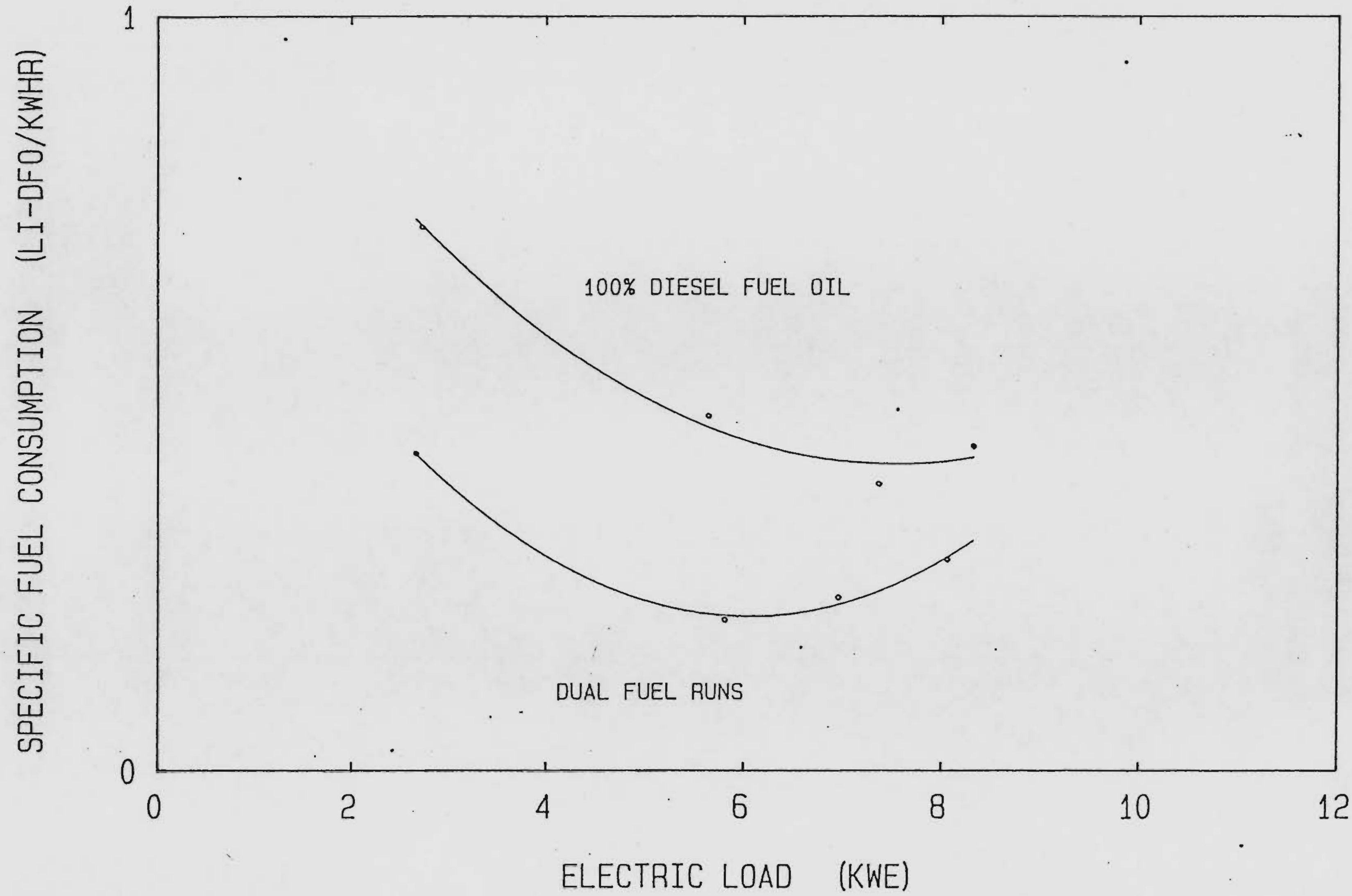

FIG. 16: Plot of Load VS. Specific Fuel Consumption

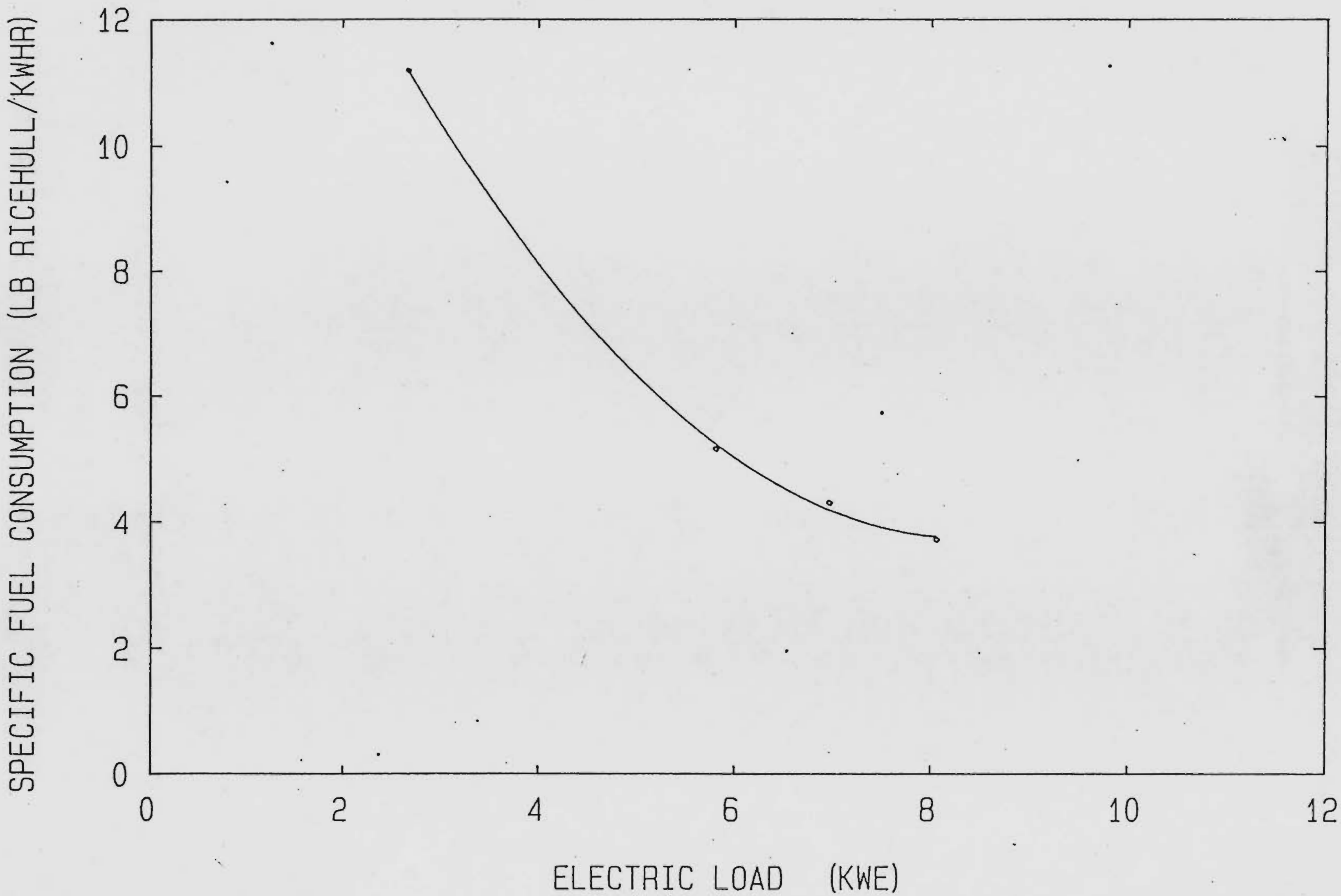

FIG: 17: Plot of Load VS. Specific Fuel Consumption on Dual Fuel Runs

8.0 OBSERVATIONS AN PRODUCT GAS QUALITY IN TERMS OF PARTICULATE AND MOISTURE LOADING.

An isokinetic gas sampler as shown in Figure 18 was fabricated and used to determine the product gas particulate and loading at the outlet of the final gas cleaning equipment - the dfo bubbler and demister. The gas sample showed an average of 0.725 g/m3 of solid particles (very fine char and ash) and trace amounts of moisture, tar and dfo. Continuous operation of both the gasoline and diesel engines showed traces of dfo, tar and moisture on the product gas intake pipe, valves and hose. However, in no case were the engines gummed up with tar so that continuous runs were affected or stopped. Each engine was started and run a number of days after product gas runs to determine whether accumulations of tar and moisture would prevent smooth start-up and continuous run. It was experienced that even at very low ambient temperatures (40-60 degrees F) the two engines could easily be started and run from a cold start. Engine oil samples for both engine were found to be clean at the end of the tests.

Inspection of the gasoline engines' carburetor showed minimal accumulation of tar and moisture. It was observed that even with small traces of tar, the two engines performed well on product gas at low ambient temperatures (40-60 degrees F).

Earlier in the test runs and prior to the use of the isokinetic sampler, the gas was passed thru a white cotton cloth or bubbled thru in clean water to determine whether some tars were still present with the gas stream. Spots of tar and moisture in the cloth or brownish-yellow coloration of the bubbled water may signify a need to replace the scrubber water, the dry filter, the dfo at the bubbler, the wood chips at the demister or cleaning of the scrubber column.

9.0 TECHNOLOGY TRANSFER AND TECHNICAL TRAINING

A major part of the research project was the technology transfer and hands-on training of two (2) Filipino engineers on the design, fabrication and operation of the 6" diameter fluidized bed gasifier and a gas cooling and cleaning component and its subsequent test on a retrofitted gasoline and diesel generator set systems.

In July 1986, Mr. Candido Miguel, the Executive Vice-President and General Manager of PADISCOR visited the GROW Project Site of the University of Missouri-Rolla. He had the chance to study and to operate the fluidized bed gasifier engine system. He was impressed with the progress of the project. After he came back to the Philippines, PADISCOR started the fabrication of a commercial prototype model of the system. The GROW project has supplied PADISCOR with the design drawings and various components for the fabrication of an 8" diameter pilot commercial model.

Another part of the research program was the academic training of the two Filipino engineers. Mr. Joaquin A. Tormo of PADISCOR and MR. Luis C. Baja, were able to pursue Masters Degrees in Engineering Management and Mechanical Engineering, respectively, at the University of Missouri-Rolla.

10.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the various findings and observations discussed earlier, the following conclusions are summarized.

1. Feeding of rice hulls at 30-32 lb/hr from the bottom section of the reactor resulted to better temperature and pressure control, improved gas quality and easier operation.
2. For a 6-inch diameter bottom fed fluidized bed gasifier using rice hulls, the air/fuel ratio of 19 to 20 SCF air per pound rice hull was found to maintain a gasification temperature ranging from 1,450 to 1,550°F.

