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DESIGN OF AN EFFECTIVE PRODUCER GAS CLEANING METHOD FOR A DOWNDRAFT GASIFIER-ENGINE-GENERATOR SYSTEM

Ramon M. Buenaventura, Ferdinand G. Manegdeg* & Ibarra E. Cruz
Department of Mechanical Engineering, College of Engineering
University of the Philippines Diliman, Quezon City, 1101 Philippines

ABSTRACT

This paper is an experimental study of the performance of a producer gas cleaning method, including a newly designed oil bath filter, for a rice husk downdraft gasifier-engine-generator system (GEGS). The resulting tar and particulate content is 1.6 mg per m^3 of producer gas which enabled a continuous operation of the system for 4 hours, limited only by the ash bin capacity. The system accumulated a total of 105 hours of operation with no harmful effects on the diesel engine as shown by the results of the engine oil analysis. A corresponding systems operations and maintenance procedure was also developed.

1. INTRODUCTION

In 2010, the Gross National Product (GNP) of the Philippines was 12 trillion pesos, and the energy consumption in all sectors is 24.7 million tons of oil equivalent (MTOE) [15]. The GNP was increasing by an average of 10.9% annually from 2005 to 2010 [15], and it is expected to be increasing by an average of 5% yearly up to 2025 [14]. However, this significant growth in GNP does not correspond to a similar growth in the utilization of energy from indigenous sources. The energy-to-GNP elasticity was negative from 2001-2006 [7]. This has been attributed to the continuous increase in international oil prices and the growth of less energy-intensive industries [7]. Furthermore, the energy sector failed to meet its objective of being 60% self-sufficient by 2010 [7], with indigenous energy sources comprising only 57.7% of the total energy supply [15].

The development of the utilization of alternative and indigenous energy sources is being emphasized [7]. Biomass energy comprised the second largest share of the indigenous energy supply at an average of 24.7% yearly from 2005 to 2010 [15]. Agricultural wastes are abundant in the Philippines, and have high potential as biomass fuel sources. In particular, rice husk which is 20% of the paddy weight of rice, is available and reasonably distributed across priority provinces in most regions of the country [15].

Consisting mainly of ligno-cellulose and silica, rice husk contains about 35 to 52% carbon, 4 to 7% hydrogen, 36 to 47% oxygen, 0.4 to 1.5% nitrogen, 0.1% sulfur, and 16 to 27% ash [2,6,18]. Its energy content ranges from 12,561 to 16,300 kJ/kg, [11,13,16,17,20], with fixed carbon content of about 15.3% and volatile matter of about 61.5% [10]. These clearly show that rice husk has good potential as an alternative fuel, but would produce more tar due to its high volatile matter content. The moisture content of rice husk varies from 8 to 12% [5,11,13,16,17,20,23], depending on handling, milling procedure, storage, and climate.

*Correspondence to: Ferdinand G. Manegdeg, Associate Professor of Mechanical Engineering, Department of Mechanical Engineering, University of the Philippines Diliman, Quezon City

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Since rice husk is one of the more abundant alternative energy sources in developing countries, many investigators [1,3,5,11,13,16] have studied its use in gasification technology. Gasification is the conversion of biomass into gaseous energy known as producer gas by partial oxidation at relatively high temperatures. This process occurs in a gasifier, which is typically characterized by its fuel bed design, feed, and airflow. The types of gasifiers are updraft, downdraft, crossdraft, and fluidized bed. The downdraft gasifier, as shown in Figure 1, was used for this study because it produces much less tar than the other types, and is thus the most suitable for engine applications because tar and particulate deposits inside the engine will cause clogging, which will then cause engine operation to cease [6,11,16,21]. Furthermore, the updraft gasifier is best suited for tar-free fuels such as coal [22], the crossdraft gasifier has high pressure drop and high sensitivity to slag formation [8], and the fluidized bed has exhibited high tar content, incomplete carbon burnout, and poor response to load changes [8].

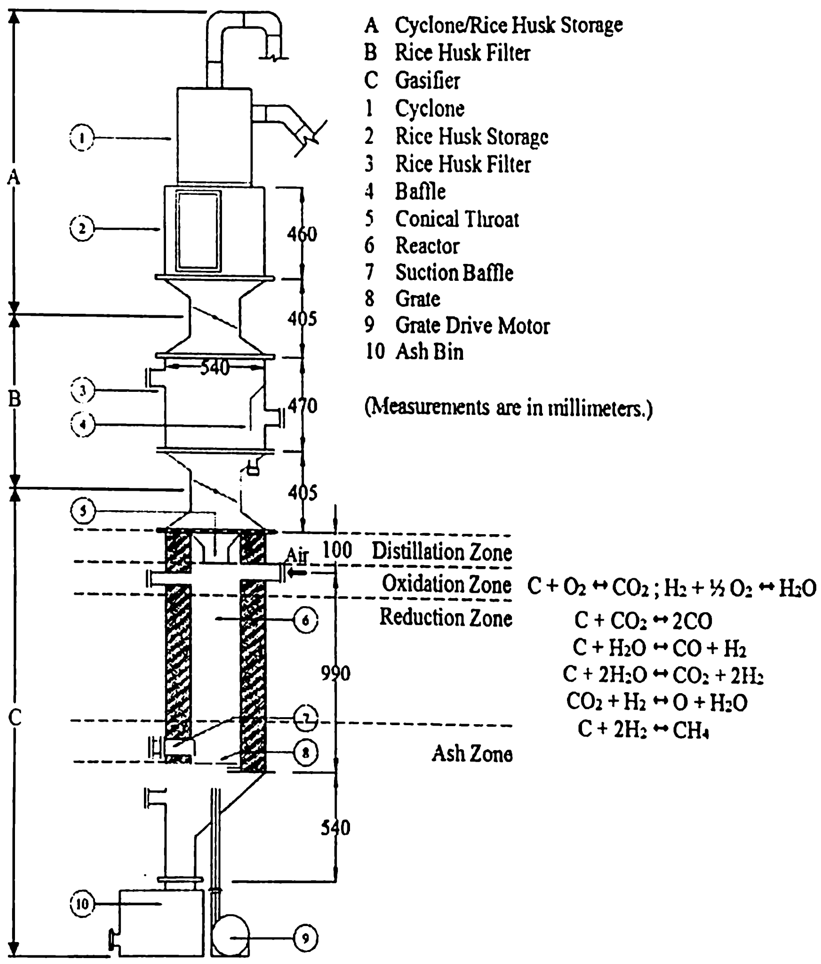

Figure 1. Details of the downdraft gasifier.

