Evaluation of Biomass Gasification Using Coconut Husks in Producing Energy to Generate Small-Scale Electricity

Dedie Tooy[1], Leopold Nelwan,[2] and Freeke Pangkerego[3]

Abstract**—**A study using coconut husks for energy production was conducted in which a downdraft gasifier system was manufactured and applied to produce gas used to generate electric power. Apparatuses were designed and implemented to filter and clean the gas produced and the gasifier's efficiency in producing gas for energy conversion evaluated. Evaluation parameters included reactor temperature, tar volume produced, bioreactor gas produced, gasification performance, and efficiency in energy production. The diesel fuel machine generated by gas had a capacity of 10 kW. Results show that using coconut husks can reduce diesel fuel consumption by 62%. In regions where coconut husk are not used productively, such as on some far islands, coconut husk waste can be effectively used to generate power by conversion into gas.

Keywords**—**Coconut husks, biomass gasification, waste, energy.

I. Introduction

ELECTRICAL energy is a vital necessity in today's economy. Unfortunately the electrical distribution network that has been developed is still not reaching all areas, including some islands or plantations that are beyond the reach of electricity. In some specific areas that are quite difficult to reach physically, or where there is little shelter, it is often considered very uneconomical for a national power company to get into these areas. Because of the high cost of installation and the vast distances, the cost required is too high for a power company to get into these areas in the short term.

In the short term, electrification in these areas is more realistically done locally, in a sense not to be dependent on a national power company. What has always been a critical issue in the development of a power plant is determining a source of energy. With a local company, the amount of energy produced is not too large. However, the cost and availability of energy sources should be cheap and sustainable. This is mainly because the people residing in these remote areas generally doing not have strong financial resources.

In some coconut-producing areas, away from the reach of a national power company, husk gasification of biomass feedstock has a high potential to be used as an energy source, as seen from the characteristics of coconut husks themselves [5]. Coconut husks are the outer portion of the fruit that wrap coconuts with a thickness of 5-6 c.m., consisting of the outermost layer (exocarpium) and the inner layer (endocarpium). Endocarpium contains tiny fibers that can be made into rope, sacks, pulp, mats, heat insulators, filters and other products. The coconut fruit yields 40 % coconut husks containing 30 % fiber, with dust making up the rest. The chemical composition of coconut husks consists of cellulose, lignin, pyroligneous acid, gas, charcoal, tar, tannin, and potassium [2]. Coconut dust has high lignin and cellulose content. The materials contained in the casing of coco dusts and coconut fibers are resistant to bacteria and fungi. They have a pH of 5.2 to 6.8 and are very difficult to disentangle. They will begin to biodegrade within a period of 10 years, so that one benefit is that coconut can be used in the long term. Lignin is a complex molecule composed of units *of phenylphropane* bound in a three-dimensional structure. Lignin is the most powerful material in biomass. Lignin is highly resistant to degradation, biological, enzymatic, or chemical. Because of the relatively high carbon content compared to cellulose and hemicellulose, lignin has high energy content [6].

In some places in the areas that produce coconut, coconut husks are considered as waste and are even burned. Though biomass waste has sufficient calorific value as fuel, it is plentiful in the coconut producing areas. Because it is only an agricultural waste, when in use, the cost of procurement for using coconut husks amount to just the cost of collection/ transportation. Thus, in terms of the availability and costs of coconut husks, they show potential for use as fuel in power plants.

Adequate technology is necessary for the utilization of biomass energy for the production of mechanical energy/electricity. Gasification shows such promise. In gasification, the engine that can be used is a type of engine that has been popular in these communities, such as diesel, so that the installation and operation of a hybrid system can be

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done more easily and will have relatively moderate costs for installation and operation.

Gasification technology involves the process of changing a solid fuel thermochemical into a gas, where the air usage is lower than the required air used for a combustion processes. There are many advantages of gasification technologies, such as the fact that they are capable of producing as consistent a product as a power plan, they are able to process a variety of inputs including fuel, coco, even waste; they are able to transform low-value biomass into higher-value products; and, they are able to reduce the amount of solid waste, while the gas produced is safe and harmless [8].

This study aimed to evaluate the conversion of coconut husk, which is a coconut waste, into energy input for small-scale gasification power plants. Evaluation was done by testing the gasification system that had been made in generating energy. Evaluation parameters included temperature reactor, volume of tar produced, the result of bioreactor gas, gasification performance, and efficiency in energy production. The evaluation process was conducted for assessing the functionality and usability of the previous process in design and manufacturing, are expected. The results of this evaluation are expected to be developed simultaneously with driving the increase in value-added coconut husk and gasification technologies that have a significant impact on improving local economies.