3. At the conditions in 2, product gas heating values from 128 to 156 BTU/SCF were maintained.

4. The optimum sand level was found to be 18 inches. The sand used in the test runs was 60 mesh.

5. The pressure drop from the bottom of the reactor to the outlet of the demister, just before the gas enters the two engines, ranged from 33 to 65 inches of water. The pressure drop across the scrubber column was observed to be 4.5 inches of water.

6. The gasification of rice hull in a fluidized bed system proved to be an effective energy conversion process since continuous fuel and air feeding and char and ash removal could be easily accomplished. Since the temperature in the reactor is closely controlled, clinkering and slagging of the ash is prevented.

7. Primary gas cleaning by the use of a double cyclone and a bubble cap-type scrubber system with a recirculating water-detergent solution proved effective in removing the product gas impurities. Consequently, final gas cleaning should be provided, in this case, by bubbling the gas on a diesel fuel oil sump and drying/demisting the gas using dried wood chips. The impurities in the gas sample after passing through the gas clean-up system averaged 745 mg/m3 of gas.

8. A gasoline engine could be adapted to product gas operation with minor modification on the carburetor air intake line. However, additional gain in power delivery and fairly constant rpm could be attained with adjustments on the spark advance and finer adjustments on the air/product gas mixing valves.

9. A diesel engine could be easily adapted to product gas operation with a simple piping and valve assembly connected to the air intake manifold.

10. The operation of both engines on product gas showed acceptable operating parameters on loads of 50-60% of rated load on with the conventional fuel (gasoline or diesel fuel oil).

With the encouraging results on the fluidized bed gasification of loose rice hull and the proven suitability of the product gas as fuel for a conventional gasoline or diesel engine, the following courses of actions are recommended;

1. Immediate development of a pilot commercial model to generate power for rice milling operation and subsequent field tests by PADISCOR in the Philippines should be undertaken. (Please refer to Appendix B).

2. Continued technical support, assistance and exchange of information between the USAID, UMR-GROW Project and PADISCOR in the pilot commercialization activities in the Philippines.

3. Closer coordination between UMR-GROW Project and PADISCOR on the product development of a commercial type rice hull storage and feeding system, product gas cleaning and cooling system and product gas-air control system.

4. Continued applied research by conducting endurance test runs on retrofitted engines running on product gas from rice hull fluidized bed gasifier system under varying loads and local operating conditions.

TABLE 1

REACTOR TEMPERATURE PROFILE

A	1	2	3	4	5	6	7
B	450	550	500	500	650	700	750
C	29.0	30.0	30.0	30.0	36.0	35.0	33.0
D	15.5	18.3	16.7	16.7	18.1	20.0	22.7
T1	1138	1250	1313	1348	1295	1254	1342
T2	1323	1229	1093	1208	1238	1145	1310
T3	1308	1219	1101	1209	1238	1260	1315
T4	1307	1239	1127	1231	1249	1274	1338
T5	1252	1212	1158	1249	1238	1264	1332
T6	1118	1157	1231	1269	1227	1233	1319
T7	1166	1289	1346	1395	1313	1258	1338
T8	1131	1305	1362	1380	1344	1272	1370
T9	664	853	736	773	1050	845	1041
T10	-	-	-	-	-	451	-
T11	-	-	-	-	-	407	-
T12	-	-	-	-	-	160	-
T13	-	-	163	215	156	122	-
T14	-	-	-	-	111	99	-
T15	-	-	107	139	84	92	-
T16	-	-	-	-	-	91	-

Note:

Legend for Table 1 is found on page .

TABLE 1 (Continuation)

REACTOR TEMPERATURE PROFILE

A	8	9	10	11	12	13	14
B	660	1000	900	850	825	600	600
C	30.0	37.0	33.0	30.0	37.5	30.0	29.0
D	22.0	27.0	27.3	28.3	22.0	20.0	20.7
T1	1304	1346	1351	1300	1368	1272	1519
T2	1317	1327	1380	1317	1366	1270	1537
T3	1324	1328	1365	1313	1368	1274	1500
T4	1323	1345	1398	1331	1391	1273	1338
T5	1319	1339	1394	1326	1393	1206	1263
T6	1319	1391	1329	1270	1332	1093	1179
T7	1342	1343	1373	1321	1398	1011	1109
T8	1251	1304	1352	1309	1374	969	1075
T9	1177	1269	1282	1238	1230	804	934
T10	633	722	773	721	653	350	426
T11	428	547	591	559	498	285	331
T12	275	351	461	423	331	195	206
T13	172	267	371	339	245	160	167
T14	101	96	87	120	128	106	91
T15	118	133	137	123	108	107	104
T16	116	129	124	102	97	114	95

Note:

Legend for Table 1 is found on page .

TABLE 1 (Continuation)

REACTOR TEMPERATURE PROFILE

A	15	16	18	19	20	21	22
B	600	600	600	600	789	673	713
C	30.0	30.0	30.0	30.0	29.6	30.0	27.0
D	20.0	20.0	20.0	20.0	26.7	22.4	26.4
T1	1391	1329	1269	1361	1336	1381	1426
T2	1426	1346	1282	1342	1371	1384	1427
T3	1356	1311	1256	1351	1330	1377	1425
T4	1184	1258	1193	1218	1294	1332	1370
T5	994	1216	1075	1107	1228	1257	1289
T6	917	1163	972	999	1130	1155	1181
T7	878	1101	885	936	1046	1073	1103
T8	726	1071	821	885	1011	1038	1063
T9	299	677	649	789	871	876	876
T10	236	405	209	228	339	290	329
T11	127	308	143	161	245	208	239
T12	126	204	118	148	139	133	124
T13	97	197	115	138	143	130	120
T14	99	146	-	-	-	-	-
T15	102	154	70	117	94	85	70
T16	98	152	73	116	93	86	53

Note:

Legend for Table 1 is found on page .

TABLE 1 (Continuation)

REACTOR TEMPERATURE PROFILE

A	23	24	25	26	27	28	29
B	603	645	600	600	578	630	600
C	29.3	28.7	29.7	30.0	30.0	30.0	30.0
D	20.6	22.5	20.2	20.0	19.3	21.0	20.0
T1	1357	1422	1375	1279	1581	1405	1518
T2	1361	1413	1386	1279	1557	1395	1495
T3	1353	1431	1364	1278	1605	1414	1541
T4	1287	1309	1246	1248	1529	1328	1412
T5	1212	1234	1163	1213	1442	1254	1361
T6	1110	1120	1051	1167	1337	1152	1284
T7	1032	1039	973	1110	1269	1085	1217
T8	997	978	941	1089	1236	1052	1191
T9	956	826	803	899	1119	981	1090
T10	298	269	211	459	498	221	422
T11	211	182	139	348	379	127	359
T12	122	92	110	-	203	98	197
T13	112	85	98	162	142	98	129
T14	-	-	-	-	-	68	-
T15	57	49	53	97	74	65	55
T16	57	49	53	97	67	72	51

Note:

Legend for Table 1 is found on page .

TABLE 1 (Continuation)

REACTOR TEMPERATURE PROFILE

A	30	31	32	33	34	35	36
B	646	614	600	600	600	600	600
C	30.0	32.0	30.0	30.0	30.0	31.0	31.0
D	21.5	19.2	20.0	20.0	20.0	19.4	19.4
T1	1275	1494	1460	1524	1460	1502	1489
T2	1309	1476	1450	1508	1452	1490	1478
T3	1241	1512	1469	1539	1468	1513	1500
T4	1116	1378	1415	1453	1380	1413	1406
T5	1080	1328	1358	1393	1325	1354	1346
T6	1023	1265	1280	1308	1251	1277	1269
T7	954	1195	1223	1245	1197	1220	1212
T8	929	1174	1197	1215	1171	1194	1186
T9	615	1041	1016	1064	1028	1049	1019
T10	360	443	477	491	494	511	507
T11	293	318	361	385	363	418	434
T12	191	147	209	231	184	234	274
T13	168	122	146	159	145	176	195
T14	98	-	93	87	109	94	103
T15	117	66	94	83	83	93	113
T16	117	61	83	61	80	90	105

Note:

Legend for Table 1 is found on the next page.

Legend:

A - TEST RUN NUMBER

B - AIR RATE, (SCFH)

C - FUEL FEED RATE, (POUNDS/HOUR)

D - AIR/FUEL RATIO, (SCF AIR/POUND RICE HULL)

T1 - AVERAGE GASIFICATION TEMPERATURE

T2 - REACTOR TEMP. 2 FT ABOVE THE BOTTOM OF THE SAND BED, F

T3 - REACTOR TEMP. 3 FT ABOVE THE BOTTOM OF THE SAND BED, F

T4 - REACTOR TEMP. 4 FT ABOVE THE BOTTOM OF THE SAND BED, F

T5 - REACTOR TEMP. 5 FT ABOVE THE BOTTOM OF THE SAND BED, F

T6 - REACTOR TEMP. 6 FT ABOVE THE BOTTOM OF THE SAND BED, F

T7 - REACTOR TEMP. 7 FT ABOVE THE BOTTOM OF THE SAND BED, F

T8 - REACTOR TEMP. 8 FT ABOVE THE BOTTOM OF THE SAND BED, F

T9 - GAS TEMPERATURE AT THE TOP OF THE REACTOR, 15 FEET FROM THE BOTTOM OF THE SAND BED.

