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Performance and Characteristics of a Cyclone Gasifier for Gasification of Sawdust

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Abstract: The performance and characteristics of a cyclone gasifier for gasification of sawdust has been studied and evaluated. The system applied a technique to gasify sawdust through the concept of cyclonic motion driven by air injected at atmospheric pressure. This study covers the results obtained for gasification of ground sawdust from local furniture industries with size distribution ranging from 0.25 to 1 mm. It was found that the typical wall temperature for initiating stable gasification process was about 400°C. The heating value of producer gas was about 3.9 MJ m^{-3} that is sufficient for stable combustion in a dual-fuel engine generator. The highest thermal output from the cyclone gasifier was 57.35 kW_T. The highest value of mass conversion efficiency and enthalpy balance were 60 and 98.7%, respectively. The highest efficiency of the cyclone gasifier obtained was 73.4% and this compares well with other researchers. The study has identified the optimum operational condition for gasifying sawdust in a cyclone gasifier and made conclusions as to how the steady gasification process can be achieved.

Key words: Renewable energy, biomass, gasifier, producer gas, power generation, sawdust

INTRODUCTION

The demand of energy around the world has been increasing at a very fast pace especially in the developing countries. In light of global issues of sustainable energy and reduction in greenhouse gases, renewable energy is getting increased attention as a potential alternative source of energy. Compared to other sources of renewable energy, biomass is seen as an interesting source of renewable energy. The significance of biomass as fuel has been amplified during the last decades driven by several reasons. Biomass technology offers a technology where the fuels needed are sustainable, resources are often locally available and conversion into secondary energy carriers is feasible without high capital investments.

Among all biomass conversion processes, gasification is one of the promising ones. Gasification is the conversion of biomass fuel to a gaseous fuel by heating with a gasification medium i.e., air, oxygen or steam. The gas produced is combustible and can be used to generate power. Normally, conventional gasifiers are based on gasification of biomass fuels in size ranges from 10 to 100 mm. Currently, cyclones gasifier were studied to be an alternative gasifier to gasify smaller particles of biomass fuels. Cyclone gasifier was used due to its robustness and simplicity, whilst also removing the need for complex hot gas clean up, which reduces the system efficiency (Syred *et al*., 2004).

Fredriksson (1999) discussed the experimental and theoretical studies of cyclone gasifier. The experiments were carried out with commercial Swedish wood powder as a biomass fuel. It was found that the temperature at cyclone outlet increased slowly to about 820°C with increasing air fuel (A/F) equivalence ratio. The calorific value of producer gas was about 4.4 MJ m^{-3}. Gabra *et al*. (2001a) discussed the performance of a cyclone gasifier for gasification of sugarcane residue (bagasse). In the study, it was found that the gasification is stable as long as cyclone wall temperature is above 600°C and the A/F equivalence ratio varied between 0.18 and 0.25. The heating values of producer gas are in the range of 3.5-4.5 MJ m^{-3}. In addition, Gabra *et al*. (2001b) also have studied the performance of a cyclone gasifier using sugar cane trash in the same cyclone gasifier. In the study, it was found that the heating value of the producer gas is in the range of 4.5-4.8 MJ m^{-3} with A/F equivalence ratios of 0.25 and 0.20.

Since, Malaysia produced about 2000 tons of sawdust daily from saw mills and wood based industries (Malaysia Forestry Department, 2003), the utilization of sawdust as a source of biomass fuels is essential. Thus,

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a newly designed cyclone gasifier has been developed at University Science of Malaysia, Penang to gasify smaller particle sizes of biomass fuel i.e., sawdust, rice husk and baggase utilizing the concept of cyclonic motion concept. The advantage of this technique is that it allows a longer retention time where the particle of biomass fuel is held in suspension over a period of time in a cyclonic motion to allow the reaction to take place, thus producing combustible gas. The design of cyclone gasifier is based on work by Fredriksson (1999) with major improvement on the gasifier efficiency was done throughout modifications of critical components i.e., cyclone geometry, fuel feeding system and injection system.

This study describes the performance and characteristics of the cyclone gasifier to gasify sawdust for the purpose of power generation. Sawdust as a waste from local furniture industries was used in the study as a biomass fuel to characterize the cyclone gasifier with different size distribution. The optimization of operating parameters for successful cyclone gasification such as temperature profile and equivalence ratio was performed and discussed.