The physical characteristics of rice husk have direct correlation to the way it is to be gasified. With bulk density of about 128 kg/m^3 [17], rice husks flow poorly under gravity and tend to bridge across the reactor. Another important characteristic of rice husk is its strong silica skeleton [12]. The rice husk largely retains its shape and size as it is being gasified which contributes to the bridging of the fuel. Because of the poor flow characteristics of the rice husks, voids are easily formed in the fuel bed, which results in excess of combustion air, thus leading to temperatures higher than the melting point of ash. This could lead to the formation of clinkers, which would impede or even completely block the flow of gas, air and rice husk in the gasifier. With the high ash content, gasification of rice husk would require continuous ash removal to prevent problems such as fouling and slagging, and a more effective producer gas cleaning method.

The challenge of an efficient downdraft gasifier-engine-generator system or GEGS is to have an effective gas cleaning method. Although recent developments have reduced these cleaning trains into more compact ones, the resulting product gas still contains considerable amount of tar and particulate, in the order of at least 4 mg per m^3 [1]. A more effective and compact cleaning method is still needed for the gas producers to operate continuously and efficiently in a limited space environment.

The general objective of this study is to evaluate the performance of a producer gas cleaning method for the continuous operation of a rice husk downdraft gasifier coupled with a diesel engine-generator. The specific objectives are:

- to design a producer gas cleaning method with an oil bath filter, and to evaluate its performance in reducing the tar content of the producer gas to less than 4 mg per m^3, which is the best performance by existing gas cleaning methods;
- to operate the GEGS continuously up to the capacity of the ash bin and to run the system for at least 100 cumulative hours;
- to determine and evaluate the performance of the diesel engine under varying loads and speeds using diesel fuel and producer gas; and
- to evaluate the effects of the producer gas on the diesel engine.

This study focuses on improving and modifying the producer gas cleaning method for the gasifier to provide a cleaner product gas, in order for the GEGS to run continuously. This is especially useful to farmer households and rice mills operating in the countryside, where fossil fuel and electricity are not readily available.

2. METHODOLOGY

The research started with a review of the gasification process, and familiarization of the GEGS used at the Mechanical Engineering Laboratory of the University of the Philippines Department of Mechanical Engineering. The gas cleaning method was studied, and modifications were made to further enhance the quality of the producer gas. The research activities required 200 man-days to complete. It consisted of modifications of the existing gasifier, including the design of its oil bath filter, the addition of the gas demister and the newly designed oil bath filter, and the coupling of the gasifier separately to two diesel engines with their respective generators; operation and test runs with the modifications; actual operation and data gathering; and evaluation of the data gathered.

2.1 Gasification Process

The gasification process generally occurs in three major zones of a fuel bed, namely, the oxidation, reduction, and distillation zones [8]. Figure 1 shows the three zones with the gasification reactions that occur within each of the zones. Suitable producer gas for an internal combustion engine should consist of about 20 to 28% CO, 12 to 18% H_2, and 1 to 5% gaseous C_mH_n by volume, with the remaining portion as nitrogen [19].

2.2 Gasifier Fuel Properties

The fuel properties to consider are energy content, moisture, volatile matter, ash and ash chemical composition, reactivity, size and size distribution, bulk density, and charring properties [8]. Compared to other producer gases, producer gas coming from rice husk has relatively low calorific value [19,23].

In a downdraft gasifier, high moisture content leads to lower or insufficient tar converting capability, and lowers the thermal efficiency of the gasifier; thus, reasonably dry fuels with less than 25% moisture on a dry basis are required [8]. Volatile matter content determines the need for additional measures to remove tars from the producer gas in engine applications. The ash content and ash properties usually determine the amount of labor needed to operate and maintain the gasifier. Ash content of 5% or more usually leads to slagging, which results from ash melting in the combustion zone [22].

The reactivity of the fuel determines the rate of reduction of carbon dioxide to carbon monoxide in the gasifier, and affects some operational characteristics, such as load response and restarting the char after a temporary shutdown [8]. Too large particle size reduces the fuel's reactivity, the gas' heating value, and the gasifier efficiency [22]. Conversely, fine grained or fluffy fuels may cause flow problems as well as pressure drop over the reduction zone, which would result in low temperatures and tar production for downdraft gasifiers [8]. High bulk density is ideal because higher energy is available for less bunker space. Charring properties of the fuel have to be considered because some fuels produce char that have tendencies to disintegrate, which would lead to inadmissible pressure drops [8].

2.3 Rice Husk Gasification Technology

A study on rice husk gasification, covering the gasifier technology of China, India, Indonesia, Italy, Thailand, Vietnam, the Philippines, and the United States of America, examined some 40 different rice husk gasifier systems [13]. The common problems are effective continuous ash removal and efficient gas cleaning and cooling system. Effective ash removal is important because it controls the height of the combustion zone, which when uncontrolled, could rise to the surface of the fuel bed. Efficient gas cleaning and cooling systems are installed to provide gas with minimum tar and particulate contents. Temperature has to be close to ambient temperature to increase gas energy density.

Studies have improved the designs of downdraft reactors and gas cleaning trains. A rotating grate was found to be essential in the continuous removal of ash after gasification [4]. A collapsible grate gave satisfactory results in the continuous removal of ash in the fuel bed [16]. Incorporating the filter in the reactor by continuously charging the rice husk to the gasifier as the filter material itself has been shown to clean off tar and other impurities [1].

The produced gas is thoroughly cleaned by using filters before being used as fuel in an internal combustion engine because tar and other impurities constrain the continuous operation of the GEGS at present. Removal of tar and ash is carried out in separate steps to ensure stable operation. Also, the filter devices can be arranged in a variety of ways to effectively clean the producer gas, which is needed for trouble-free operation of an internal combustion engine.

2.4 Gasifier Filters

Gas treatment techniques can be classified into three categories: high-temperature trapping of particles, condensation and elimination of condensate droplets, and elimination of mists [9]. For trapping of particles at high temperature, mechanical filters such as hydraulic dust removers, electrostatic filters and porous layer filters are used. These filters purify the gas at a temperature above the dew point of the gas. Mechanical filters are only suitable for removing large particles. Hydraulic dust removers utilize cleaning liquid that must remain liquid at high temperature, which leads to corrosion problems when organic fluids or salts are used. Electrostatic filters are mainly used to collect airborne ash, the main difficulty encountered with which is finding materials that remain insulators at high temperatures and removing the collected dusts. Porous layer filters clean the gas by passing it through a fabric or any porous material, which can either be flexible fibrous, rigid porous, or granular bed devices. In general, these filters cause high pressure drops, and require more maintenance.

For condensation and elimination of condensate droplets, several devices such as scrubbers, impingers, washers, and spray towers can be utilized. These devices allow either direct or indirect heat transfer. Nearly all fixed gasifiers where water is available use water scrubbers. Wet scrubbers are employed for tar removal. Demisters which usually consist of porous bed are installed to remove mists, and require frequent cleaning and replacement.