T10 - GAS TEMPERATURE AFTER PASSING THROUGH THE 2 CYCLONE SEPARATORS, F

T11 - GAS TEMPERATURE ALONG THE GAS LINE LEADING TO THE GAS CLEAN-UP SYSTEM, F

T12 - GAS TEMPERATURE BEFORE ENTERING THE DRY FILTER FOR PRODUCT GAS, F

T13 - GAS TEMPERATURE AFTER PASSING THROUGH THE DRY FILTER AND BEFORE ENTERING THE GAS SCRUBBER, F

T14 - GAS TEMPERATURE AFTER PASSING THROUGH THE GAS SCRUBBER, F

T15 - TEMPERATURE OF THE WATER EXITING FROM THE BOTTOM OF THE GAS SCRUBBER, F

T16 - TEMPERATURE OF THE WATER RECIRCULATED TO THE TOP OF THE GAS SCRUBBER, F

TABLE 2

AIR/FUEL RATIO, AVERAGE GASIFICATION TEMPERATURE AND HEATING VALUE

TEST RUN NUMBER	GAS SAMPLE NUMBER	AIR/FUEL RATIO, SCF/LB	AVERAGE GASIFICATION TEMPERATURE, F	HEATING VALUE, BTU/SCF
1	1	13.8	1,139	116
1	2	16.7	1,165	135
1	3	15.3	1,150	125
1	4	16.7	1,143	108
2	5	18.3	1,333	113
2	6	18.3	1,305	129
2	7	20.0	1,302	98
2	8	20.0	1,291	109
2	9	16.7	1,173	93
5	12	18.1	1,364	136
5	13	18.1	1,321	154
6	14	21.0	1,281	114
6	15	18.7	1,285	135
7	16	17.3	1,325	152
7	17	21.7	1,327	118
7	18	30.0	1,327	101
7	19	30.0	1,360	60
8	20	23.3	1,321	147
8	21	21.7	1,274	155
9	22	30.3	1,357	77
9	23	25.0	1,308	116

TABLE 2 (Continuation)

AIR/FUEL RATIO, AVERAGE GASIFICATION TEMPERATURE AND HEATING VALUE

TEST RUN NUMBER	GAS SAMPLE NUMBER	AIR/FUEL RATIO, SCF/LB	AVERAGE GASIFICATION TEMPERATURE, F	HEATING VALUE, BTU/SCF
10	25	27.3	1,366	68
10	26	27.3	1,414	84
11	27	23.3	1,308	134
11	28	26.7	1,254	120
11	29	33.3	1,337	85
11	30	30.0	1,332	104
16	35	20.0	1,340	123
16	36	20.0	1,335	151
16	37	20.0	1,266	114
17	38	20.0	1,320	149
17	39	23.3	1,345	135
17	40	20.0	1,250	112
18	41	20.0	1,350	159
18	42	20.0	1,240	72
18	43	20.0	1,220	61
20	44	21.4	1,380	127
20	45	26.7	1,330	61
20	46	26.7	1,310	84
20	47	26.7	1,337	107
21	49	20.0	1,478	179
21	50	20.0	1,360	130

TABLE 2 (Continuation)

AIR/FUEL RATIO, AVERAGE GASIFICATION TEMPERATURE AND HEATING VALUE

TEST RUN NUMBER	GAS SAMPLE NUMBER	AIR/FUEL RATIO, SCF/LB	AVERAGE GASIFICATION TEMPERATURE, F	HEATING VALUE, BTU/SCF
21	52	23.3	1,360	126
21	53	23.3	1,370	105
22	55	26.9	1,370	71
22	56	23.1	1,440	125
23	57	25.0	1,400	51
23	58	21.4	1,360	109
23	59	16.7	1,367	137
23	61	20.0	1,319	102
23	62	20.0	1,314	171
24	63	25.0	1,478	68
24	64	21.4	1,490	101
25	67	21.4	1,400	134
25	68	21.4	1,360	134
25	69	21.4	1,412	148
26	70	20.0	1,378	165
26	72	20.0	1,350	162
26	73	20.0	1,279	157
26	74	20.0	1,250	139
26	75	20.0	1,200	131
27	76	20.0	1,496	107
27	77	20.0	1,612	110

TABLE 2 (Continuation)

AIR/FUEL RATIO, AVERAGE GASIFICATION TEMPERATURE AND HEATING VALUE

TEST RUN NUMBER	GAS SAMPLE NUMBER	AIR/FUEL RATIO, SCF/LB	AVERAGE GASIFICATION TEMPERATURE, F	HEATING VALUE, BTU/SCF
27	79	18.3	1,546	134
29	80	20.0	1,426	115
29	81	20.0	1,380	113
30	82	20.0	1,476	91
30	83	20.0	1,499	146
30	84	20.0	1,511	133
30	85	20.0	1,504	134
30	86	20.0	1,491	127
31	87	18.8	1,510	137
31	88	18.8	1,514	150
32	89	20.0	1,470	153
32	90	20.0	1,453	151
33	91	20.0	1,525	130
33	92	20.0	1,507	139
33	93	20.0	1,551	129
33	94	20.0	1,543	128
33	95	20.0	1,549	132
34	96	20.0	1,468	147
35	97	19.4	1,496	142
35	98	19.4	1,515	146
35	99	19.4	1,493	147
35	100	19.4	1,505	144

TABLE 2 (Continuation)

AIR/FUEL RATIO, AVERAGE GASIFICATION TEMPERATURE
AND HEATING VALUE

TEST RUN NUMBER	GAS SAMPLE NUMBER	AIR/FUEL RATIO, SCF/LB	AVERAGE GASIFICATION TEMPERATURE, F	HEATING VALUE, BTU/LB
36	101	19.4	1,504	156
36	102	19.4	1,475	150
36	103	19.4	1,493	145
36	104	19.4	1,480	149

TABLE 3

GAS COMPOSITION

RUN - SAMPLE	H2	CO2	C2H4	C2H6	N2	CH4	CO	C3+	H.V.
1- 1	.0322	.1453	.1108	.0017	.5430	.0267	.1349	.0053	116
1- 2	.0359	.1657	.0103	.0022	.5897	.0295	.1583	.0083	135
1- 3	.0260	.1587	.0104	.0020	.6081	.0260	.1620	.0067	125
1- 4	.0179	.1550	.0081	.0015	.6384	.0200	.1529	.0064	108
2- 5	.0283	.1658	.0123	.0016	.6299	.0257	.1316	.0048	113
2- 6	.0345	.1606	.0125	.0020	.6028	.0281	.1531	.0065	129
2- 7	.0243	.0662	.0098	.0014	.6498	.0209	.1234	.0034	98
2- 8	.0311	.1567	.0105	.0015	.6333	.0230	.1398	.0042	109
2- 9	.0209	.1598	.0086	.0011	.6606	.0179	.1266	.0045	93
5- 12	.0411	.1763	.0146	.0018	.5956	.0311	.1308	.0086	136
5- 13	.0321	.1603	.0127	.0028	.5733	.0331	.1746	.0112	154
6- 14	.0229	.1578	.0124	.0017	.6437	.0263	.1295	.0057	114
6- 15	.0373	.1509	.0118	.0022	.6103	.0285	.1497	.0092	135
7- 16	.0216	.1537	.0157	.0027	.5919	.0356	.1694	.0095	152
7- 17	.0055	.1969	.0126	.0018	.6126	.0270	.1352	.0083	118
7- 18	.0150	.1679	.0099	.0015	.6675	.0217	.1083	.0081	101
7- 19	.0000	.1795	.0049	.0004	.7438	.0097	.0525	.0093	60
8- 20	.0178	.1537	.0178	.0022	.5951	.0403	.1679	.0052	147
8- 21	.0124	.1544	.0195	.0023	.5915	.0429	.1704	.0067	155
9- 22	.0134	.1878	.0094	.0009	.6743	.0185	.0932	.0026	77
9- 23	.0309	.1796	.0129	.0017	.6133	.0277	.1289	.0050	116
9- 24	.0260	.1769	.0118	.0014	.6379	.0246	.1174	.0042	103
10-25	.0064	.3563	.0101	.0006	.5223	.0155	.0872	.0016	63

TABLE 3 (Continuation)

GAS COMPOSITION

RUN - SAMPLE	H2	CO2	C2H4	C2H6	N2	CH4	CO	C3+	H.V.
10- 26	.0082	.1662	.0124	.0014	.6838	.0169	.1074	.0038	84
11- 27	.0095	.1669	.0167	.0023	.6005	.0233	.1727	.0081	134
11- 28	.0191	.1938	.0139	.0021	.5936	.0214	.1493	.0068	120
11- 29	.0156	.2007	.0110	.0011	.6419	.0174	.1092	.0030	85
11- 30	.0213	.2004	.0130	.0015	.6123	.0213	.1260	.0041	104
16- 35	.0271	.1734	.0119	.0020	.6013	.0295	.1495	.0053	123
16- 36	.0470	.1676	.0135	.0025	.5531	.0356	.1740	.0068	151
16- 37	.0249	.1701	.0077	.0021	.6130	.0263	.1501	.0059	114
17- 38	.0490	.1729	.0112	.0031	.5393	.0407	.1797	.0040	149
17- 39	.0262	.1738	.0128	.0024	.5717	.0328	.1759	.0045	135
17- 40	.0168	.1689	.0086	.0021	.6109	.0255	.1630	.0041	112
18- 41	.0655	.1579	.0115	.0026	.5332	.0393	.1837	.0063	159
18- 42	.0000	.1753	.0036	.0013	.6861	.0154	.1139	.0044	72
18- 43	.0002	.1775	.0035	.0009	.7027	.0115	.1001	.0035	61
20- 44	.0635	.1615	.0104	.0000	.5648	.0358	.1637	.0003	127
20- 45	.0000	.1692	.0048	.0010	.7012	.0153	.1080	.0006	61
20- 46	.0156	.1696	.0065	.0014	.6592	.0196	.1260	.0022	84
20- 47	.0267	.1656	.0077	.0017	.6271	.0247	.1421	.0044	107
21- 49	.0861	.1541	.0155	.0021	.4991	.0490	.1898	.0043	179
21- 50	.0454	.1654	.0091	.0019	.5865	.0314	.1541	.0062	130
21- 51	.0218	.1715	.0075	.0012	.6553	.0217	.1175	.0035	90
21- 52	.0431	.1617	.0093	.0020	.5887	.0309	.1602	.0041	126
21- 53	.0449	.1688	.0074	.0018	.6183	.0279	.1289	.0020	105

TABLE 3 (Continuation)

GAS COMPOSITION

RUN - SAMPLE	H2	CO2	C2H4	C2H6	N2	CH4	CO	C3+	H.V.
22- 55	.0123	.1796	.0070	.0010	.6716	.0181	.1104	.0000	71
22- 56	.0256	.1781	.0141	.0017	.5796	.0389	.1619	.0000	125
23- 57	.0039	.1865	.0056	.0005	.7123	.0148	.0765	.0000	51
23- 58	.0388	.1659	.0083	.0015	.6184	.0263	.1368	.0039	109
23- 59	.0488	.1666	.0109	.0024	.5584	.0373	.1733	.0023	137
23- 61	.0248	.1701	.0065	.0017	.6317	.0236	.1368	.0048	102
23- 62	.0599	.1639	.0103	.0030	.5157	.0424	.1958	.0090	171
24- 63	.0079	.1806	.0070	.0010	.6863	.0210	.0961	.0000	68
24- 64	.0561	.1672	.0079	.0010	.6159	.0279	.1239	.0000	101
25- 67	.0511	.1650	.0094	.0019	.5856	.0348	.1457	.0065	134
25- 68	.0496	.1652	.0090	.0023	.5802	.0343	.1534	.0060	134
25- 69	.0446	.1741	.0121	.0024	.5580	.0402	.1620	.0067	148
26- 70	.0660	.1554	.0118	.0025	.5259	.0404	.1914	.0066	165
26- 72	.0551	.1621	.0107	.0027	.5330	.0402	.1881	.0080	162
26- 73	.0378	.1658	.0088	.0029	.5444	.0390	.1920	.0093	157
26- 74	.0301	.1661	.0069	.0026	.5730	.0336	.1792	.0085	139
26- 75	.0203	.1662	.0055	.0027	.5863	.0312	.1795	.0082	131
27- 76	.0189	.1686	.0119	.0012	.6223	.0329	.1441	.0000	107
27- 77	.0397	.1665	.0115	.0004	.6083	.0321	.1414	.0000	110
27- 78	.0497	.1641	.0109	.0005	.6047	.0307	.1393	.0000	111
27- 79	.0556	.1606	.0134	.0011	.5651	.0376	.1663	.0003	134
29- 80	.0358	.1632	.0086	.0016	.6148	.0293	.1426	.0042	115
29- 81	.0400	.1666	.0073	.0016	.6117	.0280	.1402	.0045	113