II. Technical Design of Gasifier

A. Technical Considerations

Types of fixed bed gasification can be divided into updraft and downdraft. In general, the gas supplied to the top represents the updraft, while the in the downdraft type, gas is passed down. Gas downdraft gasification of biomass types are more often used as a source of energy for propulsion engines (internal combustion engines). In the downdraft gasification, zones formed by the arrangement of the position of top to bottom are as follows: the drying zone, pyrolysis zone, the combustion zone and the reduction zone. Direction of gas flow is downward so that the gas is not produced through the pyrolysis zone.

In general, the events that took place on the downdraft gasification of biomass material in the pile were burned in the combustion zone. The main gases resulting from combustion in the form of CO2 and H_2O were streamed down. Due to the amount of O_2 being less than the pile under the combustion zone (mostly C), it does not undergo combustion but is reduced as a result of the C, CO_2 and H_2O at a high temperature. At the top of the combustion zone the temperature is quite high, but very little O_2 is generated in the process of pyrolysis, while the uppermost zone is of relatively moderate temperature, so the process of drying takes place.

Pyrolysis is a process that produces many types of gas and has a long chain. Thus, the relatively low temperature of these gases can condense them into tar. Tar is not permitted to enter into a motor fuel, so the tar content in the gas must be very small. In the updraft gasification process, gas produced goes through the pyrolysis zone so that the tar content in the gas is high enough [10]. However, in the downdraft gasification process, tar produced in the pyrolysis process will be burned in the combustion zone so that the tar content is quite low. Upon consideration of the above, the downdraft gasifier type was selected for this activity.

B. Equivalence ratio (ER)

ER is the oxygen - fuel ratio and is stoichiometric. ER will determine whether the process takes place as combustion, gasification or pyrolysis. Figure 1 shows the ER and biomass equivalent air ratio corresponding to the processes of pyrolysis, gasification and combustion. ER also determines the composition of the products produced by gasification. High ER value will result in low concentrations of H_2 and CO. However, the high ER values lowered tar production. ER on several biomass gasification ranges fell between 0.2-0.4. The ER value of the gas produced was approximately 2 Nm^3/kg biomass, while the ratio of air to fuel flow was 1.5 Nm^3/kg biomass. An Imbert gasifier was used in this activity. The gasifier consists of a cylindrical vessel with a hearth at the bottom [9]. In order to meet the rate of ER producer gas generated per unit area of the throat at strived to be at 0.1 - 0.9 $Nm^3/h\text{-}cm^2$.

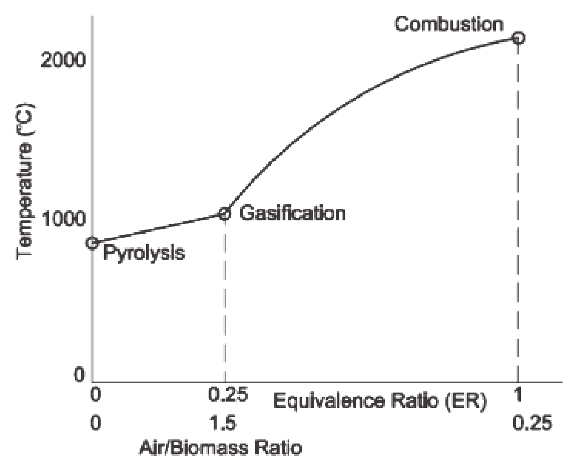

Fig. 1 Equivalence Ratio (ER) and Air/Biomass Ratio (Bhavanam and Sastry, 2011)

B. Gasification system design.

With consideration as in the earlier, the gasification system design chosen is the type using down draft. Support systems consist of a cyclone for the disposal of ash, scrubber and a gas cooler. Fig. 2 shows the scheme of the gasification system.

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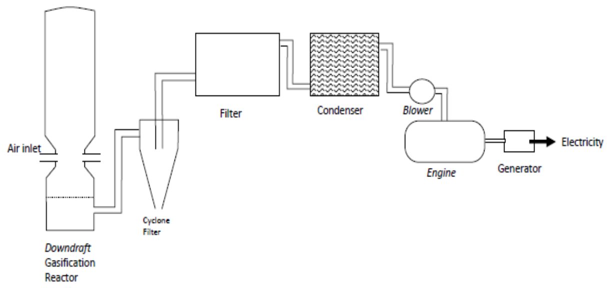

Fig. 2 Scheme of Gasification System

III. Implementation and Evaluation

A. Manufacture

In making this gasification system work and be easily implemented in rural areas that are producing coconut, the system was created to provide small-scale electric power. Therefore, the design was adapted to the capacity, and after that the gasification system was manufactured. The process of design and manufacturing was done by first leading discussions with consideration to the need, feasibility, sustainability and local carrying capacity in terms of human resources, equipment and raw materials. Manufacture of equipment and supporting facilities was accomplished in order to bridge existing problems, as well increase technical capabilities and skills of technology personnel in the use of technology and systems for an efficient gasification power plant. Figure 3 shows the results of manufacture of the gasification system with main its components: the downdraft reactor, cyclone filters, filters, cooling systems, blower pumps and engines [4].