2.5 Description of the GEGS

The GEGS has six main components: a rice husk feeder and storage system for continuous operation; a reactor for the gasification of rice husk into producer gas; a gas filtration system to condense and trap tar and other impurities; a suction blower that provides suction pressure for the circulation of the producer gas; a set of valves to mix air with the producer gas, and to regulate the air/fuel mixture that enters into the engine intake manifold; and a diesel engine coupled to a generator to produce electricity. The schematic diagram of this system showing the general system layout and instrumentation is projected in Figure 2.

The gasifier is a downdraft suction type reactor, with the inner surface lined with refractory cement. Its reaction zone is 1,090 mm high with a diameter of 440 mm. The downward movement of air, gases, and ash is facilitated by gravity. The operation was restricted only by the limited storage capacity of the ash bin.

The producer gas filtration system is composed of the water scrubber, gas demister, rice husk filter, oil bath filter, and cloth filter. The water scrubber is made of a 152.4 mm diameter cast iron pipe with a set of nozzles and an effective height of 2170 mm from the inlet. From the reactor, the producer gas is ducted to flow through the water scrubber to trap tar and other flyash particles and to cool the gas in the process. Water is pumped from the cooling tower to the scrubber and is collected in a water drum to be pumped back to the cooling tower. Water flow rate of the scrubber is about 0.18 kg/s. A gas demister is installed after the water scrubber to collect moisture and impurities from the cooled gas. A gas suction blower with a capacity of 0.236 m^3/s is installed after the gas demister to provide the necessary pressure for the circulation of the producer gas. The gas recirculation line is installed from the outlet of the blower to the water scrubber to allow recirculation of the gas and to increase its residence time in the water scrubber.

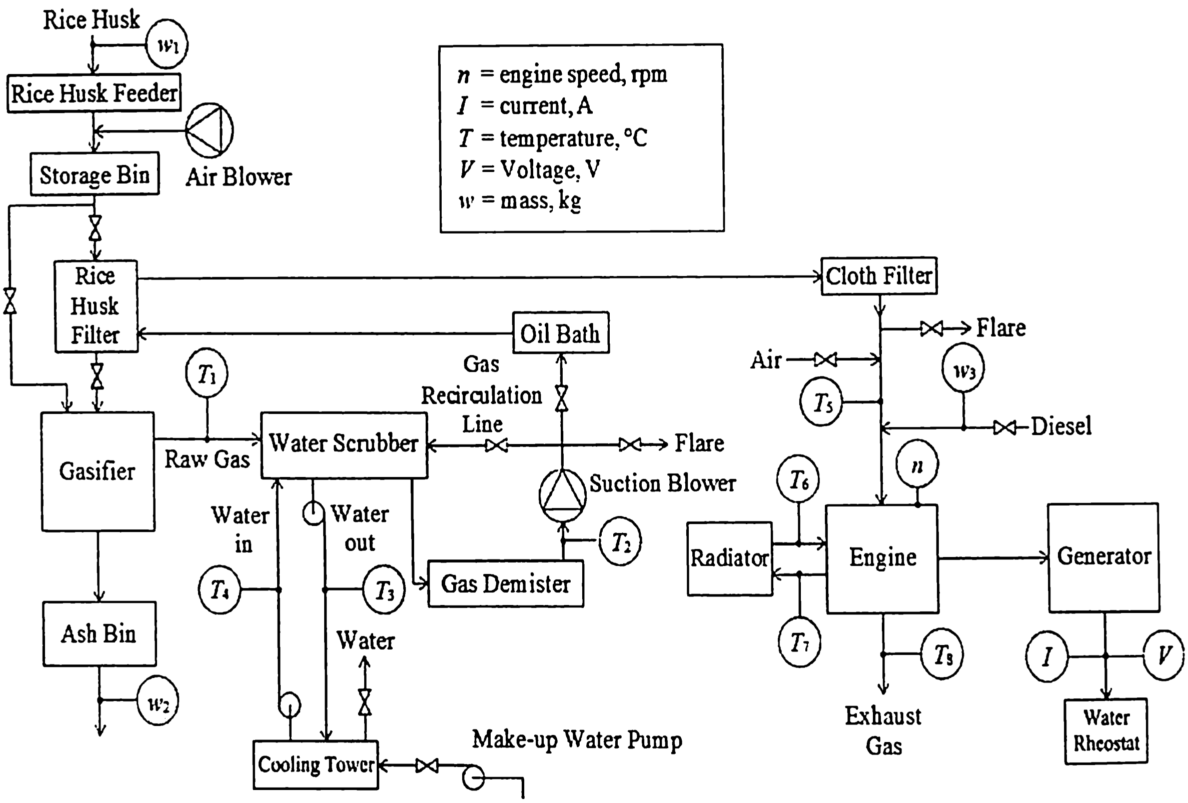

Figure 2. Schematic diagram of the GEGS.

The rice husk filter is a mechanical filter installed to trap condensed tar and dusts that are still in the producer gas. It is installed between the rice husk storage bin and the reactor, and uses the feed itself as the filtering medium. This setup eliminates the downtime required for the replacement of cloth filters, thus allowing continuous operation of the gasifier. The butterfly valves can be actuated independently to provide feed for the rice husk filter or the reactor, as the need arises.

An oil bath filter was designed, the details of which are shown in Figure 3. It is a rectangular box filled with diesel oil, placed between the gas suction blower and the rice husk filter. It washes out the dust, tar, and other impurities that are still present in the producer gas from the gas demister. The quality of the gas is seen through an installed sight glass.

The cloth filter located after the rice husk filter, is the final filter before the producer gas is fed to the engine. The cloth filter ensures that tar and dust particles do not enter the engine. It also serves as a gauge on how clean the producer gas is before it enters the engine. The dry weight of the cloth filter is taken before and after each operation to monitor the amount of tar and dust collected by it.

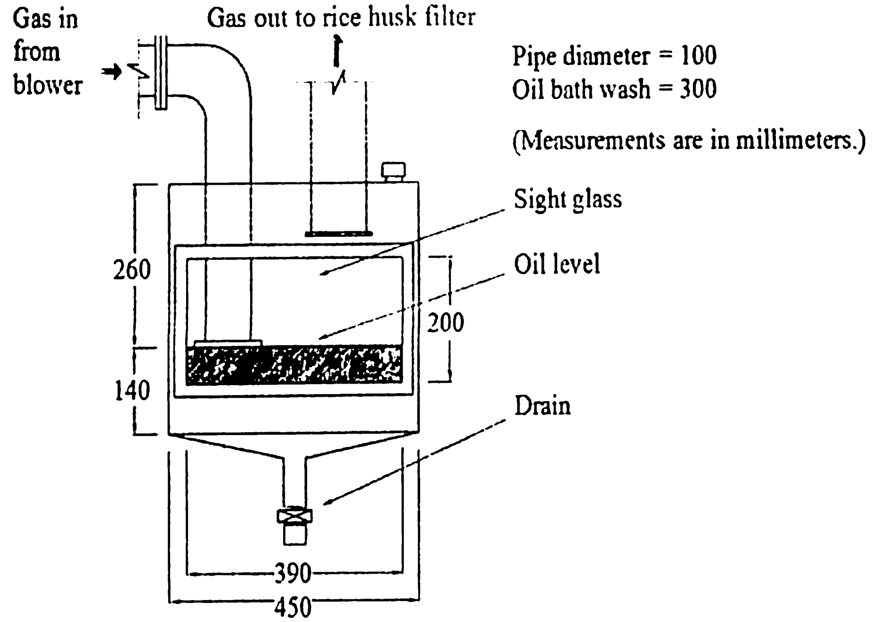

Figure 3. Details of oil bath filter.

