Study on Different Gas Outlet

by Fajri Vidian

Technical Report

Study on Different Gas Outlet Positions in Measurement of Gravimetric Tar Contents in Biomass Updraft Gasifier

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Based on the previous experiment, an updraft gasifier has been modified by adding a gas outlet for producer gas at the reduction zone. The gasifier is operated under a variety of conditions that enable investigation on the effect of gas outlet modification on the amount of tar produced. The producer gas is tapped at a gas outlet at the top of the gasifier (conventional mode), a gas outlet in the reduction zone (reduction mode), and combination of the tapping of the gas outlets at the top of the gasifier and in the reduction zone (combination mode). The experimental results show that the tar content from the gas outlet at reduction mode is less than that at the conventional mode, *i.e.* 81 g $(m^3\text{-N})^{-1}$ and 111 g $(m^3\text{-N})^{-1}$, respectively. Meanwhile, the tar content from the combination mode is about 55 g $(m^3\text{-N})^{-1}$ at the reduction zone and 102 g $(m^3\text{-N})^{-1}$ at the top. Nevertheless, the lower heating values for each mode are similar, that is in the range of 4.6 - 4.9 MJ $(m^3\text{-N})^{-1}$. The hot gas efficiency reaches a maximum of 82 % on gas outlet reduction mode.

Key Words

Updraft, Gasifier, Modification, Gas outlet, Tar

1. Introduction

Biomass is a growing renewable energy source that is used as a part of strategy for replacing fossil fuels. In many countries, biomass is widely available, with a simple and efficient conversion technology [1,2]. In addition, biomass gasification is an energy conversion technology option with a high conversion efficiency and low generation of pollutants [3-5].

In general, biomass gasification is carried out in a gasifier. An updraft fixed bed gasifier is among the most popular type of gasifier, as it has higher efficiency, as well as simplicity in terms of design and operation. Nevertheless, this gasifier is typically characterized by a higher tar yield [2]. Tar is a main problem in gasification process as it could be condensed at a low temperature. The condensed tar could cause clogging in the pipe of gas distribution system.

Gas cleaning methods can be used to clean tar, but it could result in toxic wastes [6]. A better solution would be required to reduce the amount of tar produced by the updraft gasifier. This is important to reduce demands for gas cleaning system and toxic waste.

Modification of the reactor is one of primary methods to reduce tar from gasification process before producer gas goes out from gasifier [7].

Experiments on the modification of reactors for all types of gasifiers are reviewed [8,10-22] in the present study. Some researchers made special modifications to the updraft gasifier to observe the resulting effects on the amount of tar produced. Piao *et al.* [18], modified construction of the updraft gasifier with separated parts. In this design, the bottom part of the gasifier produced combustible gas and the upper part reduces tar with catalyst. Saravanakumar *et al.* [19], modified the position of the combustion zone by moving the position to the top of the gasifier. Nowacki [20] proposed modification to the gas outlet in the combination mode with outlets at the top and at the reduction zone in an updraft gasifier for coal gasification, but results regarding gravimetric tar content were not reported. Lin *et al.* [21], conducted an experiment with modification to the gas outlet on an updraft gasifier with an embedded combustor

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This study was partly presented in the GRE2014

at the pyrolysis zone, but they did not measure gravimetric tar content.

This paper presents a comparison of tar contents in producer gas from an updraft gasifier based on variations in the position of gas outlets, including at the top, in the reduction zone, and in the combination mode (at the top and in the reduction zone).

2. Materials and methods

2.1 Gasifier system

The experimental setup is shown in Fig. 1. The gasifier is made of stainless steel SUS 304 with an internal diameter of 22 cm and a height of 63 cm. Thickness of stainless steel is 3 mm. The use of the same material is reported by Ueki *et al.*[19]. Both pipes in the air inlet and producer gas outlet measures 5 cm in diameter. The gasifier contains two outlets, i.e. one at the top and the other at the reduction zone (about 14 cm from the bottom of the gasifier). The gasifier reactor is covered by a ceramic fiber blanket with a thickness of 5 cm to prevent heat loss. Biomass is fed from the top of gasifier through a window measuring 13 cm in diameter. A grate with a space interval of 1 cm is used to support char at the combustion zone. A chamber below the combustion zone is provided to store unburned fuel, with an ash window to remove ash.