Fig. 3 Manufactured Gasification system

B. Installation and Technical Evaluation

Properties of coconut husk gasification machine in terms of operation: the heating stage where the temperature rises to solids before the drying process; the drying stage where the release of moisture from solids occurs; the warm- up phase where the temperature of the solids rose back up before the de-volatilization process; the de-volatilization stage where volatiles in the solids are processed out until all that remains is charcoal. Depending on the fuel used, volatile gases released may include H_2O , H_2N_2 , O_2 , CO , CO_2 , CH_4 , H_2S , NH_3 , C_2H_6 and unsaturated hydrocarbons[11]; the gasification stage; and, the charcoal combustion stage (occurs if there is still remaining air) .

Equipment already installed is evaluated in terms of downdraft gasification technology assessment results for using coconut husks. In this technology, coconut husks will go down because of the force of gravity and the gas flow down through the bed. This gasifier has a conventional cylindrical shape with a constriction in the middle called the throat. This form is suitable for processing biomass having a large particle size.

1. Materials and Devices

Materials used in this study are coconut husks which were in the location of the implementation of the system. It was in Pinilih Village, North Minahasa Regency, and North Sulawesi Province, Indonesia. Tools used in this study were: Downdraft gasification system (fig. 3), Generator 10 KW, Tang meters, electric oven, thermometers, analytic scales, aluminum foil, cutlery, dessicator, gas analyzer, thermocouples, RPM gauge, Cosmotector: 0_2 and CO_2 gauges, measuring cup and stationery .

2. Methods of Evaluation

Preliminary observation was done to determine the moisture content of coconut husks. Water content of coconut husks is around 29-35 % at harvest. In order to decrease the moisture content, the coconut husks go through the drying first process using natural drying. Observation used the length of drying in days: one day, two days, and three days.

Evaluation analyzed the energy generated and the efficiency with which it was generated. The energy produced from the mixture of diesel and gas was compared with the energy from diesel fuel alone. In order to do that, the setting voltages, RPM, and the electricity were measured. In this way, it could be determine how much energy was produced from coconut husk gasification. Efficiency was determined by how much of the raw material was used and how much energy was generate, For example, using the unit kilogram (kg), in the quantity of energy generated by one kg of husks was calculated, while effectiveness was determined by the period of time, that is how many kilograms of husks where used in one hour.

The procedures for technical evaluation were as follows:

a) Dry coconut fiber coconut fiber was found in a state ready to be harvested It was then separated into three sections. Separation was accomplished by long drying measured in days: one day, two days, and three days.
b) The coconut husk which had dried was placed into the reactor and burned.
c) After a few minutes of the gasification process, flammable gases resulted. These gases were tested at a place that was provided, which was part of the gasifier itself. The smoke that burned when lit was observed, then the cap was placed back on the experiments, and the gas entered the first screening. Here, setting up of

air flow at the burning container was important to ensure adequate supply of O_2. It had to be maintained well to keep the husks not in perfect burning.

d) If the biomass resulted in flammable gas, then measurements were taken as follows: duration of persistence of flammable gas, percentage of the gases created (CO_2, CO and O_2), temperature, power produced and RPM (Rotation per Minute) of engine.

e) After the flammable gas dissipated, ending a single cycle of material inputs, further measurements were recorded as follows: fuel consumption, remaining tar, and duration of the gasification process.

IV. Results and Discussions

A. Time for Gasification Process

To facilitate the user in reducing the moisture content of coconut coir, the material was dried using natural sunlight. A trial was conducted to determine the extent of the decrease in water content during a given time, and this was done by drying the coconut coir to a moisture content of 29.194%. Test results determined that in one day of drying coco, water content was reduced to 18:39%; drying two days reduced it to 16.21%; and, three days of drying reduced water content to 15.38% [7]. However, due to the intensity and duration of solar radiation that is not uniform, the long drying (days) cannot be used as the basis for determining the level of water in the drying period.

The general conditions of gasification require water content of 30%, and the water content standards required by a fixed bed gasifier with downdraft direction of flow is 20%. The actual coconut husks, then, are to be used after the first day of drying, but there remains a need to maximize the results of gasification in reviewing the results of other measurements.

Data obtained indicate that the longest time to produce flammable gas is when the husk has the highest moisture content (18.39%). It needs 7.57 minutes. The husk that has moisture content 16.21% and 15.38% needs 6.27 minutes and 5 minutes respectively. Time used for one time feeding is still varies. It needs around one hour to 30 minutes.