Two diesel engines were tested: a Ford and a Lombardini. The Ford engine is a model 2715E, 4-cycle, 6-cylinder, water cooled with a maximum engine speed of 1800 rpm; it is coupled to a three-phase Hawker-Sidelley AC Generator with a rated output of 62.5 kVA at 1800 rpm (230 V, 60 Hz, 138 A). The Lombardini engine is a model L20, 4-cycle, 2-cylinder, air-cooled with a maximum engine speed of 1800 rpm; it is coupled with a Lombardini generator with model FA7.5, single phase, with a rated output of 7.5 kW (230/115 V, 60/50 Hz, 32.6/65.2A).

2.6 Experimental Procedures

The research involved the operation of each diesel engine, fueled first by pure diesel, and then by producer gas and diesel. Three sets of data were taken for each of the engine speed and load settings for a total of 105 test runs. Experimental data was taken every five minutes, and each test run was completed after an hour of operation. The experimental flowchart is shown in Figure 4.

For operation with diesel and producer gas, the rice husk consumption at any time can be measured by monitoring through the sight glass of the rice husk storage bin. The rate of ash removal was measured by recording the number of rotations made by the ash scrapper during the run. The weights of tar and flyash taken from the drum and blower were recorded every time a significant amount was retrieved.

3. RESULTS AND ANALYSIS

The rice husk, ash, the engine oil, and the oil of the oil bath filter were analyzed. The performances for both engines were assessed.

3.1 Rice Husk Analysis

There were three sets of rice husk used, which were taken from rice mills in Bulacan. The first set (Rice Husk-1) was used for runs 1-36; the second set (Rice Husk-2) for runs 37-87; and the last set (Rice Husk-3) for runs 88-105. The results of the rice husk analysis are shown in Table 1. The tests were done at the Energy Research Laboratory of the Department of Energy.

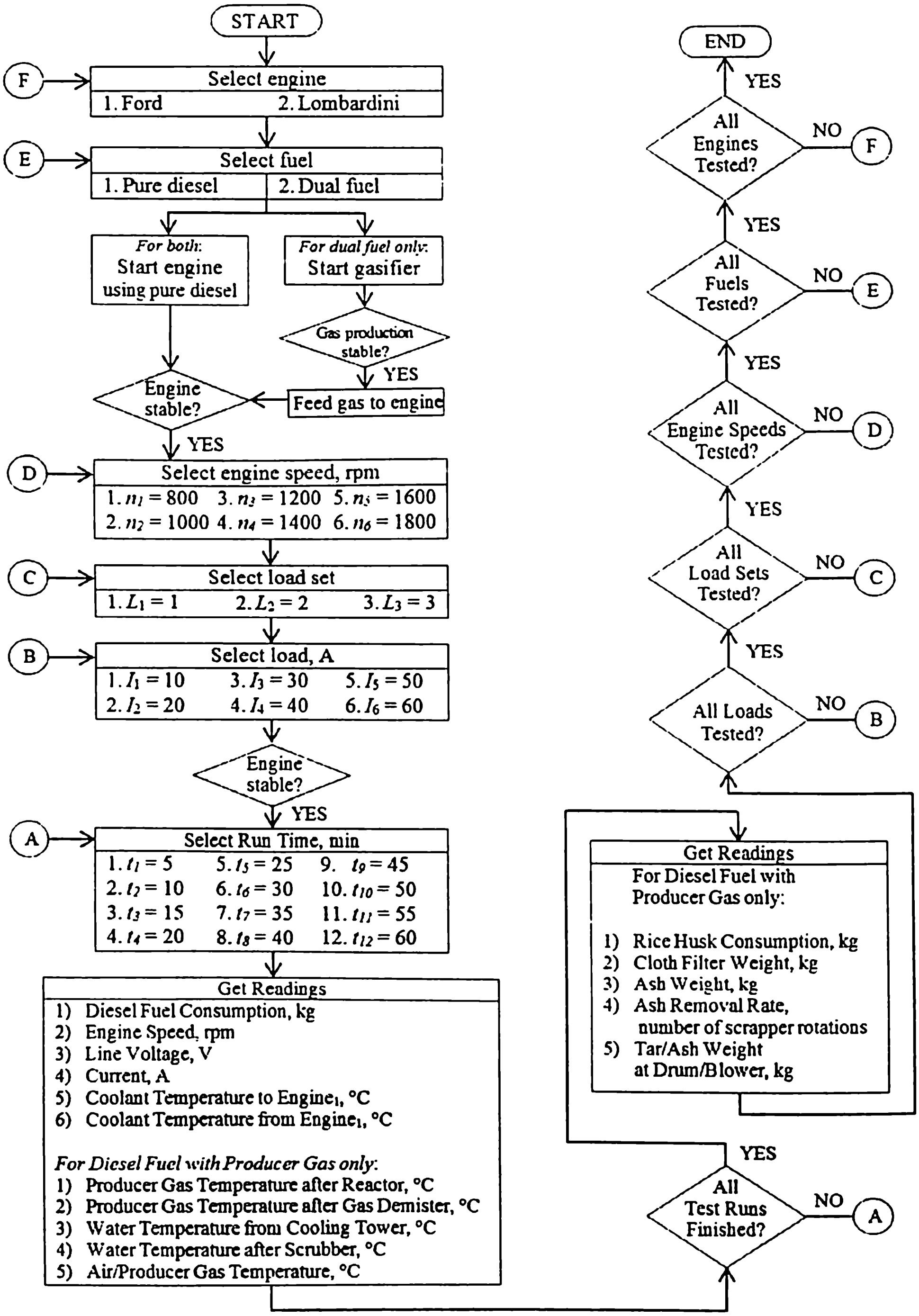

Figure 4. Experimental flowchart.

As shown in Table 1, the three sets of rice husk used have almost the same energy content and composition. The average calorific value is 13.8 kJ/gm, and the composition is about 34% carbon, 5% hydrogen, 30% oxygen, and 0.2% nitrogen. The energy potential of the rice husk is based on its calorific value and volatile combustible matter. Tar content is expected to be high due to the high volatile combustible matter content of about 54%. Fixed carbon is 15.8%. The moisture content of 9% indicated that the rice husks used were relatively dry.