The main objective of this study is to evaluate the performance of the developed cyclone gasifier using sawdust as a fuel to generate producer gas which is suitable for operation of a dual-fueled engine generator. The main purposes of the gasification tests were to:

- Characterize the sawdust as biomass fuel for cyclone gasifier.
- Determine the temperature profiles of the producer gas and wall temperature profiles inside the cyclone chamber.
- Analyze the producer gas.
- Perform thermodynamics analysis and mass balance on the cyclone gasifier.
- Determine the cyclone gasifier efficiency.

MATERIALS AND METHODS

The system consists of five main parts: fuel feeding system, cyclone gasifier unit, injector system, heat up system and removing compartment. The feeding system consists of a hopper, screw feeder and downcomer (Fig. 1). The biomass fuel (sawdust) is stored at the hopper and it is transferred to the downcomer by a screw feeder. Then, the sawdust is injected tangentially into the cyclone using an air driven injector. The injector directs the fuel and air mixture into the cyclone chamber in a tangential direction, which generates swirl flow in the cyclone. The swirl will force the incoming sawdust particles to follow the trajectory close to the cyclone wall.

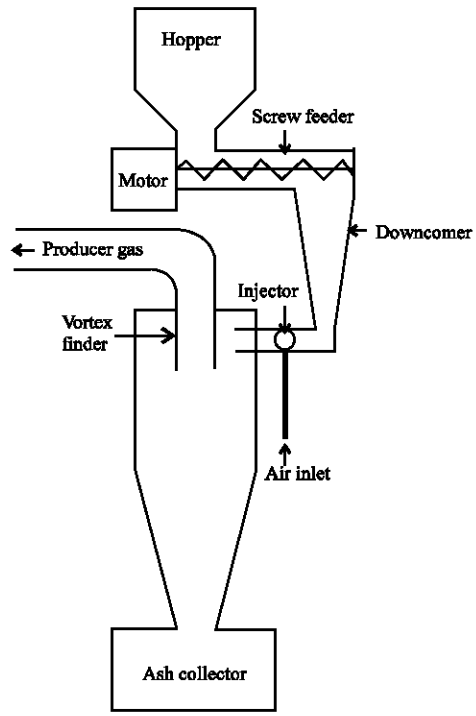

Fig. 1: Schematic diagram of a cyclone gasifier

Producer gas exits the cyclone via a vortex finder, while the char fall downwards toward the bottom outlet into ash collector.

The cyclone gasifier unit consists of conical and cylindrical parts which together form the body of the cyclone. The gasifier body is made of mild steel plate with 6 mm thickness. The cylindrical body has an internal diameter of 210 and 1080 mm height and the conical part connected to the char collector at the bottom. The inlet of the cyclone is mounted tangentially on to the sidewall of the cylindrical part of the cyclone body and has an internal diameter of 28 mm. The exit tube is usually called as a vortex finder or the vortex tube and it is fixed on top of the cyclone and has an internal diameter of 80 mm. Part of the body is insulated with refractory cement and to minimize heat loss.

The feeding consists of a hopper and a screw feeder. A hopper is used to store sawdust before being fed by a screw feeder. The diameter of helical screw and tubular shaft are 147 and 50 mm, respectively while the size of pitch is 120 mm. Sawdust flows towards the screw feeder by gravity. The hopper designed applies funnel flow where the fuel flows through the core. The hopper has a maximum capacity of 30 kg sawdust and the sawdust is stored in the hopper manually. Screw feeder is used to feed sawdust from the hopper to the downcorner. The rotation of the screw feeder is controlled by a motor while the motor itself is controlled by a micro inverter. The injector system consists of a downcomer and a fuel injector. The fuel injector is used to supply air and inject sawdust into the cyclone chamber, while the downcomer connects the fuel injector and the screw feeder. The fuel injector consists of air ejector and an air supply nozzle. The air nozzle will force the sawdust, whilst air ejector will induce the air/fuel mixture into the cyclone chamber. The cyclone chamber needs to be heated up before the injection process. LPG burner was used for heating process. Burner inlet is located tangentially to ensure good heat distribution inside the chamber.

