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Analysis of Output Power Generation in Downdraft Gasifier

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Abstract

This paper studied about the analysis of existing downdraft gasifier to generate electricity and power for rice mill. Power generation from biomass resources has started to attract public attention with gasification technology as a method to reduce air pollution. Myanmar has enormous amount of biomass resources potential in the form of agricultural residues (rice straw, rice husk) which are currently used for domestic energy and fuel applications mostly through combustion. These can be best utilized for the production of producer gas or synthetic gas that can be used for electricity production by using internal combustion engine generator for the operation of rice mills and electrification plan especially in Ayeyarwady Region where national grid network is not available yet. In accordance with theoretical calculation, the current design for rice mill operation and household purpose can produce maximum generator power (97.16 kW); however, which will be vary depending upon load application. This study analyses both of the output power generation from this gasifier and the rate of fuel (rice husk loose type) consumption.

Keywords: Power generation; Gasifier; Rice husk (loose); Producer gas; Pollution

1. Introduction

The production of a combustible gas from carbon containing materials is already an old technology. Most of these materials are solid forms called biomass materials, mainly from agriculture and forestry wastes, such as rice husk (loose and briquette type) and sawdust, which are primarily composed of carbon with varying amounts of hydrogen, oxygen and impurities such as sulphur, ash and moisture content. These wastes can be converted into useful fuel through the process called Gasification. Gasification is a thermo-chemical process which converts solid biomass into a mixture of combustible gases that can be used in various applications. Thus, the aim of gasification is the almost complete transformation of these constituents into gaseous form so that only the ashes and inert materials mostly tar remain [10].

The gasification can be carried out directly by adding oxygen (or air) and by exploiting the exothermicity of the reactions to provide the energy necessary for the process or by pyrolysis, supplying heat from outside in the complete absence of oxygen. The gaseous products, essentially hydrogen, carbon monoxide, methane and carbon dioxide, may be used for several purposes such as heating, electricity generation and production of chemicals and fuels.

Biomass gasifiers are complex equipments that require a lot of time to be mounted and to be put in operation; make it difficult to explore various working conditions. Then it is found that stability, ease of operation, tar, environmental concern, quality and quantity of gas are the most important challenges in the gasifier. In addition, there are considerable environmental problems due to the large quantities of condensate materials (mostly tar).

One of the most important technical barriers is tar problem in biomass gasification technology. Because of this, the concept of reducing tar content inside and outside the reactor has become more important and several attempts have been made to reduce tar content by modifying the traditional downdraft biomass gasification system. In the experimental cases, various parameters are to be optimized for sufficient gas quality and gas quantity with consideration of stability, ease of operation, tar limits and environmental scope [5].

2. Gasification Process

Gasification is the thermo-chemical conversion process of carbonaceous solid fuel (biomass materials) into combustible gas through thermal decomposition with an oxidizing agent (air, oxygen, water vapour). If air is used as the gasifying agent, the producer or synthetic gas consists mainly of carbon monoxide (CO), nitrogen (N_2), hydrogen (H_2), small amount of methane (CH_4) and other hydrocarbon gases. Gasification process mainly occurs in the four zones; namely drying zone, pyrolysis zone, oxidation zone and reduction zone [3].

2.1. Drying Zone

Solid fuel (biomass material) is introduced into the gasifier at the top. As a result of heat transfer from lower parts of the gasifier, drying of these fuel takes place in the bunker section to remove moisture contents (ranging from 5 to 35%) [4].

2.2. Pyrolysis Zone

Pyrolysis is the thermal decomposition of biomass fuels when this fuels heated in the absence of oxygen to about 350ºC, in addition, it is the first step in the combustion or gasification of biomass. It produces charcoal, tar vapor and gases. These products will flow down into the hotter zone of the gasifier. However, some will be burnt in the oxidation zone and the rest will break down to even smaller molecules of hydrogen, carbon monoxide, etc [3].

2.3. Oxidation Zone

A combustion (oxidation) zone is formed at the level where air (oxygen) is introduced into solid carbonaceous materials. Hydrogen present in this materials is also oxidized and a large amount of heat (800 – 1200ºC) is released with the oxidation of hydrogen and carbon [4].