Table 1.
Rice Husk Analysis

Analysis	Method	Rice Husk Sample			
		1	2	3	Average
Fixed Carbon, %	By Difference	15.8	15.9	15.7	15.8
Volatile Combustible Matter, %	ISO 652	53.4	54.4	53.8	53.9
Moisture, %	ISO 5068	8.8	9.5	8.9	9.1
Ash, %	ISO 1171	22.0	20.1	21.6	21.3
Carbon, %	Infrared	33.9	34.7	33.7	34.1
Hydrogen, %	Infrared	5.2	5.3	5.1	5.2
Nitrogen, %	TC	0.2	0.2	0.2	0.2
Oxygen, %	By Difference	30.0	30.1	30.4	30.2
Calorific Value, kJ/gm	Isoperibol	13.5	14.0	13.8	13.8

3.2 Performance of the GEGS

The system thermal efficiency is defined as the percentage of the combined energy inputs from the liquid and solid fuels that were converted into useful energy. The power output, thermal efficiency and percent diesel fuel savings were calculated from the following equations:

$$P = \frac{1.732(V)(I)(pf)}{1000} \quad (1)$$

$$\eta_{th,pure\ diesel} = \frac{P}{(HV_{PD})(m_{PD})} \times 100 \quad (2)$$

$$\eta_{th,dual\ fuel} = \frac{P}{(HV_{PD})(m_{PD}) + (HV_{RH})(m_{RH})} \times 100 \quad (3)$$

$$PDS = \frac{m_{PD} - m_{D(DF)}}{m_{PD}} \times 100 \quad (4)$$

where: P = power output, kW
pf = power factor
V = voltage, V
I = current,. A

$\eta_{th,PD}$ = thermal efficiency when using pure diesel only, %
$\eta_{th,DF}$ = thermal efficiency when using dual fuel, %
m_{PD} = pure diesel consumed, kg/s
$m_{D(DF)}$ = pure diesel (in dual fuel) consumed, kg/s
m_{RH} = rice husk consumed, kg/s
HV_{PD} = heating value of pure diesel, kJ/kg
HV_{RH} = heating value of rice husk, kJ/kg
PDS = percent diesel savings, %

Other data, such as the calorific value of the producer gas, its composition and gas flow, could not be taken due to unavailability of measuring equipment.

The efficiencies versus the power outputs of the Ford engine at various engine speeds are shown in Figure 5. With the engine speed set at 800 rpm, the power output ranged from about 1.75 to 10.5 kW using Eq. (1); the efficiency ranged from 7 to 23% on pure diesel using Eq. (2), and from 1.5 to 7% on dual fuel using Eq. (3). At 1000 rpm, the power output ranged from 2 to 13 kW; the efficiency ranged from 7 to 24% on pure diesel, and from 1.5 to 8% on dual fuel. At 1200 rpm, the power output ranged from 2.5 to 15 kW; the efficiency ranged from 7.5 to 25% on pure diesel, and from 2 to 9 % on dual fuel. At 1400 rpm, the power output ranged from 3 to almost 18 kW; the efficiency ranged from 7 to 22% on pure diesel, and from 2 to 10% on dual fuel. At 1600 rpm, the power output ranged from 3 to 20 kW; the efficiency ranged from 7 to 23% on pure diesel, and from 2 to 10% on dual fuel. At 1800 rpm, the power output ranged from 3.5 to 19 kW; the efficiency ranged from 7 to 20% on pure diesel, and from 2.5 to 8% on dual fuel.

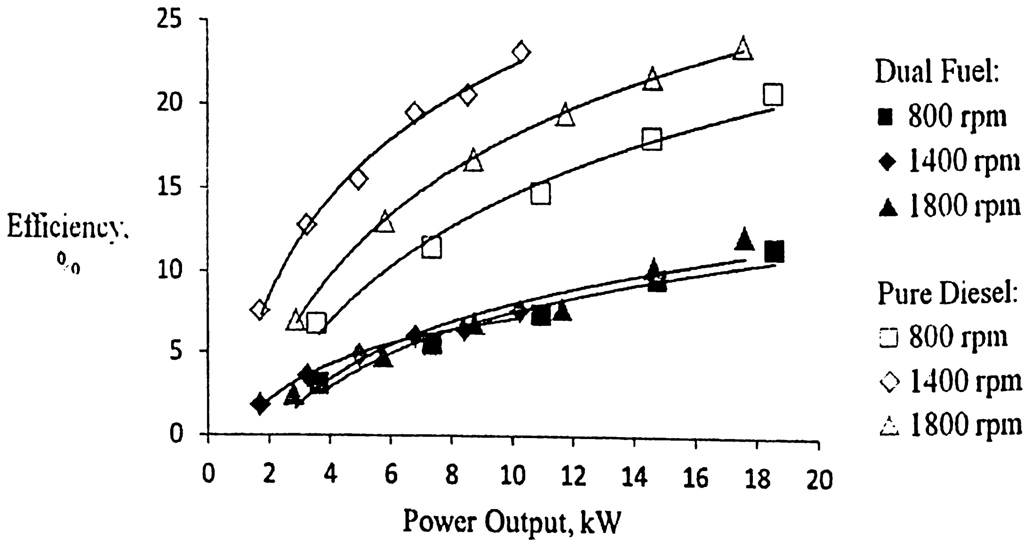

Figure 5. Efficiencies of the Ford engine at various engine speeds

The producer gas temperature is fairly constant at a range of about 350-550°C. This is consistent with findings to yield a producer gas of good quality [1], and shows that the gasifier was producing constant quality gas regardless of the engine load.

The exhaust gas temperatures versus the power outputs of the Ford engine at various engine speeds are shown in Figure 6. At 800 rpm, the exhaust gas temperature ranged from about 210 to 300°C when fueled by pure diesel and from about 270 to 400°C when using dual fuel. At 1000 rpm, it ranged from 160 to 270°C for pure diesel, and from 180 to 380°C for dual fuel. At 1200 rpm, the exhaust gas temperature ranged from 200 to 300°C for pure diesel, and from 260 to 400°C for dual fuel. At an engine speed of 1400 rpm, the exhaust gas temperature ranged from 175 to 320°C for pure diesel, and from 220 to 370°C for dual fuel. At 1600 rpm, the exhaust gas temperature ranged from 280 to 370°C for pure diesel and from 300 to 450°C for dual fuel. At 1800 rpm, the exhaust gas temperature ranged from 260 to 380°C when using pure diesel, and from 300 to 430°C when using dual fuel.