Type K thermocouples were used to measure the temperature inside the gasifier chamber. There were 4 type-K thermocouples located at different location to investigate the thermal effect and temperature distribution inside the cyclone chamber. The effort to place more thermocouples will result disturbances on the swirling flow. The selection of locations is justified as equal distant from the top of the cyclone. Figure 2 shows schematic drawing of thermocouples position for temperature monitoring. All thermocouples were connected to the data logger which is then connected to a computer. The data obtained were graphically plotted to

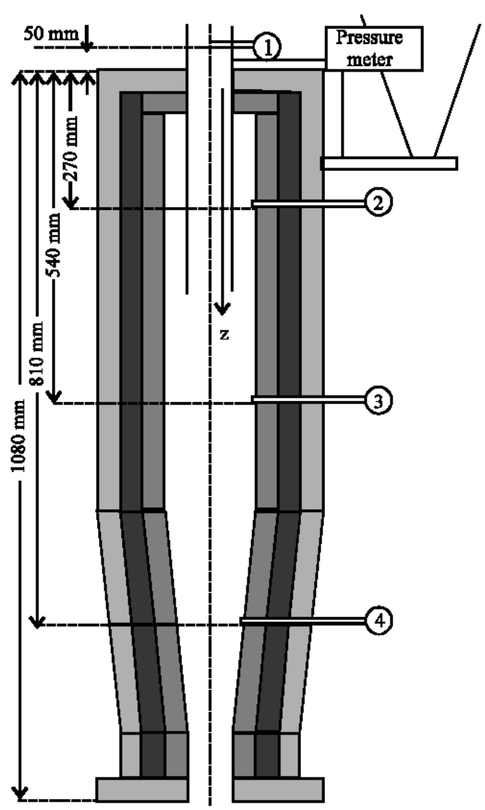

Fig. 2: Schematic drawing of thermocouples locations

illustrate temperature profiles over the period of time during the test. The thermocouple probe tips is cleaned and polished regularly with tar remover to remove any layer of tar to avoid measurement error.

EXPERIMENTAL PROCEDURE

The sawdust gasification tests were made with fuel feed rate of 13 to 37 kg h^{-1} corresponding to A/F equivalence ratios in a range of 0.19 to 0.53. The experiments were started by pre-heating the cyclone with a LPG burner until the wall temperature reach about 400°C, then the fuel injection starts. After about 15 min the system has reached stable conditions and is run smoothly. When the cyclone was run at the desired equivalence ratio, the producer gas was collected using gas sampling bag and tested in the gas chromatograph for measuring volumetric concentrations of the components in the producer gas. The flow rate of the producer gas and the pressure inside the cyclone chamber were measured using an anemometer and a pressure gauge, respectively. Fuel flow rate and air flow rate were varied to achieve optimum operation. Once the experiment was completed, ash collector equipped with an airtight cap to minimize weight loss due to combustion of the hot char. The char sample were weighed and analyzed to determine the energy content of the char.

FUEL CHARACTERISTICS

Experimental studies were carried out using different size distributions of sawdust. The fuels were produced by grinding the raw sawdust in a disk mill. The size distributions determined by sieving are shown in Table 1.

The raw sawdust from local furniture industry was tested where the type of species of wood sawn timber used by the factory was Meranti (Dark Red, Light Red and Red) (Table 2).

The amount of ash content is much lower compared to rice husk, another potential biomass fuel for application in a cyclone gasifier, which has a typical ash content of 20% (Yusoff, 2005). The selection of sawdust as the biomass fuel appear to be the right choice since ash

Table 1: Size distribution

Size (mm)	Weight (%)
S>2	0.00
1.0-2.0	0.00
0.5-1.0	48.57
0.250-0.5	32.56
0.125-0.250	11.08
0.063-0.125	3.51
0.045-0.063	3.55
S<0.045	0.13
Sum	100.00

content is very important parameter affecting the composition and calorific value of producer gas. The lower the amount of ash content the better the fuel (Table 3).

Table 2: Ultimate analysis of the sawdust

Element	Dry weight (%)
C	42.38
H	5.27
N	0.14
O	42.41
S	0.00

Table 3: Proximate analysis of the sawdust

Proximate analysis	Dry weight (%)
Moisture content	8.25
Volatile matter	76.23
Fixed carbon content	14.04
Ash content	1.49

High heating value (HHV) of sawdust was found to be about 18.23 MJ kg^{-1} with moisture content 8.25%. A low heating value (LHV) was about 16.54 MJ kg^{-1}. The result determined was in the range of various types of wood which is between 15.3 and 21.2 MJ kg^{-1} on dry fuel basis (Negi and Todaria, 1993).

