Performance monitoring of a downdraft system Johansson biomass gasifier™

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Abstract. Hydrogen production from biomass holds the greatest promise, since biomass is abundantly available everywhere in the world. However, hydrogen from biomass has major challenges. The yield of hydrogen is low from biomass since the hydrogen content in biomass is low to begin with (approximately 6%) and the energy content is low due to the 40% oxygen content of biomass. A novel gasification method for hydrogen production from carbonaceous materials using a CO_2 sorbent has been widely used. It mainly uses steam as gasification agent. For this study the above method has been adopted to test if it will work for air-blown biomass gasifiers. The main purpose of this project is to enhance the yield of hydrogen from air-blown biomass gasification process. The produced hydrogen will be further separated and purified for fuel cell application. Ultimate and proximate analyses of the biomass material were conducted and the obtained results were used for the simulations in order to determine the efficiency of the gasifier with biomass and biomass/sorbent blends. It was found that the biomass/sorbent blends increase the yield of not only H_2 but also other syngas constituents such as CO leading to enhancement of the gasifier efficiency since it is dependent on the volume of combustible gases.

1. Introduction

Biomass is a renewable energy source with a potential to meet the energy needs of both developed and developing countries throughout the world [1] and [2]. Electricity generation from woody biomass grew from 59.5 to 79.6 TWh between 1990 and 2001 around the world, yielding a 2.7% average annual growth. As the second largest renewable electricity source after hydropower, solid biomass accounted for 5.6% of renewable electricity generation in 2001. Biomass comprises unprocessed plant matter, which are wood, twigs, straw, animal dung, vegetable matter and agricultural wastes. Processed biomass includes charcoal, methane, sawdust and alcohol produced from fermentation processes. Biomass fuels can be converted to energy through thermochemical and biological processes. Biomass gasification has attracted the highest interest amongst the thermochemical conversion technologies as it offers higher efficiencies in relation to combustion [3] and [4]. The conversion efficiency of combustion processes is lowered by the converters from thermal power to electrical power. Biomass gasification also produces far much less greenhouse gases than combustion processes thereby improving the world's carbon footprint.

2. Research methods

A custom built Gas and Temperature Monitoring System was developed, the GTPS was built from three Non-Dispersive Infrared (NDIR) gas sensors, one Palladium/Nickel (Pd/Ni) gas sensor and eight type K thermocouples. The NDIR and Pd/Ni sensors were chosen due to their fast response time, accuracy and insensitivity to other gases present in the gas mixture. Type K thermocouples were chosen because of their tolerance of high temperatures (above 1200 °C). This is because temperature in the reactor reaches approximately 1300°C.

The gasifier operating conditions were as follows:

Table 1. Gasifier operating conditions.

Parameter	Value/Quantity
Fuel/air ratio	0.26
Pressure	1Bar
Temperature (maximum)	1300°C
Air temperature (before pre-heating)	25°C
Fuel moisture content	10-12%

3. Results and discussions

3.1. Gasifier conversion efficiency

Figure 1 and 2 show the overall conversion efficiency of the gasifier during the entire test period and the efficiency at 25 minutes interval respectively. The data presented in the two figures was collected using the GTMS described in the methodology section. The breakdown of the efficiency into 25 minutes time intervals is presented in figure 2 to allow for the correlation between efficiency and condensates quantity and energy content because the condensates were drained and analysed at 25 minutes time interval.

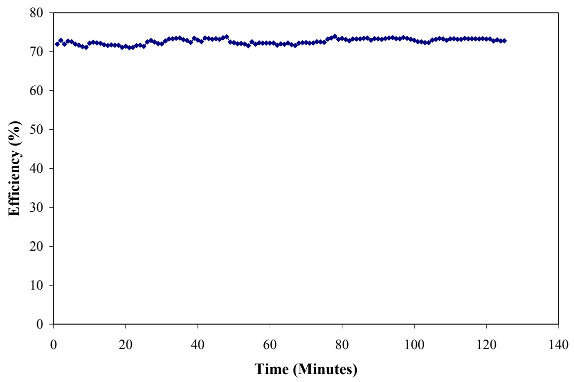

Figure 1. The overall conversion efficiency for the entire test period.

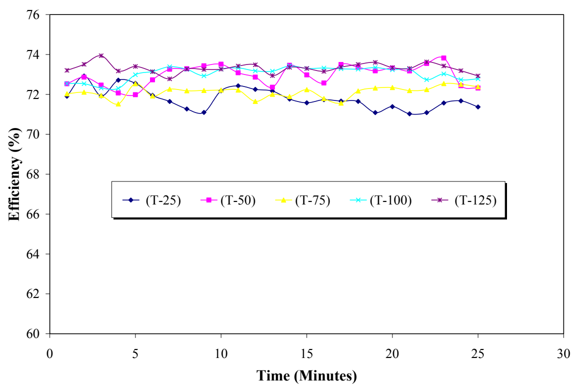

Figure 2. The conversion efficiency for the gasifier at 25 minutes interval.

The gasifier achieved an average cold gas efficiency of 72.6% over the test period. On average, higher gasifier efficiencies were observed at 75-100 minutes (73.31%) time interval followed by 100-125 minutes (73.04%) and 30-60 minutes (72.96%) time interval respectively. The difference in the conversion efficiency during the latter time intervals was found to be between 0.2 and 0.6% due to the 0.14MJ/kg difference in gas heating value, which is not significant. The quantity of condensates was observed to be lowest (75ml) at 100-125 minutes time interval. This suggests that by that time most of the water in wood entering the combustion zone had already been driven off, hence the gasifier conversion efficiency was also observed to be higher at this point.