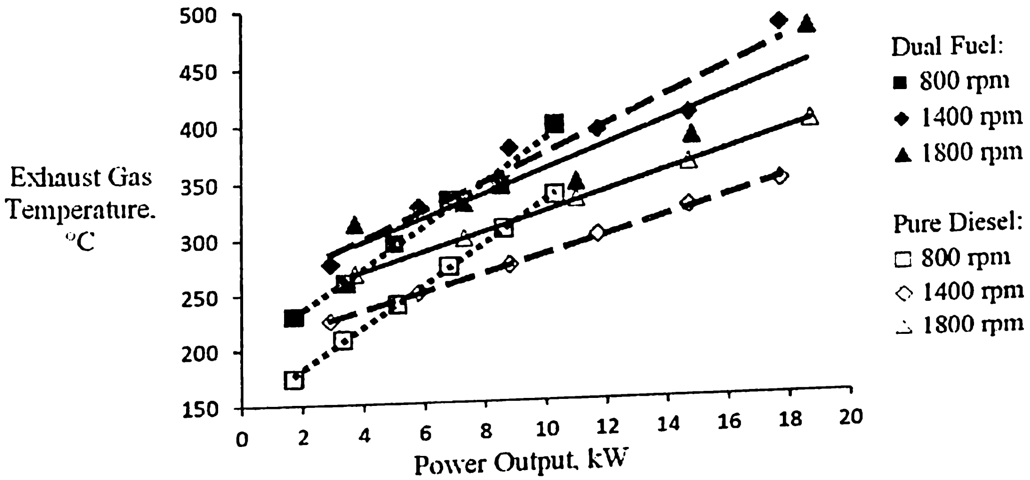

Figure 6. Exhaust gas temperatures of the Ford engine at various engine speeds.

The efficiencies and exhaust gas temperatures against the power outputs of the Lombardini engine at an engine speed of 1800 rpm are shown in Figure 7. At 1800 rpm, the power output ranged from 0 to about 6.5 kW and the efficiency ranged from 0 to 22.2% for pure diesel while it ranged from 0 to 9% for dual fuel. For the same engine speed and power output ranges, the exhaust gas temperature ranged from 228 to530°C for pure diesel and from 240 to 545°C for dual fuel. In all the various engine speeds, the Lombardini engine exhibited the same trends of efficiency, exhaust gas temperatures, and producer gas temperatures as the Ford engine.

Generally, the graphs showed that thermal efficiency increases with load, which is consistent with the behavior of the efficiency curve [5]. It showed that the thermal efficiency when using producer gas was lower than the thermal efficiency when using pure diesel. This can be attributed to the heat losses in the gasifier system and to the variation of the quality of producer gas being produced. The heating value used was that of rice husk as fuel. A more accurate system thermal efficiency could be derived when the efficiency is based on the heating value of the producer gas.

Also, it can be seen that the exhaust gas temperature with dual fuel was higher than when using pure diesel. These findings were similar to previous findings [5] in which the difference in the exhaust temperatures were due to the fact that when using pure diesel as fuel, the excess air for combustion is very high compared to that when using dual fuel. The exact air/fuel ratio could not be determined thus the correct timing of the engine could not be ascertained.

Other important findings in the experiment were the amount of tar and impurities trapped in the cloth filter, and the percent diesel fuel savings obtained when utilizing dual fuel. It can be seen that the amount of impurities trapped by the cloth filter was very minimal, the maximum of which was only 44.6 mg/kg of rice husk consumed and an average of only 4.2 mg/kg of rice husk consumed.

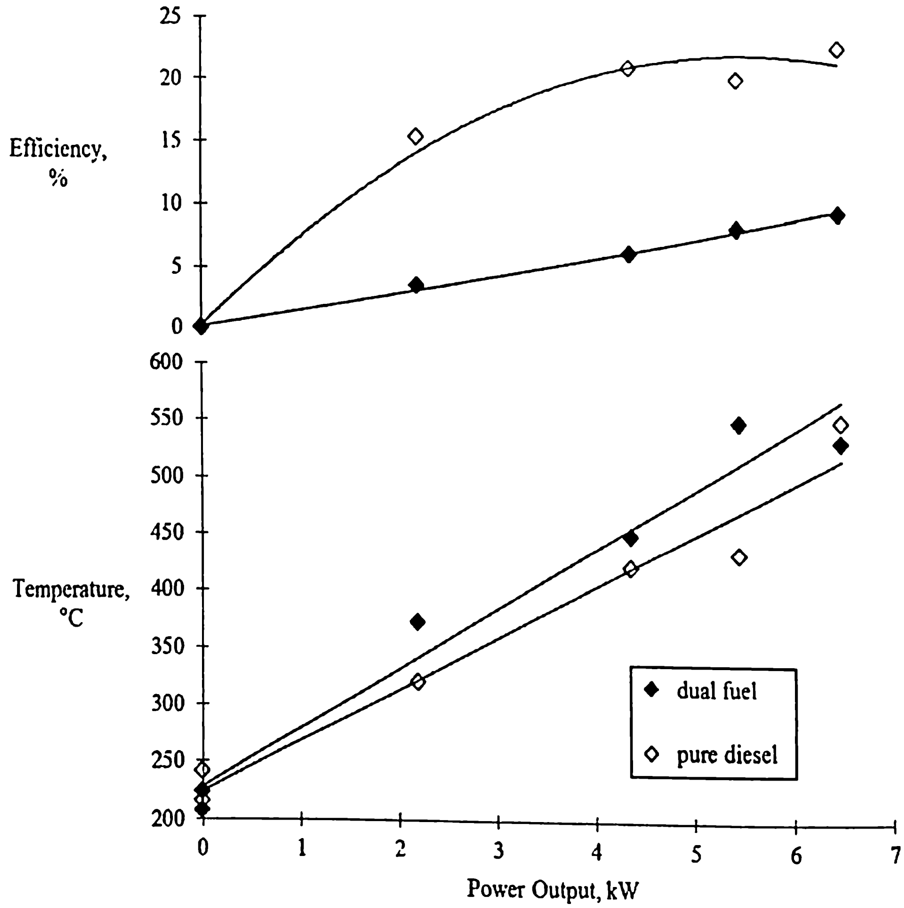

Figure 7. Efficiencies and Exhaust Gas Temperatures of Lombardini Engine at 1800 rpm.

Using the gas production rate of 60.6 m^3 per hour [1], the average tar and particulate content translates to only 1.6 mg/m^3 of producer gas. The weight of ash removed was about 6.58 kg/hr, about 30% of the rice husk consumed. It can thus be concluded that the reactor burned the rice husk fuel efficiently, and the producer gas is relatively cleaner.

Diesel fuel savings calculation was based on the data of fuel consumption when using pure diesel and when utilizing dual fuel. Diesel fuel savings was from a low of 1.8% at 1200 rpm and power output of 2.55 kW, to a high of 42.3% at 800 rpm and a load of 1.68 kW using Eq. (4). It averaged about 18% and 33% diesel fuel savings for the Ford engine and for the Lombardini engine, respectively. The Lombardini engine is relatively more efficient than the Ford engine, due to the nature of its efficiency characteristic curve and it was operating at lower loads.