B. Biomass weight and gas produced

Biomass, in this case coconut husk from coconut ready for harvest, had an average weight of 0.4 kg per fruit. Meanwhile, to meet the size requirements of the container used, the coconut husk was cut to the size of 3-5 cm If the water level were lowered, then surely more would be lightweight husks, but the number quantity of coconut husks would remain the same. The effects of moisture content on the percentage of gas produced are shown in Fig.4.

In order to check the gas produced, a Cosmotector gauge was used. O_2 was relatively low 0.22%, while CO_2 was 7.5%. It is expected that in the gasification process, the concentration of O_2 is less because it is already used for combustion, but high CO is expected as it is the flammable gas that is used for combustion in engines. From fig.4 it can be seen that the content of CO decreased by water content, while the actual content of CO_2 was relatively increased by the increment of water contained in the coconut husks. This can be considered good. A good outcome is if the result of flammable gas from gasification such as CO, H_2 and CH_4 are high.

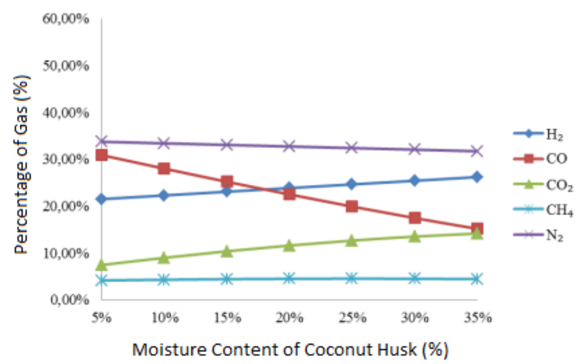

Fig. 4 Effects of Moisture Content on the percentage of gas produced (Dzulfansjah, 2013).

C. Temperature and Tar

The temperature of gasification is a factor that may change depending upon the water content. Temperature will tend to run a little lower if the water level is high and will be higher if the water level is low. The Temperature (T) in the oxidation process is around 733 ° C. In general, the process of gasification is divided into four stages: Drying: T> 150 ° C; Pyrolysis/De-volatilization: 150<T<700°C; oxidation / combustion: 700 <T <1500 ° C; and, reduction: 800 <T <1000 ° C [11].

Tar is the liquid that is derived from biomass feed stocks. Tar is not good for the engine generator motor. Because of this, it is important that we know the amount of tar produced by this process in order to eliminate the as much tar as possible from the gas production. It can be seen that the tar started to follow the existing moisture content, with higher levels of water content resulting in higher levels of tar produced. Tar amount relative to moisture content of 18.39, 16.21 and 15.38 were 180 ml, 80 ml and 10 ml, respectively. In order to eliminate those tars, it is important to decrease the moisture content of coconut husks that will be used for fuel. It is also important for the gasifier to be equipped with a filtering system. As the process of gasification requires high temperatures, it is also important to cool the gas, so the system is equipped with a cooling system which cools the gases before it is transferred and used in the engine. For best utilization of coconut husk is having moisture content less than 15%, but the system needs a maximum filter in reducing tar and produce optimal flammable gases. In the tropical area like the place, where this system is implemented that has high humidity, it needs special effort in order to drying the coconut husks in the field.

D. Energy produced by the engine

Diesel fuel consumption when measured for 30 minutes was 1000 ml. When gasification was used, fuel consumption was 380 ml. This means that substituting gasification is able to generate a fuel savings of 62 %. Gasifier capacity that has produced flammable gas has demonstrated the ability to reduce the consumption of diesel fuel. In trials, the power used is maintained at about 1500 W. Generator voltages could actually be set through gasification. The generator used was set to 220 V, because 220 V is the voltage used for electric power in the village.

The measure of power used is identified by Rotations per Minute (RPM). The RPM meter determines the strength and the amount of power that is produced by the engine. Observation found that in the operation of the gasifier the RPM was around 810-941. In these trials, it can be calculated how much diesel fuel can be saved. If the count for one day in electricity to runs six hours, then the diesel fuel that can be saved is 7.44 liters. And for 30 days, the resulting savings will amount to approximately 223.2 liters. This value is very significant in the effort to save fossil fuels (non-renewable energy).

IV. Conclusions

The study found that coconut husks have advantages for producing small scale electricity through gasification technology. Savings of about 62% is very significant in efforts to increase the added value of waste coconut and in reducing dependence on fossil energy. The effort to develop the maximum potential of coconut husks using gasification technology may be extended to integrate it with practical preparation of raw materials to be input for the fuel. Deeper exploration of gasification technology already in use needs to be increased again to reduce dependence on fossil energy and to utilize agricultural waste that is easily found in the area of coconut production.

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