Figure 3 shows the quantity of condensates and gasifier conversion efficiency at 25 minutes time interval. The condensates constitute the water driven off from the feedstock during drying. The water vaporizes and condenses at the fuel compartment (top part) of the gasifier after reaching dew point temperature. This water is drained out of the fuel compartment through a condensate trap fitted to the gasifier. The other part of the condensates is the tar, which also condenses in the water. It was necessary to establish the impact of condensates on the efficiency of the gasifier since they result in some operational challenges if they are not well taken care of.

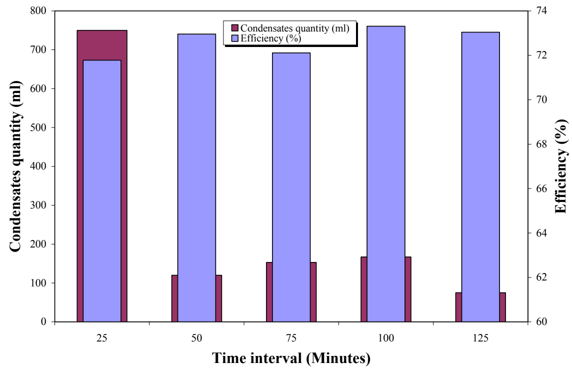

Figure 3. The quantity of condensates and gasifier efficiency at 25 minutes interval.

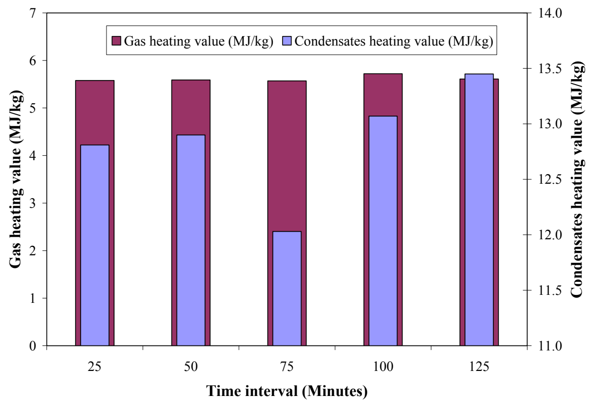

Figure 4. The condensates heating value and gas heating value.

It was found that there was no clear relationship between condensates and gasifier conversion efficiency. Theoretically the production of condensates should lower gasifier efficiency since some of the energy needed for reduction reactions would no longer be available because it would be used in driving off the condensates from the feedstock in the drying and carbonization zones.

Figure 4 presents the condensates heating value and the gas heating value. The condensates heating value was determined using a cone calorimeter after the drying of the condensates using a freeze dryer. This process left the tar component of the condensates, which was then analysed for heating value. It was also established that there is no direct relationship between condensates heating value and gas heating value. The gas heating value influences the gasifier efficiency.

3.2. Mass and energy balance

Table 2 shows the mass and energy balance of the gasifier.

Table 1. Mass and energy balance of the gasifier.

	Gross weight full (Eucalyptus) (kg)	Consumption (kg/h)	Heating value (MJ/kg)	Energy input/output (MJ)	Quantity (kg/h)	Quantity (ml)	Max. output (Nm^3/h)	Heating value (MJ/Nm^3)	Thermal (kW_{th})
Fuel	240	60	17.5	2730	-	-			-
Gas	-	-	5.6	-	-	-	120.0	6.37	-
Charcoal	-	-	28.5	444.6	6.0	-	-	-	-
Cyclone fine carbon	-	-	11.23	1.20	0.107	-	-	-	-
Operating condensates (wet)	-	-	-	-	-	253.0	-	-	-
Operating condensates (Dry)	-	-	12.85	0.00576	0.00045	-	-	-	-
Close down condensates (wet)	-	-	-	-	-	420.0	-	-	-
Close down condensates (Dry)	-	-	12.85	0.80955	0.063	-	-	-	-
Thermal output	-	-	-	-	-	-	-	-	180.0

It is clear from the table that most of the energy goes to the charcoal, unlike updraft gasifiers, downdraft gasifiers do not achieve high charcoal burnout and internal heat exchange that leads to low gas exit temperatures and high efficiencies [5]. The resultant charcoal has higher energy per volume (28.5MJ/kg) than the fuel (17.5MJ/kg), however the quantity of charcoal is less than that of the original fuel therefore the quantity of energy in charcoal becomes less than the input energy from the original wood. The input energy from the original fuel is 2730MJ, while that of the charcoal is 444.6MJ. The energy in charcoal represents 16.37% of the input energy; the combined energy in charcoal, cyclone carbon and condensates is 16.44%, which implies an overall hot gas efficiency of 83%. This gasifier achieved an average cold gas efficiency of 72.8% (figure 8) considering the gas calorific value of $6.37MJ/Nm^3$, fuel consumption of 60kg/h and gas production of $120Nm^3/h$. This translates to an average gas production of $2Nm^3/kg$ fuel.

The average energy lost with condensates is about 0.8MJ of the original 2730MJ energy input with eucalyptus wood with 12-15% moisture content. This implies that condensates carry 0.03% of the total energy input. The cyclone fine carbon particles carry 0.043% of the total energy input.

4. Conclusions

The paper focused more on the conversion efficiency of the gasifier and the impact of condensates on efficiency. The system Johansson biomass gasifier achieved an overall conversion efficiency of approximately 85%. The production of condensates was found to have no direct impact on gasifier efficiency. The gasifier can be used to generate electricity at reasonable price especially in rural areas that are endowed with biomass resources and lie outside the national utility grid. The by-products of the gasifier such as the charcoal and fine carbon particles can be further processed and used in other areas such as production of activated carbon and soil conditioning. The tar in condensates can also be used on road surfaces.

5. References

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