TABLE 3 (Continuation)

GAS COMPOSITION

RUN - SAMPLE	H2	CO2	C2H4	C2H6	N2	CH4	CO	C3+	H.V.
30- 82	.0203	.1741	.0095	.0010	.6498	.0281	.1170	.0003	91
30- 83	.0410	.1632	.0146	.0017	.5613	.0421	.1733	.0029	146
30- 84	.0363	.1678	.0144	.0015	.5700	.0410	.1690	.0000	133
30- 85	.0371	.1632	.0142	.0015	.5730	.0414	.1695	.0000	134
30- 86	.0342	.1655	.0137	.0015	.5832	.0385	.1634	.0000	127
31- 87	.0396	.1595	.0131	.0017	.5790	.0385	.1655	.0032	137
31- 88	.0425	.1584	.0144	.0018	.5581	.0419	.1791	.0037	150
32- 89	.0450	.1590	.0139	.0019	.5558	.0421	.1777	.0046	153
32- 90	.0440	.1603	.0135	.0020	.5581	.0411	.1762	.0048	151
33- 91	.0459	.1640	.0135	.0014	.5763	.0379	.1610	.0000	130
33- 92	.0475	.1643	.0138	.0015	.5684	.0391	.1631	.0023	139
33- 93	.0475	.1668	.0136	.0013	.5743	.0385	.1580	.0000	129
33- 94	.0455	.1691	.0134	.0012	.5745	.0382	.1581	.0000	128
33- 95	.0477	.1687	.0139	.0013	.5665	.0395	.1624	.0000	132
34- 96	.0499	.1618	.0134	.0018	.5559	.0396	.1738	.0038	147
35- 97	.0474	.1596	.0138	.0016	.5684	.0389	.1672	.0031	142
35- 98	.0485	.1573	.0146	.0015	.5607	.0401	.1744	.0029	146
35- 99	.0487	.1593	.0141	.0017	.5602	.0396	.1728	.0036	147
35-100	.0475	.1584	.0142	.0016	.5646	.0393	.1713	.0030	144
36-101	.0522	.1598	.0158	.0017	.5460	.0430	.1778	.0038	156
36-102	.0475	.1650	.0143	.0018	.5478	.0408	.1790	.0038	150
36-103	.0456	.1610	.0141	.0017	.5625	.0395	.1722	.0034	145
36-104	.0481	.1592	.0144	.0017	.5558	.0404	.1767	.0037	149

TABLE 4

AIR/FUEL RATIO, TEMPERATURE, HEATING VALUE, COLD GAS EFFICIENCY AND GAS COMPOSITION

RUN - SAMPLE	AIR FUEL RATIO (SCF/LB)	AVE. GAS. TEMP (F)	H.V. (BTU/SCF)	E[a]	H2	CO2	C2+	N2	CH4	CO
30- 83	20.0	1499	146	73.7	.0410	.1632	.0192	.5613	.0421	.1733
30- 84	20.0	1511	133	66.2	.0363	.1678	.0159	.5700	.0410	.1690
30- 85	20.0	1504	134	66.3	.0371	.1632	.0157	.5730	.0414	.1695
32- 89	20.0	1470	153	72.5	.0450	.1590	.0204	.5558	.0421	.1777
32- 90	20.0	1453	151	71.2	.0440	.1603	.0203	.5581	.0411	.1762
33- 91	20.0	1525	130	59.4	.0459	.1640	.0149	.5763	.0379	.1610
33- 92	20.0	1507	139	64.4	.0475	.1643	.0176	.5684	.0391	.1631
33- 93	20.0	1551	129	59.2	.0475	.1668	.0149	.5743	.0385	.1580
33- 94	20.0	1543	128	58.7	.0455	.1691	.0146	.5745	.0382	.1581
33- 95	20.0	1549	132	61.4	.0477	.1687	.0152	.5665	.0395	.1624
34- 96	20.0	1468	147	69.6	.0499	.1618	.0190	.5559	.0396	.1738
35- 97	19.4	1496	142	63.7	.0474	.1596	.0185	.5684	.0389	.1672
35- 98	19.4	1515	146	66.4	.0485	.1573	.0190	.5607	.0401	.1744
35- 99	19.4	1496	147	66.9	.0487	.1593	.0194	.5602	.0396	.1728
35-100	19.4	1505	144	65.0	.0475	.1584	.0188	.5646	.0393	.1713
36-101	19.4	1504	156	72.8	.0522	.1598	.0213	.5460	.0430	.1778
36-102	19.4	1475	150	69.8	.0475	.1650	.0199	.5478	.0408	.1790
36-103	19.4	1493	145	65.7	.0456	.1610	.0192	.5625	.0395	.1722
36-104	19.4	1480	149	68.3	.0481	.1592	.0198	.5558	.0404	.1767
AVE.	19.7	1495	143	66.4	.0460	.1625	.0181	.5632	.0401	.1702

E[a] - COLD GAS EFFICIENCY, %

TABLE 5

GASOLINE ENGINE-GENERATOR PERFORMANCE
ON 100% GASOLINE FUEL.

A	B	C	D	E	F	G	H	I	J	K	L	M
1	0	14.14	1000	1800	60.0	120	-	-	-	140	60	-
2	1/4	12.23	1000	1800	60.0	120	25.0	2.85	1.72	140	60	5.87
3	1/2	10.16	1000	1800	60.0	118	49.0	5.49	1.07	150	60	9.44
4	3/4	9.09	1000	1785	59.5	117	71.5	7.95	0.84	160	60	12.03
5	Full	7.86	1000	1785	59.5	116	95.0	10.47	0.73	160	60	13.84

Note:

A - Run No.
B - Approximate Fraction of Rated Generator Load
C - Time (min) to Consume Gasoline Volume at D
D - Gasoline Consumption (cc)
E - Rpm (rev/min) of Engine/Generator
F - Frequency (hz) of Engine/Generator
G - Voltage (v) of Load
H - Current (amps) of Load
I - Load Power (kw)
J - Specific Fuel Consumption (li-gasoline/kw-hr)
K - Cooling Water Temperature of Engine (degree F)
L - Oil Pressure (psi) of Engine
M - Thermal Efficiency, % Using Gasoline
HHV = 20,750 BTU/lb

TABLE 6

GASOLINE ENGINE-GENERATOR PERFORMANCE ON 100% PRODUCT GAS WITH ENGINE SPARK ADVANCE ADVANCED BY 8-10 DEGREES AND USING TWO AIR INLETS (VALVES A AND B).

A	B	C	D	E	F	G	H	I	J	K	L	M
1	0	-	-	1800	60.0	120.0	-	-	-	-	-	-
2	1/4	-	-	1785	59.5	117.5	23.0	2.57	11.67	140	60	4.87
3	1/2	-	-	1770	59.0	110.0	45.5	4.76	6.30	150	60	9.03
4	1/2	-	-	1740	58.0	100.0	60.0	5.70	5.26	160	60	10.82
5	3/4	-	-	1740	58.0	95.0	70.5	6.70	4.48	160	60	12.70

Note:

A - Run No.

B - Approximate Fraction of Rated Generator Load

C - Time (min) to Consume Gasoline Volume at D

D - Gasoline Consumption (cc)

E - Rpm (rev/min) of Engine/Generator

F - Frequency (hz) of Engine-Generator

G - Voltage (v) of Load

H - Current (amps) of Load

I - Load Power (kw)

J - Specific Fuel Consumption , lb(rice-hull)/kw-hr

K - Cooling Water Temperature of Engine (degree F)

L - Oil Pressure (psi) of Engine

M - Thermal Efficiency, % Using Rice Hull Average

Heating Value = 6,000 BTU/lb

TABLE 7

NO ADJUSTMENT ON THE ENGINE AND ONE AIR INLET (VALVE B).

A	B	C	D	E	F	G	H	I	J	K	L	M
1	-	-	-	<1800	<60	100	-	0	-	140	60	-
2	1/4	-	-	<1800	<60	95	19.0	1.71	17.54	140	60	3.24
3	1/4	-	-	<1800	<60	85	33.0	2.66	11.28	140	60	5.04
4	1/2	-	-	<1800	<60	95	58.5	5.28	5.68	150	60	10.02
5	-	-	-	<1800	<60	120	-	-	-	150	60	-
6	1/4	-	-	<1800	<60	110	19.3	1.83	16.39	160	60	3.47
7	1/2	-	-	<1800	<60	90	36.0	3.08	9.74	160	60	5.84
8	-	-	-	<1800	<60	50-85	-	-	-	160	60	-

Note:

A - Run No.
B - Approximate Fraction of Rated Generator Load
C - Time (min)
D - Gasoline Consumption (cc)
E - Rpm (rev/min) of Engine/Generator
F - Frequency (hz) of Engine/Generator
G - Voltage (v) of Load
H - Current (amps) of Load
I - Load Power (kw)
J - Specific Fuel Consumption, lb(rice-hull)/kw-hr
K - Cooling Water Temperature of Engine (degree F)
L - Oil Pressure (psi) of Engine
M - Thermal Efficiency, % Using Rice Hull Average Heating Value = 6,000 BTU/lb
<1800 - Less than 1800 rpm
<60 - Less than 60 hertz

Gasoline Engine-Generator Set Specifications.

1. Gasoline Engine: 4 cylinders, 1800rpm.
2. Gasoline Engine-Generator Set: 12.5 kw., 0.8 pf, 60 cps, 125 or 250 VAC 50-100 A, 1800 rpm, 2 phase wire, SN 149 ON 38203-PHLA 53-31.

TABLE 8

DIESEL FUEL OIL (DFO) SUBSTITUTION ON DUAL FUEL RUNS.*

Average Generator Load & Rpm 100% Dfo				Dual Fuel				ASFC 100% Dfo	ASFC Dual Run		A%PGS	E %
v	amp	kw	rpm	v	amp	k	rpm	a	b	c		
120	24.0	2.74	1665	115	24.5	2.68	1851	0.72	0.42	11.19	42	4.06
104	57.9	5.64	1359	120	50.9	5.81	1747	0.47	0.20	5.16	57	8.75
100	77.4	7.36	1312	112	65.5	6.96	1600	0.38	0.23	4.31	40	9.72
117	75.2	8.32	1552	105	80.8	8.06	1416	0.43	0.28	3.72	35	10.17

Note:
ASCF - Average Specific Fuel Consumption

A%PGS - Average Percentage Product Gas Substitution

E - Thermal Efficiency, % Using Dfo Heating

Value = 18,500 BTU/lb

a - li/kw-hr

b - li/kw-hr

c - lbf/kw-hr

* Using data for the most stable runs

Diesel Engine-Generator Set Specifications.