RESULTS

Temperature profiles in the gasifier: Dynamic temperature profiles are important to assist in the understanding of the gasification process in terms of the thermochemical phases. But more importantly, it can also be used as a process control indicator inherently measuring disturbances occurring in the feed rate and the air flow rate. The effect of using different A/F equivalence

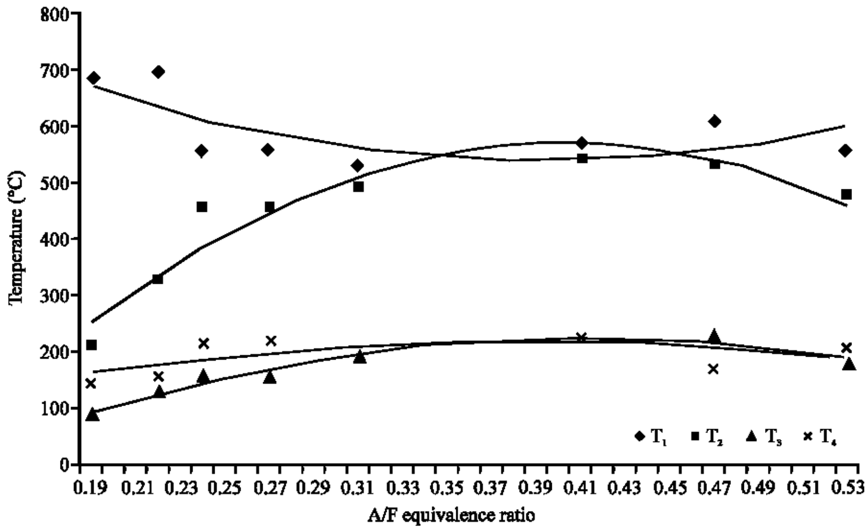

Fig. 3: Temperature profiles values A/F equivalence ratio

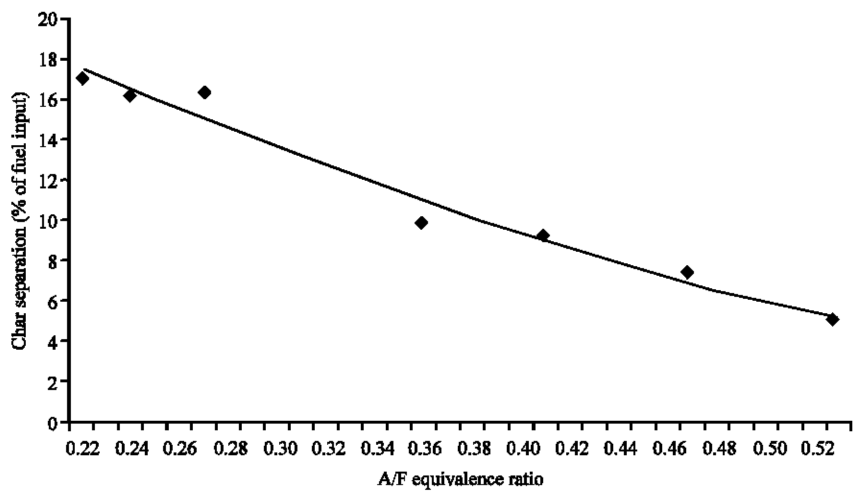

Fig. 4: Char separation versus A/F equivalence ratio

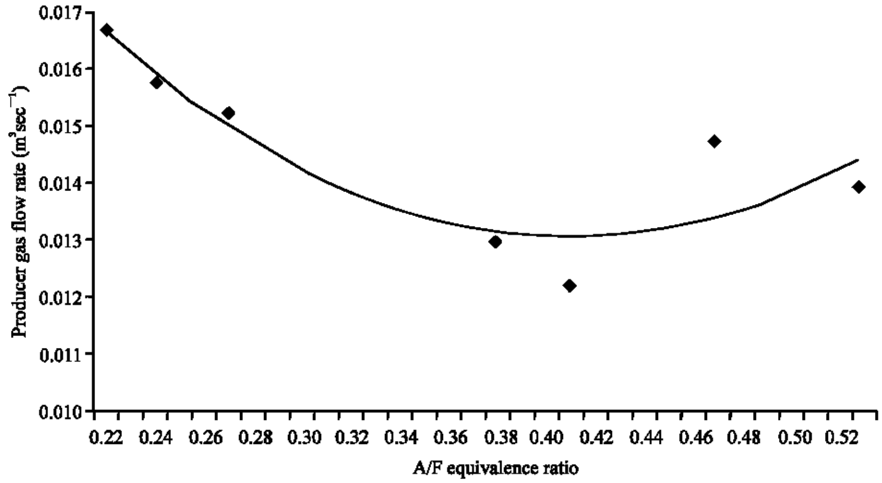

Fig. 5: Flow rate of producer gas versus A/F equivalence ratio

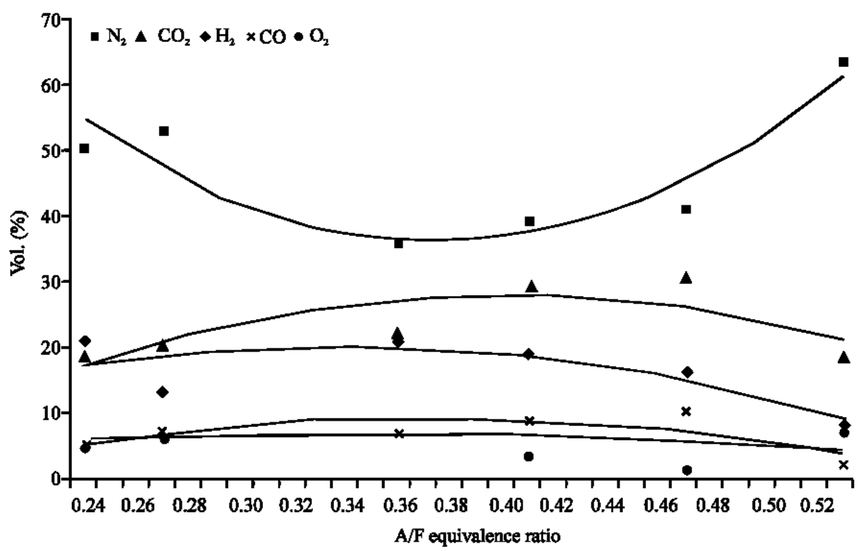

Fig. 6: Variation of gas concentration values A/F equivalence ratio

ratios the temperature profiles of the gasification process was investigated in the ranges of 0.19 to 0.53.

Figure 3 shows the measured mean values of gas outlet and wall temperature against equivalence ratios. The temperature of producer gas decreases with the increase in equivalence ratio up to about 0.31 and then increases. The highest mean value of producer gas temperature was 700°C with equivalence ratio of 0.19. The wall temperature increases with the increase in equivalence ratio up to about 0.41 and then decreases. This is because the process appeared had rich of air supply, thus gave quenching effect that cooled the zone at the particular section.

Char separation: The amount of char that was separated and collected at the bottom of the cyclone is plotted against equivalence ratio and is shown in Fig. 4. The char separation decreases with the increase in equivalence ratio.

Pressure drop and flow rate of producer gas: The static pressure drop inside the cyclone chamber was measured between the inlet and the outlet of cyclone gasifier. The measured pressure drop was about 60 to 80 Pa for the entire test. The flow rate of producer gas against the equivalence ratio is shown in Fig. 5. From the results, the flow rate of producer gas decreases with the increase in