2.4. Reduction Zone

In absence of oxygen, several reduction reactions occur in the temperature range of 800-1000ºC. These reactions are mostly endothermic. The major in this category are as follows:

$$C + CO_2 \rightleftharpoons 2CO + 173\ MJ/kmol$$

$$C + H_2O \rightleftharpoons CO + H_2 + 131\ MJ/kmol$$

$$CO_2 + H_2 \rightleftharpoons CO + H_2O\ \ -41\ MJ/kmol$$

$$C + 2H_2 \rightleftharpoons CH_4\ \ -75\ MJ/kmol$$

$$CO + 3H_2 \rightleftharpoons CH_4 + H_2O\ \ -205\ MJ/kmol$$ [4].

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Table 1. Chemical analysis of rice husk

Elements	Mass Fraction (%)
Carbon	41.44
Hydrogen	4.94
Nitrogen	0.57

Table.1 shows chemical composition of rice husk, whereas carbon percent is 41.44, hydrogen 4.94 percent, oxygen is 37.32 and nitrogen is 0.57 percent. So, nitrogen content is relatively low with the other chemical contents, however moisture content will be high according to oxygen percentage. Thus, it will take time to volatise and remove ash or particulates in drying and pyrolysis zones [9]. Fig.1 shows the composition of producer gas in any kinds of biomass materials that are used in the gasifier to operate rice mills and power consumption especially in rural areas. In this chart, minimum percent of CO (carbon monoxide) is 22.7 and maximum 25%, that of CH_4 (methane) are 4.5 to 7.2 % and H_2 (hydrogen) minimum 4.8 % and maximum 7.8 %. These three gases are used as producer gas source. Other composition contains as moisture contents and volatile matter in biomass materials [11].

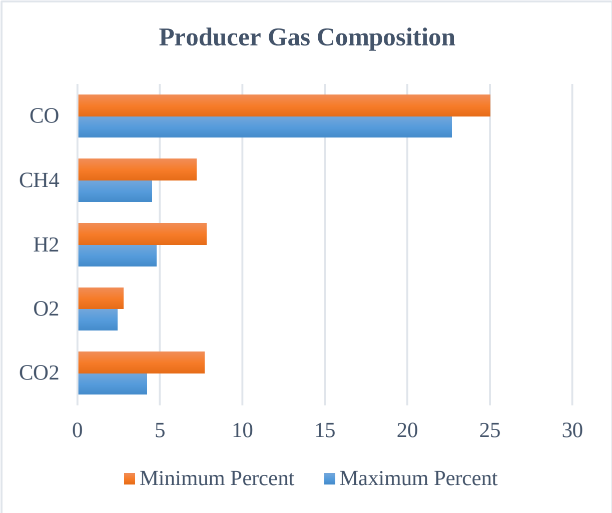

Fig. 1. Producer Gas Composition Chart

3. Operation And Application of Downdraft Gasifier

Biomass material (fuel source) is introduced from the top of the gasifier and moves downward. Oxidizing agent (air) is introduced at the top and flows downward. Producer gas is extracted at the bottom. This producer gas is passed over into water scrubber and gas cleaning components in order to remove any kinds of unnecessary things (particulates, ash and mainly tars). Afterwards, this gas can be applied as fuel source to drive internal combustion engine generator for the operation of rice mills and electrification for the rural areas where cannot access national grid yet [11]. But, some of the weaknesses are low heating value of gas and moisture content of biomass materials. In the other hand, tar and particulates in the producer gas are lower in this gasifier type relatively the other fixed bed gasifier classes (updraft and cross draft gasifier types).

Currently some Myanmar rice husk gasifiers find problems related with technology, trouble free operation and environmental concern. Complicated parameter variations (equivalence ratio, moisture content, operating temperature and gasifying agents) make restriction to develop this technology. When solving these problems related to gas quality, it is equally important to take care of the financial and practical viability of the technology. A gasifier system producing high quality gas demanding more capital investment and complex operation and maintenance will not be able to promote [5]. The present work is focused to analyze both output power generation which depends on the load application and time and fuel consumption rate (rice husk loose type) for one unit power generation.

4. Availability of Biomass Materials Source in Myanmar

Myanmar, being an agricultural country, is rich in biomass resource especially from agricultural residues (rice husk and rice straw). Among them, rice husk is one of the most common by-products from rice mills.

According to Department of Agriculture (DOA) statistics, about 28 % of total paddy (rice) are produced by the Ayeyarwaddy Region, and followed by the Bago Region at about 17 % and the Sagaing Region at 12 %. In 2015, Myanmar was been flooded. As a result, the market demand of rice was fluctuated. During these years, the business of rice was not stable [8].