1. Diesel Engine Specification: 3 cylinders, 1800 rpm, 18 hp, Monarch Engine Corporation SN CSR 320 1897 MOI.

2. Diesel Engine-Generator Set: 10 kw, 1800 rpm, 0.8 pf, 60 cps, 35 amps, 120/208 v, 3 phase, 4 wire, SN PU-669 A/G, Consolidated Diesel Electric Co.

TABLE 9

AVERAGE DFO SUBSTITUTION ON DUAL FUEL RUNS **

Average Generator Load & Rpm 100% Dfo				Average Generator Load & Rpm Dual Fuel				ASFC 100% Dfo	ASFC Dual Run		A%PGS	E
v	amp	kw	rpm	v	amp	kw	rpm	a	b	c		%
120	24.0	2.74	1665	115.0	24.5	2.68	1860	0.72	0.42	11.19	42	4.06
104	57.9	5.64	1359	112.0	54.3	5.78	1519	0.47	0.29	5.19	38	7.50
100	77.4	7.36	1312	112.0	65.4	6.96	1600	0.38	0.23	4.31	40	9.72
117	75.2	8.32	1554	105.0	80.8	8.06	1416	0.43	0.28	3.72	35	9.99

Note:

ASFC - Average Specific Fuel Consumption

A%PGS - Average Percentage Product Gas Substitution

E - Thermal Efficiency, % Using Dfo Heating
Value = 18,500 BTU/lb

a - li/kw-hr

b - li/kw-hr

c - lbf/kw-hr

** - Using data on stable runs (stable fuel feed rate, stable average reactor temperature, no product gas back flow or leak at feeder, no rice bridging at hopper, etc.)

TABLE 10

AVERAGE DFO SUBSTITUTION ON DUAL FUEL ON ALL RUNS ***

Average Generator Load & Rpm 100% Dfo				Average Generator Load & Rpm Dual Fuel				ASFC 100% Dfo	ASFC Dual Run		A %G G S	E %
v	amp	kw	rpm	v	amp	kw	rpm	a	b	c		
120	24.0	2.74	1665	115.0	24.5	2.68	1860	0.72	0.42	11.19	42	4.06
104	57.9	5.64	1359	112.0	51.8	5.51	1458	0.47	0.32	5.44	32	7.50
100	77.4	7.36	1312	106.7	68.5	6.94	1245	0.38	0.26	4.32	32	9.38
117	75.2	8.32	1554	109.4	83.6	8.69	1510	0.43	0.29	3.45	32	0.55

Note:

ASFC - Average Specific Fuel Consumption

A%PGS - Average Percentage Product Gas Substitution

E - Thermal Efficiency, % Using Dfo Heating Value = 18,500 BTU/lb and Rice Hull Average Heating Value = 6,000 BTU/lb

a - li/kw-hr

b - li/kw-hr

c - lbf/kw-hr

*** - Using data on all runs

TABLE 11
DIESEL ENGINE PERFORMANCE ON DUAL FUEL

A	B	C	D	E	F	G	H	I
1	1/4	40.62	1000	-	115.0	24.50	2.68	0.55
2	1/4	51.74	1000	1870	115.0	24.50	2.68	0.43
	1/4	52.75	1000	1851	115.0	24.50	2.68	0.42
	1/4	45.50	1000	1806	115.0	24.50	2.68	0.49
3	1/2	25.90	1000	1910	120.0	49.80	5.68	0.41
	1/2	27.30	1000	1840	120.0	49.60	5.65	0.39
	1/2	27.47	1000	1820	120.0	50.00	5.70	0.38
4	1/2	30.20	1000	-	120.0	50.10	5.81	0.27
	1/2	50.70	1000	1747	120.0	50.10	5.81	0.20
	1/2	39.40	1000	1805	120.0	50.10	5.70	0.27
5	3/4	28.86	1000	1665	115.0	69.00	7.54	0.27
6	3/4	20.55	1000	-	115.0	65.19	7.12	0.41
	Full	23.60	1000	1650	110.0	83.80	8.76	0.29
	Full	22.18	1000	1554	112.0	85.12	9.06	0.30
7	3/4	30.86	1000	1700	111.0	67.08	7.07	0.27
	3/4	38.20	1000	1600	112.0	65.46	6.96	0.23
	Full	26.40	1000	1416	105.0	80.80	8.06	0.28
	Full	23.39	1000	1420	110.5	84.72	8.89	0.29
	3/4	25.65	1000	1240	97.4	71.80	6.64	0.35
8	1/2	42.14	1000	1232	95.0	52.23	4.71	0.30
	1/2	32.10	1000	1184	85.0	32.10	5.11	0.37
	1/2	32.69	1000	1239	100.0	32.69	5.10	0.36
9	1/2	31.56	1000	1811	122.0	50.50	5.85	0.28
	3/4	26.42	1000	1684	111.0	64.26	6.78	0.33
	3/4	25.32	1000	1405	105.0	62.49	6.23	0.38
	3/4	25.38	1000	1278	98.0	25.38	6.67	0.35
	3/4	23.40	1000	1304	100.0	23.40	6.93	0.37
	3/4	23.30	1000	1374	103.0	23.30	7.47	0.34

A -Run No.
B - Approximate Fraction of Rated Engine Load
C - Time (min) to Consume Volume at D
D - Dfo Consumption (cc)
E - Rpm (rev/min)
F - Voltage (v) of Load
G - Current (amps) of Load
H - Load Power (kw)*
I - Specific /fuel consumption (li/kw-hr)
* - Since loads were all resistive, a power factor of
0.95 was used in the computation of gen. load

TABLE 12

DIESEL ENGINE PERFORMANCE ON 100% FUEL OIL (DFO).

A	B	C	D	E	F	G	H	I	J
1	1/4	30.12	1000	1650	120	24.6	2.80	0.71	11.95
	1/4	30.80	1000	1680	120	23.4	2.67	0.73	11.62
	1/2	21.42	1000	1600	120	46.0	5.24	0.53	16.01
2	1/2	18.12	1000	1383	110	61.7	6.44	0.51	16.64
3	Full	16.70	1000	1600	120	72.9	8.31	0.43	19.73
	Full	16.50	1000	1609	120	73.5	8.38	0.43	19.73
4	3/4	18.26	1000	1452	105	78.0	7.78	0.42	20.20
	Full	17.28	1000	1452	110	79.3	8.28	0.42	20.20
5	1/2	26.02	1000	1292	101	57.4	5.51	0.42	20.20
	1/2	28.12	1000	1161	85	66.7	5.39	0.42	20.20
	3/4	24.34	1000	1210	100	81.4	7.73	0.32	26.51
	3/4	22.35	1000	1275	95	72.7	6.56	0.41	20.69

Note:
A - Run No.
B - Approximate Fraction of Rated Engine Load
C - Time (min) to Consume Volume at D
D - Dfo Consumption (cc)
E - Rpm (rev/min)
F - Voltage (v) of Load
G - Current (amps) of Load
H - Load Power (kw)
I - Specific Fuel Consumption (li/kw-hr)
J - Overall Thermal Efficiency, % Using HHV = 18,500 BTU/lb

11.0 APPENDICES

APPENDIX A BIBLIOGRAPHY

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APPENDIX B A PRELIMINARY ECONOMIC STUDY

Economic Evaluation of Fluidized Bed
Gasifier Using Rice Hull As Fuel as
a Non-Conventional Source of Energy

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INTRODUCTION

This report will consider the use of engineering economy methods in evaluating the economic feasibility of utilizing Fluidized Bed Gasifiers as source of non-conventional energy in operating rice milling plants in the Philippines. The Fluidized Bed Gasifier will use the rice hull, a by-product of milling operation, as the source of energy.

This study will be made from the point of view of an equipment supplier or manufacturing company which would like to determine the market potential of fluidized bed gasifiers in the Philippines.

This study would help the company in the following areas of its interest;

1. Determination of the possible demand for the project.

2. Determination of the most likely buyers among the possible customers.

3. Determination of the Selling Price at which the equipment or the project will still be attractive.

The Rice Milling Industry is chosen as a possible market because of the following reasons;

1. The rice milling industry is not as sensitive as the other industries with regards to fluctuations in economic conditions of the country. This is primarily because rice is the staple food of the people, therefore, even if the economy turns from bad to worse, continued demand for rice is still assured.

2. There are thousands of rice milling plants in the country. Among these, about 1,000 plants are of adequate capacity to afford having a gasifier system installed.

3. Rice milling plants produce a lot of rice hulls (this is about 25% of the production input by weight) which is more suitable for gasification in a fluidized bed than in fixed bed systems[6,13,14,15]. Right now, these hulls are just dumped or burned in the fields, resulting in environmental problems[5,15].

4. The reduction in the cost of processing rice will result to profitability and competitiveness of the millers. Therefore, it is anticipated that an equipment that would

reduce this cost would be very attractive to them.

No single economic analysis method is considered ideal in this study. Therefore, the following methods are to be used in the evaluation;

1. Internal Rate of Return
2. Net Present Value
3. Benefit Cost Ratio
4. Sensitivity analysis on fuel and energy cost.
5. Analysis on inflation and its effect on the economic feasibility of the project.

STATEMENT OF THE PROBLEM

This study will evaluate the economic feasibilty of installing a gasifier-engine system in the various rice milling plants using different types of prime movers. These are the rice mills that we can consider as the target market for this product. Listed below are the 3 types of prime movers considered in this report.

1. Diesel Engine Prime Mover (Target Market A)

   This is used to drive the central shaft of the traditional rice mill. Central shaft rice mills driven by diesel engines are usually found in the countrysides where the electrical utilities are generally designed for domestic use only.

2. Diesel Gen-Set Prime Mover (Target Market B)

   The diesel gen-set prime movers are used to drive the individual equipment electric motors of later models of rice mills which are located in the remote areas of rice producing regions. Also, some millers who do not want to be bothered by frequent power failure in the provinces use this type of prime mover.

3. Electric Motor Prime Mover (Target Market C)

   The electric motor prime movers are used to drive the central shaft of traditional rice mills that are located in the Central Plains of Luzon Island, commonly known as the rice granary of the country, where the electric service is more dependable.

Typical size rice mills with a production input capacity of 3.0 Tons per Hour (TPH) are considered in this study. Rice mills of this capacity requires 60 to 70 shaft horsepower or 45 to 50 Kw of electricity.

They are operated 12.0 hours a day and normally five days per week year round. This size of rice mills produces polished rice at the rate of 2.0 TPH. Also, the hulls and bran by-products are produced at the rate of 0.75 TPH and .25 TPH, respectively.