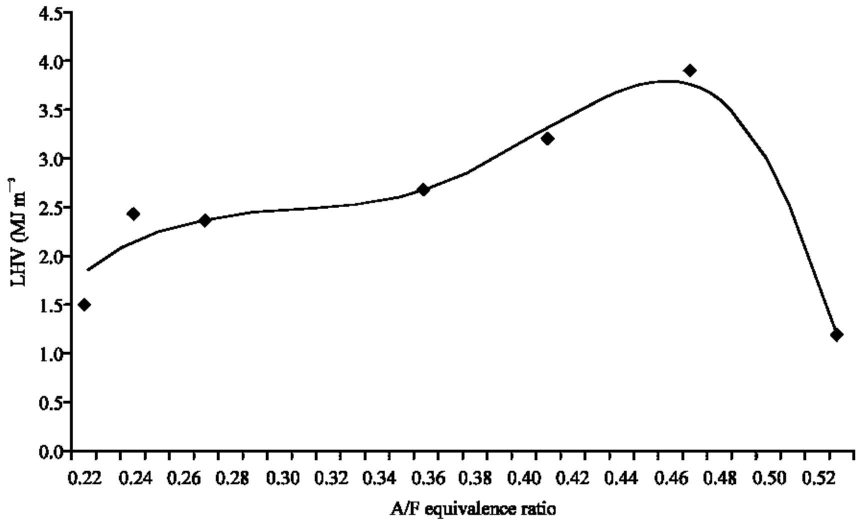

Fig. 7: Calorific value of producer gas versus A/F equivalence ratio

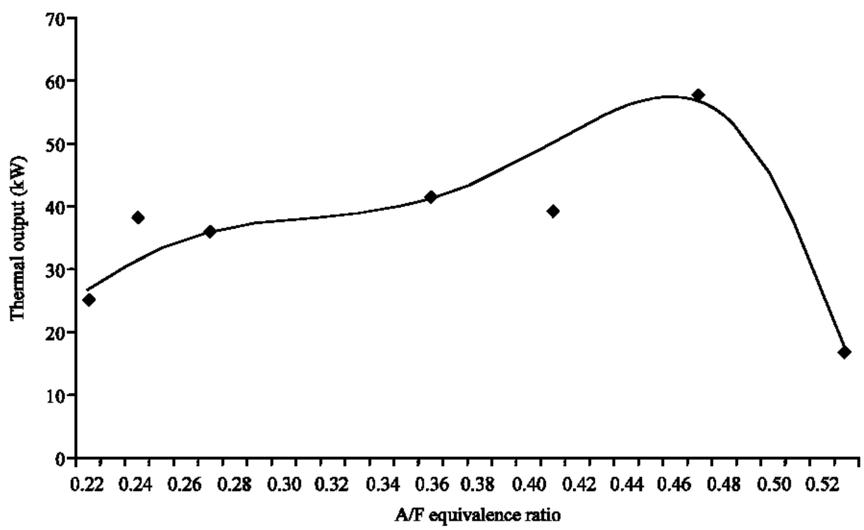

Fig. 8: Thermal Output of cyclone gasifier versus A/F equivalence ratio

equivalence ratio up to about 0.41 and then increases. The equivalence ratio increases with decrease in the mass of the fuel for a given air supply and duration of the run. As a result the combustible gas also reduces. This explains the reason for decreasing trend of producer gas flow rate.

Characteristics of producer gas: Figure 6 shows the percentage of the components of the producer gas against the equivalence ratio.

The lowest amount of CO_2 concentration is about 18% at equivalence ratio of 0.22. The decrease in the percentage of CO_2 shows better conversion into CO in the gasification process. The highest amount of CO concentration is about 11% at equivalence ratio of 0.47. It was found that, the highest concentration of H_2 was 21%. The concentration of H_2 is the most significant contributor to the calorific value of producer gas because LHV of H_2 is higher than CO. Thus it is desirable to increase its concentration in order to increase the calorific value of producer gas.

The calorific value of producer gas against the equivalence ratio is shown in Fig. 7. The calorific value increases with the increase in equivalence ratio up to 0.47 and then decreases. The increase in calorific value is due to the increase in the percentage of CO and H_2. The