Air is supplied to the gasifier using a blower with a maximum capacity of 500 L-N min^{-1} and a control valve is used to set supply air at a constant volume. Air and producer gas flow rates are measured using an orifice differential manometer.

There are twelve ports for the Cromel-Alumel thermocouple. The lowest one is located at a height of 4 cm above the grate, and the others are located at an interval of 5 cm upwards to the top. The temperature is recorded using data acquisition and the digital data are displayed through a computer monitor.

Producer gas sample is taken as it exits the heated bath using tight sample bags, and it is analyzed for its gas composition by gas chromatography with a thermal conductivity detector (TCD). The sampling bags are evacuated before they are used for gas sampling.

The tar component in producer gas is trapped in a series of impinger bottles filled with isopropanol as a solvent[20,21]. The mixture of solvent and gas is dried in an oven until all solvents have evaporated within the temperature ranging from 105 to 107 °C [illegible]. The remaining tar from the producer gas is weighed and measured in g (m^3-N)$^{-1}$.

2.2 Fuel

Table 1 shows the proximate and ultimate analyses, as well as some physical properties of rubber wood. Rubber wood chips are 3 cm × 3 cm × 3cm in size.

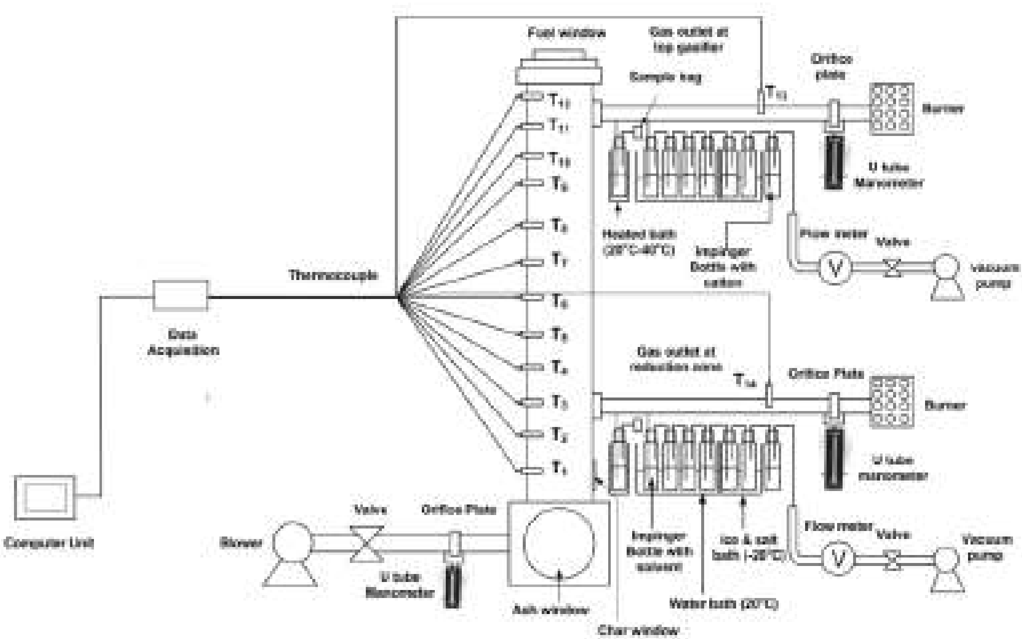

Fig. 1 Experimental set up

Table 1 Proximate and ultimate analysis of rubber wood

Proximate Analysis	Unit	Value
Moisture (adb)	kg/kg dry	10.24
Ash	kg/kg dry	2.71
Volatile	kg/kg dry	71.80
Fixed Carbon	kg/kg dry	15.25
Ultimate Analysis		
Carbon	kg/kg dry	43.33
Hydrogen	kg/kg dry	5.11
Nitrogen	kg/kg dry	Not detected
Sulfur	kg/kg dry	Not detected
Oxygen	kg/kg dry	38.61
Calorific Value	kJ kg-1	17024
Density	kg m-3	640

2.3 Equation for Calculation

The caloric content in producer gas is calculated based on the lower heating value (LHV) of producer gas using the following equation, according to Seggiani *et al.* [20].

$$LHV = [illegible]621 y_{CO} + 10779 y_{H_2} + 35874 y_{CH_4} \quad kJ(m^3\text{-}N)^{-1} \qquad (1)$$

Where yi values are fractions of main combustible gas in the producer gas (mol/mol).