BACKGROUND OF THE PROJECT

The Gasification Research On Wastes (GROW) Project of the University of Missouri-Rolla, has been conducting research on gasification of rice hull and other agricultural byproducts since 1978. In 1985, the US Agency for International Development has started funding the rice hull gasification research with the objective of transferring the technology, initially to the Philippines, and ultimately to the rest of the third world countries.

This research project is done in collaboration with a Philippine company to assure effective technology transfer. A commercial proto-type of the fluidized gasifier has been designed and is now under fabrication in the Philippines. The fabrication of the proto-type model is being done by Pasig Agricultural Development & Industrial Supply Corporation (PADISCOR). This company will test the equipment under local conditions and market it, initially to the rice millers and to other industries in the long run.

The gasifier can be retro-fitted to diesel or gasoline engines. When retro-fitted to gasoline engines, 100% of fuel substitution is achieved. Diesel fuel substitution (3,4) ranges from 60-90 %, only[3,4]. Diesel fuel substitution of 75.% will be used in this study to get conservative results. In the Philippines, gasoline is more expensive than diesel fuel. For this reason, most rice mills and other industries use diesel engines than gasoline engines as prime mover for their specific applications.

SIGNIFICANCE OF RICE HULL GASIFICATION

In 1973, imported oil accounted for 92 % of the total energy requirements of the country[7]. Since then, the government has tried every effort to lessen this fuel dependency from abroad. The utilization of geothermal, hydroelectric, dendrothermal and coal energy, oil exploration and the promotion of gasifiers were encouraged by the government[17.16]. These programs resulted to the[7,12] reduction in dependency from imported oil. In 1985, the indigenous share in total energy consumption increased to about 50%. However, the decline in the price of imported in 1986 resulted in a decrease of this indigenous share to 44.0%[7]. With the expected advent of another series of oil price increases in 1987, the country is again looking for ways to further develop domestic energy sources to meet the increasing demand for energy and conservation of meager foreign currency reserves.

Capital intensive oil exploration, coal and geothermal power, are again given the priority in the energy self-reliance program of the government for 1987[7]. However, tapping of these resources would require additional loan from international financial institutions. Furthermore, this kind of endeavor could only be undertaken by the government or other large foreign or local corporations.

The other source of non-oil energy can be found in agriculture. The Philippines, as an agriculture-based country, produces an abundance of renewable energy sources in the form of agricultural wastes or by-products. Rice, as the main crop and staple food of the people, is one of the biggest contributors of by-product among the different crops produced by the country.

Continuous generation of rice hulls has created problems in its disposal. Rice hull is a non-biodegradable waste and improper disposal has led to pollution of rivers, land and air. Rice hull is a suitable fuel material with calorific value of 6,000 BTU/pound. This can be converted into usable energy and the resulting ash can be co-produced as a marketable commodity[11]. The fluidized bed gasification of rice hull results to efficient production of combustible gases and homogenous silica-ash. The combustible gases, known as producer gas, can be conveniently used to heat steam boilers or to generate power in an internal combustion engine. The ash can be used for cement making[15]. It can also be used to condition acidic soil prior to planting, as commonly practiced by the rice farmers. When the rice hull is burned, the remaining ash is only 20% of the original weight. This will further alleviate the problems of disposal.

The manufacture and utilization of fluidized bed gasifiers does not require so much capital investment as compared to biomass boiler systems or the more complex oil exploration. The technology can be easily adapted to local conditions. The government has supported the promotion of this technology in the past and now is the time for the private sector to take the initiative to promote this project[16]. Its impact, though not as great as other non-oil projects, can contribute a significant amount in the reduction of oil importation which will result to savings in the country's dollar reserve and self-reliance in energy.

The manufacture of fluidized bed gasifiers will create a new product in the market. This will result to employment opportunity for the skilled labor which is in abundant supply in the country. The installation of gasifier plants throughout the country could also provide temporary jobs. The gasifier plants require two (2) laborers to operate and this will result to employment of 2,000 workers if all the target market in the rice milling industry alone is saturated. The development of small scale cement-making industry from rice hulls will also generate employment opportunities in the villages[15]. These developments, though seemingly insignificant, are important, particularly in a country where the per capita GNP in 1986 was only about P 1,581 or US$ 77.30[8].

GASIFICATION: AN ELEMENT IN THE NATIONAL ENERGY STRATEGY

The Committee for Economic Development based in New York had presented to the US government and the private sector six (6) basic principles which are expected to help the United States to lessen its dependence on foreign oil and adjusts to the problems concerning energy use and supply, with a minimum of disruption and risk. These principles will also help prevent another oil embargo which was experienced in 1973-74.

The following are the principles formulated by CED;(2)

1. Promotion of increased supplies and greater conservation.
2. Reliance on the market system.
3. Increased reliance on coal and nuclear energy.
4. Development of energy technologies for the next century.
5. Resolving of conflicts between energy and the environment.
6. Strengthening of international cooperation.

The Philippine government, to be able to cope with its energy problems, should study these basic principles and find ways to adapt them in the local environment. These would be a practical guideline in the overall formulation of a national energy strategy.

Principles 1, 4 and 5 are directly related to the promotion and further development of gasifiers for agricultural by-products. The first principle calls for a policy that would promote increased supplies of presently usable fuels and encourage conservation in their use. The fourth principle deals with the research and development of nuclear technology, solar energy and other energy technologies in preparation for the time when fossil fuels become seriously depleted. The fifth principle deals with the prevention or avoidance of environmental problems created by the exploitation of energy resources(2).

ECONOMIC EVALUATION OF FLUIDIZED-BED GASIFIER SYSTEMS

The Internal Rate of Return is used in the evaluation in order to determine, at a glance, if the project is economically feasible or not. The Net Present Value and the Benefit Cost Ratio, are used to measure the effectiveness and efficiency of the investment. Sensitivity analyses on the cost of diesel and electrical energy are used to determine how many percent from the base prices should these costs decrease before the project becomes uneconomical. Sensitivity analyses is also applied on inflation in order to determine its effect.

The cash flows evaluated are before tax cash flows. Quoting from Richard Gordon(9), "In investment analysis, only the actual cash outlays are considered. The costs recorded are the expenditures for equipment and other investment. We look at the profile of cash inflows and outflows over the life of the venture, because in investment analysis, it is spending cash that necessitates a loan and it is the receipt of sufficient cash that permits repayment with interest. Depreciation accounting convention still matters, but only indirectly because of tax conventions."

Also, the consideration of depreciation and tax matters if there are available government tax incentives to make the project more attractive. However, there are no available incentives for this kind of project in the country, except for whatever amount of savings would be realized in its undertaking.

This evaluation involves only such apparent cash flow factors expressed in constant Philippine Peso (US$ 1.00 = P 20.00), prior to actual installation and operation of the system. It is recommended that a detailed operational and economic analyses be made on an operating system to be able to actually determine its economic characteristics over time(1).

FLUIDIZED-BED GASIFIER SPECIFICATIONS

Reactor Diameter	:	15.0 Inches
Rice Hull Requirement	:	100 - 150 Kgs./Hour
BTU Generation	:	600,000 - 900,000 BTU/Hr
Rice Hull Feeder Motor	:	0.746 Kw.
Pressure Blower Motor	:	2.238 Kw.
Gas Scrubber Pump Motor	:	0.373 Kw.

ECONOMIC EVALUATION MODELS

The following economic evaluation models were set up and evaluated using Interactive Financial Planning System (IFPS) software which is available at University of Missouri-Rolla Computer System.

TARGET MARKET A

MODEL A

```
1 COLUMNS 1-5
2 * TARGET MARKET A - DIESEL ENGINE PRIME MOVER
3 *
5 * EVALUATION OF THE EXISTING SYSTEM
7 *
10 ENGINE RATED HP        = 250
20 DIESEL FUEL CONSUMPTION = 19
30 ANNUAL OPERATING TIME   = 2880
40 DIESEL FUEL COST        = 5.85
45 *
50 * OPERATING COSTS USING THE DIESEL ENGINE
60 FUEL = L20 * L30 * L40
70 REPAIR & MAINTENANCE = 0.05 * L60
80 OIL & LUBRICANTS = 0.03 * L60
90 TOTAL ANNUAL OPERATING COST = L60 + L70 + L80
95 *
100 *EVALUATION OF THE PROPOSED SYSTEM
105 *
110 *INVESTMENT COST TO INSTALL A GASIFIER SYSTEM
120 COST OF GASIFIER SYSTEM  = 200000,0
```

```
130 INSTALLATION COST = 0.15 * L120,0

140 TOTAL INVESTMENT = L120 + L130,0

145 *

150*OPERATING REQUIREMENTS USING GASIFIER/ENGINE SYSTEM

160 ANNUAL OPERATING TIME DIESEL ENGINE = 2880

170 ANNUAL OPERATING TIME GASIFIER = 3360

180 OPERATORS FOR GASIFIER SYSTEM = 2

190 COST OF LABOR              = 7

195 TOTAL ELECTRICAL LOAD        = 3.357

200 COST OF ELECTRICAL ENERGY     = 1.90

205 *

210 * OPERATING COST OF THE DIESEL ENGINE

220 FUEL = 0.25 * L20 * L160 * L40

230 REPAIR AND MAINTENANCE = 0.07 * L60

240 OIL AND LUBRICANTS = 0.05 * L60

250 ANNUAL OPERATING COST = L220 + L230 + L240

255 *

260 * OPERATING COST OF THE GASIFIER SYSTEM

270 LABOR = L170 * L180 * L190

280 REPAIR AND MAINTENANCE = 0.075 * L120, PREVIOUS

290 COST OF ELECTRICAL ENERGY = L170 * L195 * L200

300 ANNUAL OPERATING COST = L270+ L280 + L290

310 TOTAL ANNUAL OPERATING COST = L250 + L300

320 *

325 * INCREMENTAL CASH FLOW ANALYSIS

330 *

335 * INVESTMENT COSTS
```

```
340 INVESTMENT COST = L120 - 0,0
350 INSTALLATION COST = L130 - 0,0
360 TOTAL INVESTMENT COST = L340 + L350,0
365 *
370 *ANNUAL OPERATING COSTS
375 *
380 * DIESEL ENGINE
390 FUEL = L60 - L220
400 REPAIR AND MAINTENANCE = L70 - L230
410 OIL AND LUBRICANTS = L80 - L240
420 * GASIFIER SYSTEM
430 LABOR = 0 - L270
440 REPAIR AND MAINTENANCE = 0 - L280
450 ELECTRICAL ENERGY = 0 - L290
460 TOTAL ANNUAL OPER COSTS = L390+L400+L410+L430+L440+L450
470 *
475 INTEREST RATE = 0.15
477 INFLATION RATE = 0.015
480 DISCOUNT RATE = (1 + L475) * (1 + L477) - 1
485 *
490 I R R = IRR(L460,L360)
500 N P V = NPVC(L460,L480,L360)
510 B C R = BCRATIO(L460,L480,L360)

END OF MODEL
```