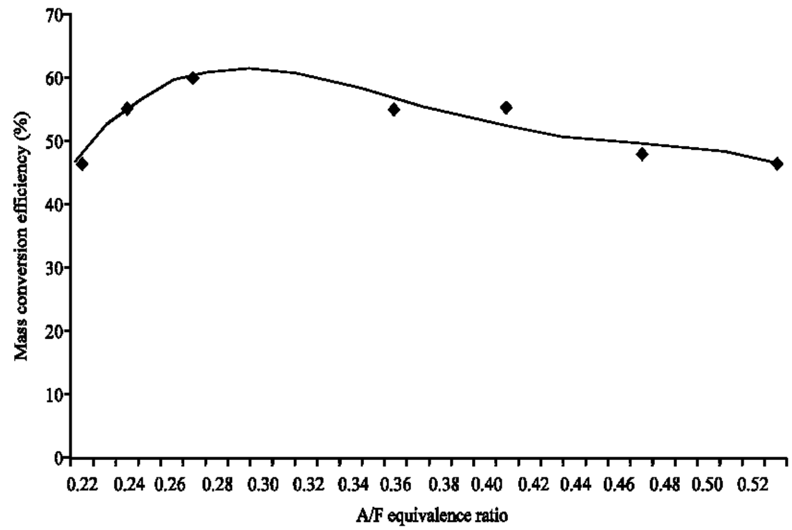

Fig. 9: Mass conversion efficiency versus A/F equivalence ratio

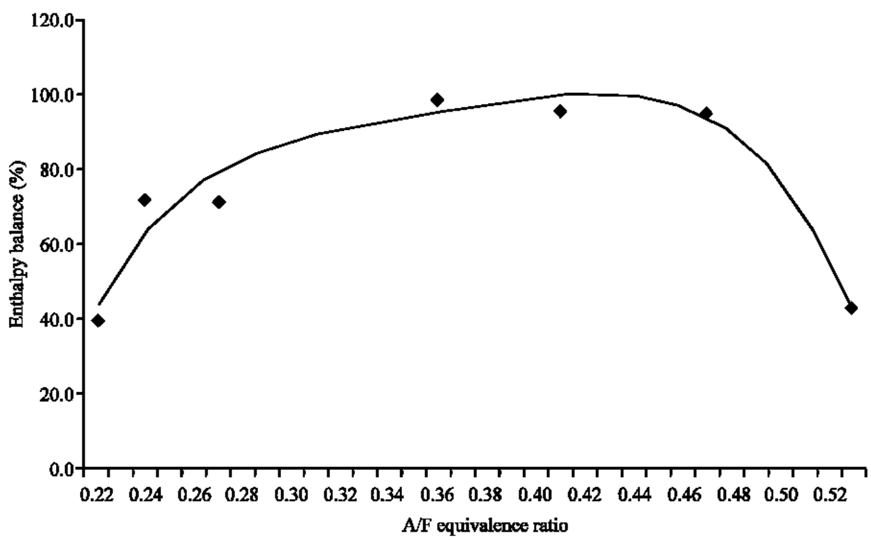

Fig. 10: Enthalpy balance versus A/F equivalence ratio

highest calorific value, LHV of the producer gas is an average of 3.90 MJ m^{-3}. The trend of calorific value is in confirmation with Fig. 6 for CO and H_2, respectively.

Thermal output of the gasifier: From the results, the thermal output increases with the increase in equivalence ratio up to about 0.47 and then decreases. The trend was resulted from amount of calorific value and volume flow rate of producer gas produced. The highest thermal output from the cyclone gasifier was found to be 57.35 kW_T at equivalence ratio equal to 0.47 (Fig. 8).

Mass conversion efficiency: The mass conversion efficiency increases with the increase in equivalence ratio up to a peak value at an equivalence ratio of 0.27 before it starts to decrease. The highest mass conversion efficiency was found to be about 60% (Fig. 9).

Enthalpy balance of cyclone gasifier: From the results, the enthalpy balance increases with an increase in the equivalence ratio up to about 0.47 and then decreases. The highest enthalpy balance was about 98% (Fig. 10).

Cyclone gasifier efficiency: As a result, the efficiency of cyclone gasifier increases with the increase in equivalence ratio up to about 0.47 and then decreases. The highest efficiency of cyclone gasifier obtained was about 73.4% (Fig. 11).

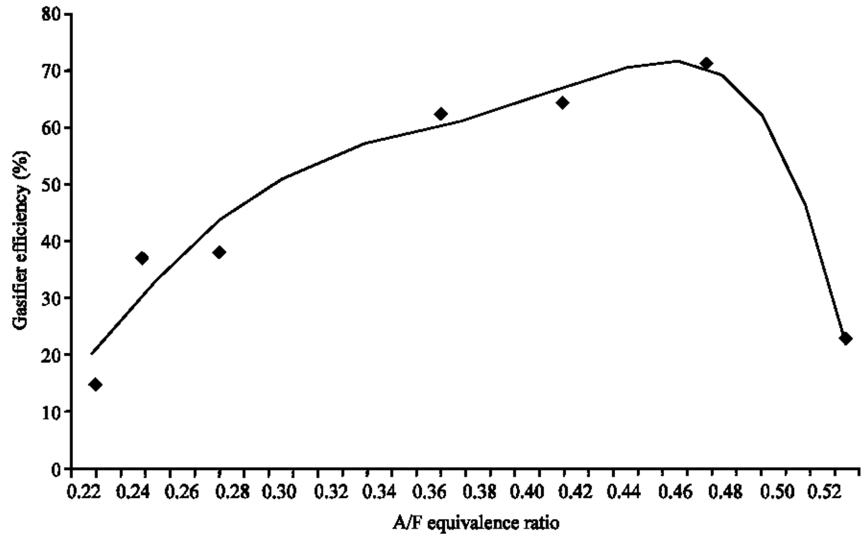

Fig. 11: Cyclone Gasifier efficiency versus A/F equivalence ratio

Table 4: Comparison of biomass fuel moisture content

Researchers	Biomass fuel	Type of gasifier	Moisture content (% dry basis)
Gabra *et al.* (2001a)	Ground bagasse	Cyclone gasifier	5.9
Gabra *et al.* (2001b)	Sugar cane trash	Cyclone gasifier	6.0
Fredriksson (1999)	Commercialize wood powder	Cyclone gasifier	5.6