3.3 Evaluation of Ash Analysis

Rice husk ash is of two kinds: charred rice husk, which remain on the grate, and the flyash particles, which are carried by the producer gas. For each kind of ash, filtering and disposal has to be considered to be able to have a viable gasifier system. Its analysis is necessary to find out if the use of rice husk as fuel is being maximized during the experiment. The analysis of the rice husk ash is presented in Table 2. The tests were conducted at the Energy Research Laboratory of the Department of Energy.

The ash samples were grouped according to the amount of rice husk consumed (e.g., Ash samples 1 are the experimental runs that have a rice husk consumption range of 14.2-17.6 kg per hr). Energy content of the ash was about 13.2 kJ/gm, although its volatile combustible matter had been reduced to about 5.8%. The experiment produced an almost constant quality of rice husk ash which could mean that a fairly constant quality of producer gas was produced.

Table 2.
Ash Analysis

Ash Sample	Rice Husk Consumed Range Per Run kg/hr	Fixed Carbon %	Volatile Combustible Matter %	Moisture %	Ash %	Calorific Value kJ/gm
1	14.2-17.6	34.4	8.1	5.2	52.3	13.1
2	18.1-19.8	35.7	5.7	5.5	53.1	13.3
3	20.0-20.5	35.0	5.7	5.1	54.2	13.0
4	20.6-21.5	35.1	4.6	5.5	54.9	13.0
5	21.6-22.4	37.8	6.0	5.5	50.7	14.1
6	22.6-23.6	34.8	5.8	5.2	54.3	12.7
7	24.0-24.8	34.7	5.0	5.0	55.3	12.8
8	25.0-25.7	35.6	6.4	5.2	52.8	13.2
9	26.4-28.0	35.4	6.3	5.4	52.9	13.2
10	28.4-32.5	37.7	5.0	5.9	51.4	13.8

3.4 Engine Oil Analysis

The main reason for analyzing the lubricating oil of the engine is to determine the condition of the engine using the lubricating oil as indicator. The results of the lubricating oil analysis are shown in Table 3. The tests were conducted at the Fuels and Appliance Testing Laboratory of the Department of Energy. The specific gravity used for weight/volume calculations was taken to compare the four oil samples. Notably, the samples have more or less equal specific gravity.

Table 3.
Engine Oil Analysis

Test	Method	Sample			
		1	2	3	4
Specific Gravity @ 15.5°C	ASTM D 287	0.89	0.91	0.91	0.91
Kinematic Viscosity @ 50°C, cSt	ASTM D 445	86.75	55.36	83.24	78.78
Pentane Insoluble, %	ASTM D 893	0	6.12	1.15	3.68
Water, %	ASTM D 95	trace	0.40	trace	0.20
Flash Point (COC), °C	ASTM D 92	252	199	234	224
BS & W, vol %	ASTM D 1796	0	0.10	0.10	0.10

Sample 1 – new oil
Sample 2 – oil previously used by the engine before the experiment
Sample 3 – oil taken after 50 hours of operation of the engine using dual fuel
Sample 4 – oil taken after 105 hours of operation of the engine using dual fuel

Viscosity is the most important property of lubricating oil. It determines not only the oil volume, but also the oil thickness that circulates in the engine. As shown in the viscosity test of samples 3 and 4, the lubricating oil used by the engine in the experiment was still in good condition. It was actually in a far better condition than the oil previously used by the engine. This was also evident from the results of the flashpoint test, a test that also indicates contamination of the lubricant by the fuel.

Pentane insoluble indicates the amount of solid contaminants in the oil, including soot and neutralized calcium compounds from lubricants and oil oxidation products. As seen from the results in Table 3, the accumulation of insoluble in the diesel engine was very minimal.

Water affects the viscosity of the lubricating oil and may form an emulsion with the lubricant. It also tends to wash the oil film from the cylinder walls and can contribute to the corrosion of the engine. Comparison of the test results showed that only a small amount of water was present in the oil and this was only after more than 100 hours of operation of the engine.

The water and sediment (BS & W) test indicate the sediments that form from the oil itself when exposed to a very high temperature, and also indicate the products of combustion that gets through the crankcase of the engine. The test results showed that the three used oil samples had the same level of water and sediment content.

It can be seen from these test results that the Ford engine was still in good condition after accumulating over 100 hours of operation using dual fuel. Similar trends were obtained using the engine lubricating oil of the Lombardini engine.

3.5 Analysis of the Oil Bath Filter Medium

The diesel oil in the oil bath was also analyzed using similar tests done with the engine lubricating oil to find out its characteristics before and after being used in the experiment. The results of the analysis are shown in Table 4. The tests were done by the Fuels and Appliance Testing Laboratory of the Department of Energy. From the viscosity tests on the oils, it can be seen that the diesel oil became more viscous after the experiment. Coupled with the results of the specific gravity and the flash point tests, it also suggests that the condition of the diesel oil deteriorated as it became more viscous and less flammable. Sulfur, water, and sediment content were also found to have increased. The BS & W test shows that the diesel oil initially does not contain water and sediments but when used in the experiment, it was tested to have accumulated water and sediments. These tests indicated that the diesel oil was indeed removing impurities from the producer gas. However, the weight of the impurities trapped by the oil bath filter was not determined.

3.6 System Operations and Maintenance

The GEGS with the improved filtering system is easier to operate than those previous designs. It can be operated continuously due to the installation of the rice husk feeder/storage/filter system. Maintenance on the filter system had been simplified by eliminating the need to constantly change the filter material. Downtime is also reduced by the installation of the air-conveying rice husk feeder. Still, some reactor maintenance is necessary for continuous production of the producer gas. The shortest maintenance interval is only after 4 hours of accumulated operation. While the longest cumulative period without cleaning is 27 hours or an average of about 10.5 hours of accumulated operation during the more than 100 cumulative hours of experiment. Re-gasketing of the suction baffle and the pipe links are required after being opened for the fourth time. The water drum needs cleaning due to the tar and flyash accumulation. The gas demister and gas suction blower were checked for tar, flyash, and water condensate accumulation. The oil bath filter needs refilling after about 60 hours of operation. Corrosion of the butterfly valve housing on top of the reactor was observed and this was later repaired. The inlet and outlet pipes of the rice husk filter required cleaning. The cooling tower and water pumps were checked for clogging.