TARGET MARKET A - DIESEL ENGINE PRIME MOVER

	1	2	3	4	5
EVALUATION OF THE EXISTING SYSTEM					
ENGINE RATED HP	250	250	250	250	250
DIESEL FUEL CONSUMPTION	19	19	19	19	19
ANNUAL OPERATING TIME	2880	2880	2880	2880	2880
DIESEL FUEL COST	5.850	5.850	5.850	5.850	5.850
OPERATING COSTS USING THE DIESEL ENGINE					
FUEL	320112	320112	320112	320112	320112
REPAIR & MAINTENANCE	16006	16006	16006	16006	16006
OIL & LUBRICANTS	9603	9603	9603	9603	9603
TOTAL ANNUAL OPERATING C	345721	345721	345721	345721	345721
EVALUATION OF THE PROPOSED SYSTEM					
INVESTMENT COST TO INSTALL A GASIFIER SYSTEM					
COST OF GASIFIER SYSTEM	200000	0	0	0	0
INSTALLATION COST	30000	0	0	0	0
TOTAL INVESTMENT	230000	0	0	0	0
OPERATING REQUIREMENTS USING GASIFIER/ENGINE SYSTEM					
ANNUAL OPERATING TIME DI	2880	2880	2880	2880	2880
ANNUAL OPERATING TIME GA	3360	3360	3360	3360	3360
OPERATORS FOR GASIFIER S	2	2	2	2	2
COST OF LABOR	7	7	7	7	7
TOTAL ELECTRICAL LOAD	3.357	3.357	3.357	3.357	3.357
COST OF ELECTRICAL ENERG	1.900	1.900	1.900	1.900	1.900
OPERATING COST OF THE DIESEL ENGINE					
FUEL	80028	80028	80028	80028	80028
REPAIR AND MAINTENANCE	22408	22408	22408	22408	22408
OIL AND LUBRICANTS	16006	16006	16006	16006	16006
ANNUAL OPERATING COST	118441	118441	118441	118441	118441
OPERATING COST OF THE GASIFIER SYSTEM					
LABOR	47040	47040	47040	47040	47040
REPAIR AND MAINTENANCE	15000	15000	15000	15000	15000
COST OF ELECTRICAL ENERG	21431	21431	21431	21431	21431
ANNUAL OPERATING COST	83471	83471	83471	83471	83471
TOTAL ANNUAL OPERATING C	201913	201913	201913	201913	201913

INCREMENTAL CASH FLOW ANALYSIS

INVESTMENT COSTS					
INVESTMENT COST	200000	0	0	0	0
INSTALLATION COST	30000	0	0	0	0
TOTAL INVESTMENT COST	230000	0	0	0	0
ANNUAL OPERATING COSTS					
DIESEL ENGINE					
FUEL	240084	240084	240084	240084	240084
REPAIR AND MAINTENANCE	-6402	-6402	-6402	-6402	-6402
OIL AND LUBRICANTS	-6402	-6402	-6402	-6402	-6402
GASIFIER SYSTEM					
LABOR	-47040	-47040	-47040	-47040	-47040
REPAIR AND MAINTENANCE	-15000	-15000	-15000	-15000	-15000
ELECTRICAL ENERGY	-21431	-21431	-21431	-21431	-21431
TOTAL ANNUAL OPER COSTS	143808	143808	143808	143808	143808
INTEREST RATE	.1500	.1500	.1500	.1500	.1500
INFLATION RATE	.0150	.0150	.0150	.0150	.0150
DISCOUNT RATE	.1673	.1673	.1673	.1673	.1673
I R R		.1629	.3949	.5026	.5569
N P V	-106797	-1248	89178	166647	233016
B C R	.5357	.9946	1.388	1.725	2.013