DISCUSSION

From previous study, Fredriksson (1999) using commercialize Swedish wood powder, the largest percentage of size distribution is in the range of 0.25-1.0 mm which is about 60%. Gabra *et al.* (2001b) using sugar cane residue and the largest percentage of size distributions is in the range of 0.25-1 mm which is about 70%. Therefore, the ranges of size distributions used were comparable with other researchers, which are 80% of size distribution in the range of 0.25-1.0 mm. According to the above proximate analysis, moisture content of sawdust is around 8.25%. This moisture content is relatively higher compared to other types of biomass fuel used by other researchers using cyclone gasification technique as shown in Table 4. The typical maximum amount of moisture content of wood acceptable for gasification process is in the range of 30 to 60% depending on types of gasifier design. The moisture content of the fuels will affect the performance of the gasifier and thus a pre-treatment process is required to reduce the moisture content for optimum operating condition. But any extra pre-treatment process on the sawdust will render the cyclone gasifier to be impractical and uneconomical and direct use of the sawdust with the typical moisture content is still within acceptable value for smooth operation. Extra caution has been made for the sawdust used in this study to be in the dry condition as-it-is basis.

It can be concluded that the drying and devolatilisation zones are minimal and the fuel oxidized almost instantly (looking at the temperature at T_2). The drying and devolatilisation zones can be said to co-exist theoretically but experimentally it is difficult to be determined. This is caused by the nature of the fuel used. The sawdust is in the particle form so when it was injected into the chamber, it reacted almost as gaseous fuel. Meaning that sawdust can be considered to react and combust with the same behavior like gaseous fuel and does not undergo drying and devolatilisation processes. It went straight to combustion. This phenomenon is contrary to other gasifiers and is an exclusive characteristic of a cyclone gasifier.

The calorific value, LHV of the producer gas increased from 1.5 to 3.9 MJ m^{-3} with the increased in equivalence ratios. Other researchers have also observed a similar trend. Gabra *et al.* (2001a) found that the LHV increased from 2 to 4 MJ m^{-3} with the increased in equivalence ratios, while Syred *et al.* (2004) found the LHV increased from 2.99 to 4.26 MJ m^{-3}. Fredriksson (1999) found that the LHV was about 4.4 MJ m^{-3}. The result obtained for mass conversion efficiency is low because the water vapour was not condensed and ash particle cannot be determined because the cooling and cleaning system was not installed. The cyclone gasifier efficiency obtained is comparable with other researchers. Syred *et al.* (2004) found that the inverted cyclone gasifier efficiency was about 36 to 76% with respect to different types of fuel and equivalence ratio from 0.17 to 0.27.

CONCLUSIONS

Experimental study at atmospheric pressure showed that it is possible to generate a combustible gas when injecting the ground sawdust from furniture industries with air as a gasifying agent. All the runs were performed using ground sawdust with particle size distribution in the range from 0.25-1 mm comprising about 80%. It is almost impossible to use raw sawdust directly in the cyclone gasifier because it contains different sizes and shapes of particles thus blocking the flow at feeding and injector system.

The low heating value of sawdust was found to be about 16.54 MJ kg^{-1} with moisture content of 8.25%. The study confirmed that sawdust is suitable to be used for gasification process and this is proven via proximate and ultimate analysis, where the results show that sawdust contained high volatile matter and low ash content that were about 76.23 and 1.49%, respectively while the percentage of carbon content (dry basis) was about 42.38%. The result correlates with other biomass wood fuels.

The temperature profiles of producer gas and inside the cyclone chamber are significant in order to understand the phenomena taking place for this cyclone gasifier system. It has been shown that the temperature levels in the gasifier affected the gas compositions and the calorific value of the producer gas. Consequently, the knowledge of the temperature profiles is necessary in optimizing the performance of the gasifier. Good heating up process in the initial stage results in the minimum wall temperature for initiating gasification process found to be about 400°C at T_2 region. In addition, the average temperature of producer gas was about 600°C. The highest Low Heating Value (LHV) of the producer gas was 3.9 MJ kg^{-1}. The highest thermal output from the cyclone gasifier was 57.35 kW_T. The highest value of mass conversion efficiency was about 60% while enthalpy balance was found to be 98%. As a conclusion, the efficiency of cyclone gasifier increases with increasing equivalence ratios in the range of 0.19 to 0.47 and the maximum efficiency of the gasifier obtained was about 73.4%. The gasifier efficiency obtained is comparable with other researcher which is within the range of 36-76%.

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