Table 4.
Oil Bath Filter Oil Analysis

Test	Method	Sample 1- Oil before the experiment	Sample 2 – Oil after the experiment
Specific Gravity @ 15.5°C	ASTM D 1298	0.84	0.86
Kinematic Viscosity @ 50°C, cSt	ASTM D 445	2.66	3.51
Sulfur, %	ASTM D 1552	0.38	0.61
Water, %	ASTM D 95	Trace	0.40
Flash Point (PM), °C	ASTM D 93	67	108
BS & W, vol %	ASTM D 1796	0	0.10

Necessary engine maintenance includes checking and adding of lubricating oil, and daily replenishment of engine coolant. Most maintenance done was on the cleaning of the grate and the exhaust baffle, both of which easily got clogged with hardened ash. It was observed that the clogging is due to the hardening of the ash as the feed in the reactor is allowed to burn and cool down after the run was completed for the day. The problem was then minimized by removing the ash and unburned rice husk right after the run for the day was completed. This is evidenced by the minimal grate and baffle cleaning at the later part of the experiment .Other maintenance work done were cleaning of the gas demister and the suction blower, refilling of the oil bath filter medium, replacement of the engine fan belt, repairing of the iron dips of the water rheostat due to corrosion, and cleaning of the cooling tower and the water pump due to clogging with ash, tar and particulate.

Further maintenance activities include the repair of the butterfly valve housing, the installation of an access for the agitator at the rice husk filter, the installation of a removable filter at the rice husk filter gas outlet, and the installation of a wire mesh filter at the rice husk filter gas inlet. The latter two improvements were done due to the frequent clogging of the rice husk filter pipes during the latter half of the experiment. The said improvements generally minimized the maintenance time needed in cleaning the said pipes.

4. CONCLUSIONS AND RECOMMENDATIONS

1. The oil bath filter and the improved filtering scheme were successfully designed and implemented. This new gas cleaning method is more effective than existing methods as indicated by the resulting tar and particulate content of 1.6 mg per m^3 of producer gas.
2. The GEGS is capable of continuous operation as shown by its continuous operation of up to 4 hours at a time, this being limited only by the capacity of the ash bin.
3. The results showed that the efficiency of the diesel engine when utilizing dual fuel is lower than its efficiency when utilizing pure diesel. For both types of fuel, the efficiency increases with increasing loads. When using dual fuel, the engine exhaust temperature is higher than when using pure diesel as fuel.
4. The diesel engine can be operated reliably using the dual fuel as evidenced by the accumulation of 105 hours of operation with no major breakdown or trouble encountered, and the engine was still in good condition as shown by the results of the analysis of its engine oil.
5. It is recommended that studies on the economic and financial feasibility, operational safety, and the environmental impact of its waste products be conducted.
6. A study for a modified version of the GEGS with a more appropriate capacity is also recommended.

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6. REFERENCES

1. Antenor, Rogelio A. "Development of Modified Rice Husk Gasifier with Improved Gas Cleaning Method". MS Thesis (Mechanical Engineering) University of the Philippines Diliman, Philippines (1995).
2. Boateng, A. A. et al. "Fluidized-Bed Steam Gasification of Rice Hull". Technical Information Service. ASEAN Subcommittee on Non-Conventional Energy Research. Thailand (1992).
3. Coovattanachai, N. "Gasification of Rice Husk for Small Scale Power Generation". Technical Information Service. ASEAN Subcommittee on Non-Conventional Energy Research. Thailand (1989).

4. Cruz, Ibarra E. "Producer Gas from Agricultural Residues – its Production and Utilization in Internal Combustion Engines". Technical Information Service. ASEAN Subcommittee on Non-Conventional Energy Research. Thailand (1982).
5. Cruz, Ibarra E. "Development of Rice Husk Gas Producer Systems in the Philippines". Paper presented at the FAO Second Expert Consultation on Producer Gas Development in Asia and the Pacific Region, Malaysia and Thailand (1983).
6. Cruz, Ibarra E. "Producer Gas Technology for Rural Application". FAO Agricultural Services Bulletin No. 61(1985).
7. "Energy Planning and Monitoring Bureau". Philippine Energy Plan 1996-2025. Department of Energy. Philippines (1996).
8. Department of Energy. Philippine Energy Plan 2007-2014 (2007).
9. Food and Agriculture Organization. Forestry Department. Mechanical Wood Products Branch. Forest Industries Division. "Wood Gas as Engine Fuel". Rome: Food and Agriculture Organization. FAO Forestry Paper No. 72 (1986).
10. Guigon, P. and Large, J. F. "Gas Purification Review of Available Methods of Gas Cleaning". Pyrolysis and Gasification. Elsevier Science Publishers Ltd. Essex, England (1989).
11. Hall, D.O. and Overend, R.P. "Biomass: Regenerable Energy". Great Britain: John Wiley and Sons (1987).
12. Jain, V.K., Patel, S.R., and Rao, C.S. "Performance of a Continuous 3.5 kW Throatless Rice Husk Gasifier System for Power Generation". Technical Information Service. ASEAN Subcommittee on Non-Conventional Energy Research. Thailand (1991).
13. Knoef, H. A. M, Bussmann, P.J.T. and Stassen, H. E. M. "State of the Art in Rice Husk Gasification in Honduras". Proceedings of the Second International Energy Conference. Institute of Energy. Malaysia (1992).
14. Mahajan, K.C. and Mishra, J. "Energy from Paddy Husk – An Overview". Technical Information Service. ASEAN Subcommittee on Non-Conventional Energy Research. Thailand (1992).
15. "Government Aims for Balanced Budget by the Year 2000". *Manila Bulletin*, August 24, 1998.
16. "2011 Philippine Statistical Yearbook". National Statistical Information Center. National Statistical Coordination Board. Philippines (2011).
17. Padullon, David P. "Gasification of Rice Hulls and its Use as Fuel for Gasoline Engine". MS Thesis (Mechanical Engineering). University of the Philippines (1983).
18. Pitakarnnop, Nara and Boonrowd, Chirasak. "Conversion of Rice Husks to Pyrolytic Gas for Rice Mill Application in Thailand". Second Expert Consultation on Producer Gas Development in Asia and the Pacific Region. Thailand (1983).
19. Robinson, A.P. "The Design and Development of a Suspension Burner System for Particulate Forestry and Agricultural Residues". United Kingdom. Natural Resources Institute. Bulletin No. 41 (1991).
20. Stahl, G. "Some Aspects on Producer Gas Operation of Internal Combustion Engines". Technical Information Service. ASEAN Subcommittee on Non-Conventional Energy Research. Thailand (1984).
21. Terdyothin, A. and Wibulswas, P. "Feasibility of Cogeneration Using Rice Husk as Fuel". Technical Information Service. ASEAN Subcommittee on Non-Conventional Energy Research. Thailand (1988).

22. Tuyan, B. "Multistage Reactor for Tar Cracking in Thermal Gasification of Wood". Technical Information Service. ASEAN Subcommittee on Non-Conventional Energy Research. Thailand (1992).
23. U.S. National Research Council. Board of Science and Technology for International Development. Report of an Ad Hoc Panel of the Advisory Committee on Technology Innovation. "Producer Gas: Another Fuel for Motor Transport". Washington, D.C., U.S.A. (1983).
24. Zhiying, Fang. "The Progress of Research Work on Gasification of Agricultural Residues in China". Second Expert Consultation on Producer Gas Development in Asia and the Pacific Region. Thailand (1983).