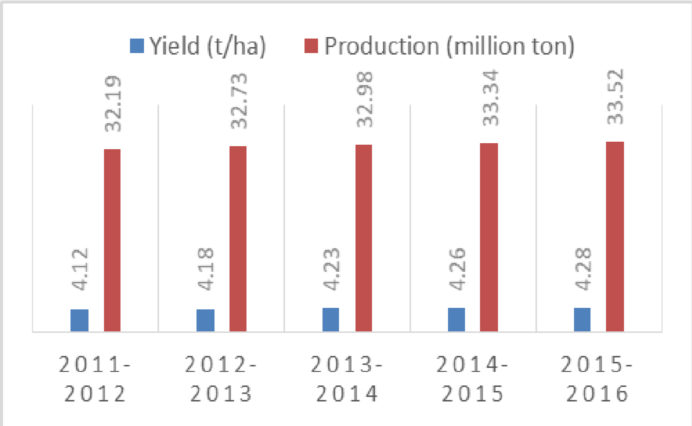

Fig. 2. Column Graph of Yield and Production of Rice in Myanmar

5. Design Performance of Output Power

5.1. Real Gas Intake

In order to supply for combustion of the engine, the real gas intake can be determined by using equation

Real Gas Intake=Max; Gas Intake $\times \eta_v$

Where, η_v is the volumetric efficiency and maximum gas intake can be calculated through the following equation

$$\text{Max;air/gas intake} = \frac{0.5 \times N \times V_d}{60}$$

Where, N is the engine speed and V_d is the displacement of the engine. In this work, the engine generator model is Nissan RH 10, whereas engine speed and displacement volume are 1800 revolution per minute (rpm) and 0.026507 cubic meter (m^3). By assuming air gas ratio for combustion in the engine for power by volume (1: 1.225), maximum gas intake (0.2189 m^3/sec) is obtained from calculation.

To compute volumetric efficiency for real gas intake consideration, the following equation

$$\eta_v = \frac{m_a \times n}{N \times \text{Air Density} \times Vd}$$

Where, n is the number of crankshaft rotation for a complete engine cycle (n = 2), N and V_d is the speed and displacement of the engine. In this calculation, air density is 1.293 kg/m^3 as assumed data.

Where, m_a is air mass flow rate and it is computed from air gas ratio for engine combustion. From this ratio, mass of gas flow rate is required and can be derived through this equation

$$m_g = \text{Vol of fuel} \times \rho\ (\text{rice husk}) \times \eta\ (r)$$

Where, ρ (rice husk) is density of rice husk (340 kg/m^3) and η (r) is efficiency of reactor (60 %). In consequence, volume of fuel can be obtained through this equation

$$\text{Vol of fuel} = \pi\, r^2\, h$$

Where, r is the radius of the reactor (1.125 m) and h is the height of fuel (rice husk) (0.89 m). So, volume of fuel (rice husk) is obtained 3.54 m^3/hrs in one hour incineration. Hence, m_g (mass of gas flow rate) is 0.2 kg/sec.

Thus, volumetric efficiency is obtained 31.7% and consequently, real gas intake is 0.0694 m^3/sec respectively.

5.2. Thermal Power Output

From effective power of engine combustion, the heating value of producer gas is found to be 5 MJ/m^3. Taken into account the real gas intake is 0.0694 m^3/sec, therefore, the thermal power by producer gas is obtained 347 kW.

5.3. Mechanical Power Output

In this case, engine efficiency depends partly on the compression ratio. For an efficient engine cycle compression, efficiency can be estimated at 40%.Hence, the maximum mechanical power in this engine generator design is achieved 138.8 kW.

5.4. Final Power output

In this work, the second-hand generator is used. So, the efficiency of this generator is found to be 70 %. The final power output by the generator is 97.16 kW.

6. Fuel Consumption Rate

6.1. Calculation of Thermal Power Consumption

This power consumption will be taken by the engine for full operation period. Thus, the thermal efficiency of the engine is to be 70 %.

$$\text{Thermal power consumption }(\text{Full load})=\frac{\text{Thermal Power by Gas}}{\text{Thermal efficiency of the engine}}$$

Hence, the thermal power consumption for full load operation time is achieved 495.71 kW.

6.2. Calculation of Rice Husk Consumption

$$\text{Rice husk consumption} = \frac{\text{Thermal power consumption}}{\text{Heating value of rice husk}}$$

From this above equations, heating value of rice husk is found to be 5000 kJ/kg. Hence, rice husk consumption is 356.4 kg/hr.