TARGET MARKET B

MODEL B

```
 1 COLUMNS 1-5
 2 * TARGET MARKET B - DIESEL GEN-SET PRIME MOVER
 3 *
 5 * EVALUATION OF THE EXISTING SYSTEM
 7 *
 10 GEN SET RATING KW        = 60
 20 DIESEL FUEL CONSUMPTION = 25
 30 ANNUAL OPERATING TIME   = 2880
 40 DIESEL FUEL COST        = 5.85
 45 *
 50 * OPERATING COSTS USING THE GEN SET
 60 FUEL = L20 * L30 * L40
 70 REPAIR & MAINTENANCE = 0.05 * L60
 80 OIL & LUBRICANTS = 0.03 * L60
 90 TOTAL ANNUAL OPERATING COST = L60 + L70 + L80
 95 *
 100 *EVALUATION OF THE PROPOSED SYSTEM
 105 *
 110 *INVESTMENT COST TO INSTALL A GASIFIER SYSTEM
 120 COST OF GASIFIER SYSTEM  = 200000,0
 130 INSTALLATION COST = 0.15 * L120,0
 140 TOTAL INVESTMENT = L120 + L130,0
 145 *
 150*OPERATING REQUIREMENTS USING GASIFIER/ENGINE SYSTEM
 160 ANNUAL OPERATING TIME GEN SET = 3360
 170 ANNUAL OPERATING TIME GASIFIER = 3360
 180 OPERATORS FOR GASIFIER SYSTEM = 2
 190 COST OF LABOR                 = 7
 205 *
 210 * OPERATING COST OF THE GEN-SET
 220 FUEL = 0.25 * L20 * L160 * L40
 230 REPAIR AND MAINTENANCE = 0.07 * L20 * L160 * L40
 240 OIL AND LUBRICANTS = 0.05 * L20 * L160 * L40
 250 ANNUAL OPERATING COST = L220 + L230 + L240
 255 *
 260 * OPERATING COST OF THE GASIFIER SYSTEM
 270 LABOR = L170 * L180 * L190
 280 REPAIR AND MAINTENANCE = 0.075 * L120, PREVIOUS
 300 ANNUAL OPERATING COST = L270+ L280
 310 TOTAL ANNUAL OPERATING COST = L250 + L300
 320 *
 325 * INCREMENTAL CASH FLOW ANALYSIS
 330 *
 335 * INVESTMENT COSTS
 340 INVESTMENT COST = L120 - 0,0
 350 INSTALLATION COST = L130 - 0,0
 360 TOTAL INVESTMENT COST = L340 + L350,0
 365 *
 370 *ANNUAL OPERATING COSTS
 375 *
 380 * GEN-SET
```

```
390 FUEL = L60 - L220
400 REPAIR AND MAINTENANCE = L70 - L230
410 OIL AND LUBRICANTS = L80 - L240
420 * GASIFIER SYSTEM
430 LABOR = 0 - L270
440 REPAIR AND MAINTENANCE = 0 - L280
460 TOTAL ANNUAL OPER COSTS = L390+L400+L410+L430+L440
470 *
475 INTEREST RATE = 0.15
477 INFLATION RATE = 0.015
480 DISCOUNT RATE = (1 + L475) * (1 + L477) - 1
490 I R R = IRR(L460,L360)
500 N P V = NPVC(L460,L480,L360)
510 B C R = BCRATIO(L460,L480,L360)

END OF MODEL
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TARGET MARKET B - DIESEL GEN-SET PRIME MOVER

	1	2	3	4	5
EVALUATION OF THE EXISTING SYSTEM					
GEN SET RATING KW	60	60	60	60	60
DIESEL FUEL CONSUMPTION	25	25	25	25	25
ANNUAL OPERATING TIME	2880	2880	2880	2880	2880
DIESEL FUEL COST	5.850	5.850	5.850	5.850	5.850
OPERATING COSTS USING THE GEN SET					
FUEL	421200	421200	421200	421200	421200
REPAIR & MAINTENANCE	21060	21060	21060	21060	21060
OIL & LUBRICANTS	12636	12636	12636	12636	12636
TOTAL ANNUAL OPERATING C	454896	454896	454896	454896	454896
EVALUATION OF THE PROPOSED SYSTEM					
INVESTMENT COST TO INSTALL A GASIFIER SYSTEM					
COST OF GASIFIER SYSTEM	200000	0	0	0	0
INSTALLATION COST	30000	0	0	0	0
TOTAL INVESTMENT	230000	0	0	0	0
OPERATING REQUIREMENTS USING GASIFIER/ENGINE SYSTEM					
ANNUAL OPERATING TIME GE	3360	3360	3360	3360	3360
ANNUAL OPERATING TIME GA	3360	3360	3360	3360	3360
OPERATORS FOR GASIFIER S	2	2	2	2	2
COST OF LABOR	7	7	7	7	7
OPERATING COST OF THE GEN-SET					
FUEL	122850	122850	122850	122850	122850
REPAIR AND MAINTENANCE	34398	34398	34398	34398	34398
OIL AND LUBRICANTS	24570	24570	24570	24570	24570
ANNUAL OPERATING COST	181818	181818	181818	181818	181818
OPERATING COST OF THE GASIFIER SYSTEM					
LABOR	47040	47040	47040	47040	47040
REPAIR AND MAINTENANCE	15000	15000	15000	15000	15000
ANNUAL OPERATING COST	62040	62040	62040	62040	62040
TOTAL ANNUAL OPERATING C	243858	243858	243858	243858	243858

INCREMENTAL CASH FLOW ANALYSIS

INVESTMENT COSTS					
INVESTMENT COST	200000	0	0	0	0
INSTALLATION COST	30000	0	0	0	0
TOTAL INVESTMENT COST	230000	0	0	0	0
ANNUAL OPERATING COSTS					
GEN-SET					
FUEL	298350	298350	298350	298350	298350
REPAIR AND MAINTENANCE	-13338	-13338	-13338	-13338	-13338
OIL AND LUBRICANTS	-11934	-11934	-11934	-11934	-11934
GASIFIER SYSTEM					
LABOR	-47040	-47040	-47040	-47040	-47040
REPAIR AND MAINTENANCE	-15000	-15000	-15000	-15000	-15000
TOTAL ANNUAL OPER COSTS	211038	211038	211038	211038	211038
INTEREST RATE	.1500	.1500	.1500	.1500	.1500
INFLATION RATE	.0150	.0150	.0150	.0150	.0150
DISCOUNT RATE	.1673	.1673	.1673	.1673	.1673
I R R		.5209	.7448	.8370	.8783
N P V	-49201	105693	238392	352078	449474
B C R	.7861	1.460	2.036	2.531	2.954

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TARGET MARKET C

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MODEL C
 1 COLUMNS 1-5
 2 * TARGET MARKET C - ELECTRIC MOTOR PRIME MOVER
 3 *
 5 * EVALUATION OF THE EXISTING SYSTEM
 7 *
 10 ELECTRIC MOTOR RATING KW = 56
 30 ANNUAL OPERATING TIME   = 2880
 40 COST OF ELECTRICAL ENERGY = 1.90
 45 *
 50 * OPERATING COSTS USING THE ELECTRIC MOTOR
 60 ELECTRICAL ENERGY = L10 * L30 * L40
 70 REPAIR & MAINTENANCE = 0.02 * L60
 90 TOTAL ANNUAL OPERATING COST = L60 + L70
 95 *
 100 *EVALUATION OF THE PROPOSED SYSTEM
 105 *
 110 *INVESTMENT COST TO INSTALL A GASIFIER SYSTEM
 120 COST OF GASIFIER SYSTEM  = 200000,0
 125 COST OF DIESEL ENGINE    = 30000,0
 130 INSTALLATION COST = 0.15 * (L120 + L125),0
 140 TOTAL INVESTMENT = L120 + L130 + L125,0
 145 *
 150*OPERATING REQUIREMENTS USING GASIFIER/ENGINE SYSTEM
 160 ANNUAL OPERATING TIME DIESEL ENGINE = 2880
 170 ANNUAL OPERATING TIME GASIFIER = 3360
 175 DIESEL FUEL CONSUMPTION = 19
 177 DIESEL FUEL COST        = 5.85
 180 OPERATORS FOR GASIFIER SYSTEM = 2
 190 COST OF LABOR                 = 7
 195 TOTAL ELECTRICAL LOAD         = 3.357
 200 COST OF ELECTRICAL ENERGY     = 1.90
 205 *
 210 * OPERATING COST OF THE DIESEL ENGINE
 220 FUEL = 0.25 * L160 * L175 * L177
 230 REPAIR AND MAINTENANCE = 0.07 * L160 * L175 * L177
 240 OIL AND LUBRICANTS = 0.05 * L160 * L175 * L177
 250 ANNUAL OPERATING COST = L220 + L230 + L240
 255 *
 260 * OPERATING COST OF THE GASIFIER SYSTEM
 270 LABOR = L170 * L180 * L190
 280 REPAIR AND MAINTENANCE = 0.075 * L120, PREVIOUS
 290 COST OF ELECTRICAL ENERGY = L170 * L195 * L200
 300 ANNUAL OPERATING COST = L270+ L280 + L290
 310 TOTAL ANNUAL OPERATING COST = L250 + L300
 320 *
 325 * INCREMENTAL CASH FLOW ANALYSIS
 330 *
 335 * INVESTMENT COSTS
 340 INVESTMENT COST = (L120 + L125) - 0,0
 350 INSTALLATION COST = L130 - 0,0
 360 TOTAL INVESTMENT COST = L340 + L350,0
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365 *
370 *ANNUAL OPERATING COSTS
375 *
380 * DIESEL ENGINE
390 FUEL = 0 - L220
400 REPAIR AND MAINTENANCE = 0 - L230
410 OIL AND LUBRICANTS = 0 - L240
420 * GASIFIER SYSTEM
430 LABOR = 0 - L270
440 REPAIR AND MAINTENANCE = L70 - L280
450 ELECTRICAL ENERGY = L60 - L290
460 TOTAL ANNUAL OPER COSTS = L390+L400+L410+L430+L440+L450
470 *
475 INTEREST RATE = 0.15
477 INFLATION RATE = 0.015
480 DISCOUNT RATE  = (1 + L475) * (1 + L477) - 1
485 *
490 I R R = IRR(L460,L360)
500 N P V = NPVC(L460,L480,L360)
510 B C R = BCRATIO(L460,L480,L360)

END OF MODEL
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TARGET MARKET C - ELECTRIC MOTOR PRIME MOVER

	1	2	3	4	5
EVALUATION OF THE EXISTING SYSTEM					
ELECTRIC MOTOR RATING KW	56	56	56	56	56
ANNUAL OPERATING TIME	2880	2880	2880	2880	2880
COST OF ELECTRICAL ENERG	1.900	1.900	1.900	1.900	1.900
OPERATING COSTS USING THE ELECTRIC MOTOR					
ELECTRICAL ENERGY	306432	306432	306432	306432	306432
REPAIR & MAINTENANCE	6129	6129	6129	6129	6129
TOTAL ANNUAL OPERATING C	312561	312561	312561	312561	312561
EVALUATION OF THE PROPOSED SYSTEM					
INVESTMENT COST TO INSTALL A GASIFIER SYSTEM					
COST OF GASIFIER SYSTEM	200000	0	0	0	0
COST OF DIESEL ENGINE	30000	0	0	0	0
INSTALLATION COST	34500	0	0	0	0
TOTAL INVESTMENT	264500	0	0	0	0
OPERATING REQUIREMENTS USING GASIFIER/ENGINE SYSTEM					
ANNUAL OPERATING TIME DI	2880	2880	2880	2880	2880
ANNUAL OPERATING TIME GA	3360	3360	3360	3360	3360
DIESEL FUEL CONSUMPTION	19	19	19	19	19
DIESEL FUEL COST	5.850	5.850	5.850	5.850	5.850
OPERATORS FOR GASIFIER S	2	2	2	2	2
COST OF LABOR	7	7	7	7	7
TOTAL ELECTRICAL LOAD	3.357	3.357	3.357	3.357	3.357
COST OF ELECTRICAL ENERG	1.900	1.900	1.900	1.900	1.900
OPERATING COST OF THE DIESEL ENGINE					
FUEL	80028	80028	80028	80028	80028
REPAIR AND MAINTENANCE	22408	22408	22408	22408	22408
OIL AND LUBRICANTS	16006	16006	16006	16006	16006
ANNUAL OPERATING COST	118441	118441	118441	118441	118441
OPERATING COST OF THE GASIFIER SYSTEM					
LABOR	47040	47040	47040	47040	47040
REPAIR AND MAINTENANCE	15000	15000	15000	15000	15000
COST OF ELECTRICAL ENERG	21431	21431	21431	21431	21431
ANNUAL OPERATING COST	83471	83471	83471	83471	83471
TOTAL ANNUAL OPERATING C	201913	201913	201913	201913	201913

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INCREMENTAL CASH FLOW ANALYSIS

INVESTMENT COSTS					
INVESTMENT COST	230000	0	0	0	0
INSTALLATION COST	34500	0	0	0	0
TOTAL INVESTMENT COST	264500	0	0	0	0
ANNUAL OPERATING COSTS					
DIESEL ENGINE					
FUEL	-80028	-80028	-80028	-80028	-80028
REPAIR AND MAINTENANCE	-22408	-22408	-22408	-22408	-22408
OIL AND LUBRICANTS	-16006	-16006	-16006	-16006	-16006
GASIFIER SYSTEM					
LABOR	-47040	-47040	-47040	-47040	-47040
REPAIR AND MAINTENANCE	-8871	-8871	-8871	-8871	-8871
ELECTRICAL ENERGY	285001	285001	285001	285001	285001
TOTAL ANNUAL OPER COSTS	110648	110648	110648	110648	110648
INTEREST RATE	.1500	.1500	.1500	.1500	.1500
INFLATION RATE	.0150	.0150	.0150	.0150	.0150
DISCOUNT RATE	.1673	.1673	.1673	.1673	.1673
I R R			.1228	.2432	.3098
N P V	-169706	-88495	-18920	40686	91751
B C R	.3584	.6654	.9285	1.154	1.347

SUMMARY OF ECONOMIC ANALYSIS

	TARGET MARKET A DIESEL ENGINE PRIME MOVER	TARGET MARKET B DIESEL GEN SET PRIME MOVER	TARGET MARKET C ELECTRIC MOTOR PRIME MOVER
I R R , % :	55.69	87.83	30.98
N P V , P :	233,016.00	449,474.00	91,751.00
B C R :	2.013	2.954	1.347

INTEREST RATE = 15.0 % (8)

INFLATION RATE = 1.5 % (8)

SENSITIVITY ANALYSIS ON THE COST OF DIESEL
AND ELECTRICAL ENERGY

TARGET MARKET A

	PERCENTAGE DECREASE FROM BASE PRICE					
	36.0	35.0	30.0	20.0	10.0	BASE
IRR, %	15.67	16.73	23.01	34.48	45.30	55.69
NPV, P	-5,579	1,049	45,057	114,061	183,065	252,068
BCR	0.98	1.005	1.20	1.50	1.80	2.10

TARGET MARKET B

	PERCENTAGE DECREASE FROM BASE PRICE					
	52.0	51.0	40.0	20.0	10.0	BASE
IRR, %	15.26	16.93	34.03	61.89	75.02	87.83
NPV, P	-7,722	1,070	97,785	273,629	361,551	449,474
BCR	0.97	1.005	1.425	2.190	2.572	2.954

TARGET MARKET C

	PERCENTAGE DECREASE FROM BASE PRICE				
	15.0	14.0	10.0	5.0	BASE
IRR, %	16.40	17.42	21.43	26.28	30.98
NPV, P	-1,999	4,251	29,251	60,501	91,751
BCR	0.99	1.016	1.111	1.229	1.347

BASE PRICES:

Diesel Fuel Cost = P 5.85

Cost of Electrical Energy = P 1.90 per KW-HR

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SENSITIVITY ANALYSIS ON THE EFFECTS OF INFLATION

TARGET MARKET A

	ANNUAL INFLATION RATE					
	6.0	10.0	20.0	30.0	35.0	36.0
NPV, P	182,698	145,146	78,829	45,154	1,427	-2,268
BCR	1.794	1.631	1.317	1.094	1.006	0.99

TARGET MARKET B

	ANNUAL INFLATION RATE					
	10.0	25.0	40.0	50.0	63.0	64.0
NPV, P	320,524	214,399	83,982	42,029	897	-1,790
BCR	2.39	1.93	1.37	1.18	1.004	0.992

TARGET MARKET C

	ANNUAL INFLATION RATE					
	4.0	6.0	8.0	10.0	13.0	14.0
NPV, P	69,339	53,035	38,013	24,142	5,250	-587
BCR	1.26	1.20	1.14	1.09	1.02	.99

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CONCLUSION

The following are the conclusions derived after reviewing the paper and analysing the economic evaluation results:

1. There is a potential of creating a demand for the introduction the product in the market.
2. The introduction of the product to other industries aside from the rice milling industry can be expected to create similar savings in operation.
3. The owners of diesel engine driven and diesel gen set powered rice mills are the most prospective customers that will be interested in this project.
4. The owners of electric motor driven rice mills are likely to be conservative in assessing this undertaking because of its sensitivity to inflation and decrease in the cost of conventional energy.
5. With the recent creation of the Congress and the Senate, the opportunity of pressing for incentives for these kinds of projects should be considered by the company and prospective users.
6. Further research and study on the proportion of each target market should be undertaken.
7. The gasification of other byproducts such as sawdust, corn cobs, etc., should also be considered in order to expand the market horizon and the beneficiaries of the system.
8. The gasification of rice hulls is an effective approach in promoting the utilization of non-conventional energy in support of the energy program of the government.
9. It is also a practical approach in solving the rice hull disposal problem by tapping its potential energy.
10. The creation of employment opportunity is a significant contribution of this project to the present economic difficulty in the nation.

11. Its effect in reducing the oil-import bill is a welcomed relief.

12. The availability of low cost renewable energy will result to productivity in industry and expansion of business activities.

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