6.3. Required Weight of Rice Husk (loose) for One Unit Electricity

For one unit electricity generation from this gasifier, required weight of rice husk is considered by the following equation

$$\text{Weight of rice husk}= \frac{\text{Rice husk consumption}}{\text{Final power output}}$$

Where, rice husk consumption is 356.4 kg/hr and final power output by this generator is 97.16 kW. Therefore, 4 kg of rice husk source are required to produce one unit electricity.

7. Discussion and Conclusion

This work was undertaken in Aung Pyae Sone Rice Mill, one of the rice mills in Dedaye Township, Ayeyarwady Region. In this mill, not only rice mill operation but also household purposes still apply through this downdraft gasifier. The following data and Fig. 3 of output power in normal operation time was measured in 18^{th} August, 2018.

The rice husk was introduced when load application was very low depending upon sound and vibration of the engine by the assigned operator. Thus, there was no fill of rice husk from the hopper in M – 4 (Measurement

Four) because one of the motors to drive some cleaning system for pure rice was stopped and it had some technical errors and clog in this motors.

The following pie chart shows percentages of power application not only for household purposes but also for both household and rice mill operation. Therefore, household purposes are 18 % consumption of generated final power output (82 %).

The measurement equipment was really needed to achieve the actual operation process. In the other hand, existing design analysis was totally different with the new design consideration through prototype construction. Moreover, it can also be analysed by engineering software like CFD (computational fluid dynamics). As a result, it will be effective to point some technical error and weaknesses that are concerned with the environmental and social issues because there are not to make measure quality flow equipment or devices in this mill. They emphasized that a large amount of rice can produce in one day since most of the gasifier design were constructed. However, only sharing culture for the optimization of gasifier design between rice mill owners and operators are common in Ayeyarwady Region.

Table 2. Practical Measurement in Operation Time

Measurement Items	**M - 1 (11:48 AM)**	**M - 2 (12:58 PM)**	**M - 3 (2:16 PM)**	**M - 4 (2:50 PM)**	**M - 5 (3:39 PM)**
Voltage (V)	391.1	391.1	392.07	391.53	391.73
Ampere (A)	144	142.27	104.67	126.07	124.1
Power (kW), $P = \sqrt{3}\ VI \cos\emptyset$	79.402	78.448	57.858	69.592	68.539
Volume of fuel (m^3)	3.54	3.89	3.66	3.66	3.89

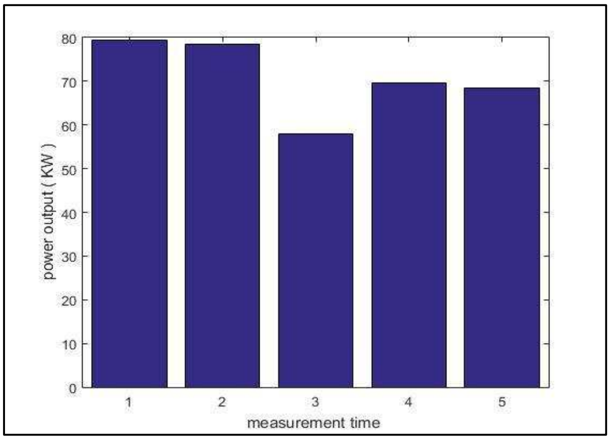

Fig. 3. Bar Chart of Power Consumption in operation time

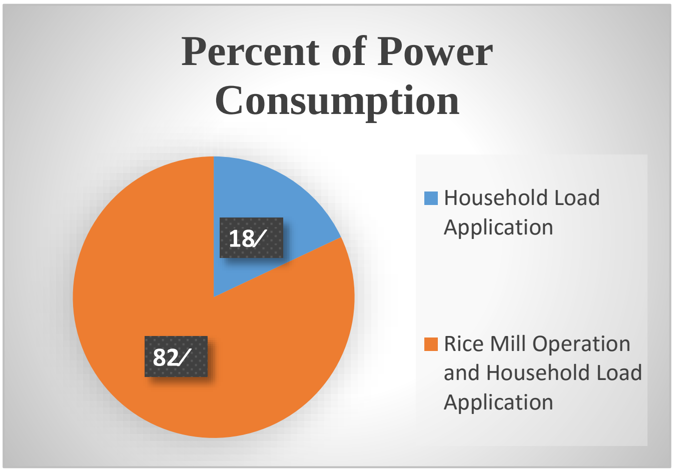

Fig. 4. Pie Chart of Power Consumption Percentages by Usages

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