The performance of the gasifier is estimated based on hot gas efficiency, which is calculated as follows, according to Basu *et al.* [9]:

$$\text{Hot Gas Efficiency} = \frac{(H_g.Q_g) + (Q_g.\rho_g.C_p.\Delta T)}{H_f.M_f} \qquad (2)$$

Where the parameter of the equations are explained below:

H_g = Lower heating value (LHV) of producer gas at normal condition MJ $(m^3\text{-}N)^{-1}$

Q_g = Volume flow rate of producer gas at normal condition (m^3-N min^{-1})

H_f = Lower heating value (LHV) of fuel (MJ kg^{-1})

M_f = fuel consumption (kg min^{-1})

ρ_g = Density of producer gas (kg m^{-3}), calculated based on the temperature of the producer gas

C_p = Specific heat of the producer gas (kJ kg^{-1} K^{-1}), calculated based on temperature of the producer gas [9]

ΔT = Temperature difference between the producer gas outlet and fuel inlet (K)

The tar content is estimated based on gravimetric tar in producer gas calculated according to Neeft *et al.* [21]:

$$W_{tar} = \frac{M1\text{-}M0}{Qs.t} \qquad (3)$$

W_{tar} = tar content g $(m^3\text{-}N)^{-1}$

M1 = mass of tar containing flask after evaporation (g)

M0 = mass of empty flask (g)

Qs = flow rate of producer gas sampling at normal condition (m^3-N min^{-1})

t = duration of sampling (min)

Table 2 Total measurement uncertainties

No	Variables	Uncertainties (%)
1	Temperature	± 3.7
2	Air flow rate	± 3.9
3	Gas composition	± 5.27
4	Gas flow rate	± 3.8
5	Fuel consumption	± 3.6
6	Hot gas efficiency	± 16.0
7	Weight of Tar	± 14.0

2.4 Experimental procedures

The typical run is initiated by burning 0.5 kg of rubber wood as biomass fuel inside the gasification reactor. The fuel is ignited using paper and kerosene. After the self-sustained combustion is completed about 5 min after ignition of fuel, the gasifier reactor is filled with 5.5 kg of fuel and the air flow rate is set to 108 L-N min^{-1}. Each test uses 6 kg of rubber wood per batch. After the temperature at the combustion zone reaches 500 °C, the producer gas ignites. The test duration for each batch is about 60 min. The test condition gets stable in about 20 min after start-up. Gas samples are taken when a stable operation has been reached at an approximate temperature of about 1000 °C. Tar samples are taken after the temperature at the combustion zone has reached 600 °C, while the flow rate of gas sampling is set at 2 L-N min^{-1}. The sampling time is about 40 min for each experiment. A typical testing has been completed when the producer gas flame extinguishes itself. The producer gas is pulled out at the top outlet of the gasifier (the conventional mode), at the reduction zone (the reduction mode) and the combination of the two (the combination mode).

2.5 Uncertainty analysis

The prediction of the cause of the data error is very important for experimental process, as it is usefull to have the accuracy of the data in the experimental work. The uncertainty analysis in this experimental calculation follows the formulation of Dogru *et al.* [8] and Coleman *et al.* [22]. The result of measurement uncertainties such as temperature, air flow rate, gas composition, gas flow rate, fuel consumption, hot gas efficiency, and weight of tar are presented in Table 2.

3. Results and discussion

3.1 Producer gas flow rate

The flow rate, temperature, tar contents, gas composition, calorific value of the producer gas, and gasification efficiency are important parameters in gasifier operation. Fig. 2 shows gas flow rates for each experimental

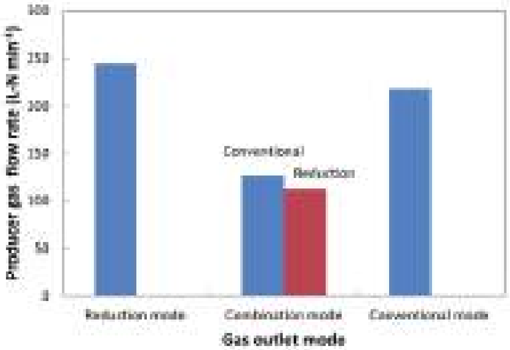

Fig. 2 Gas flow rate based on gas outlet mode

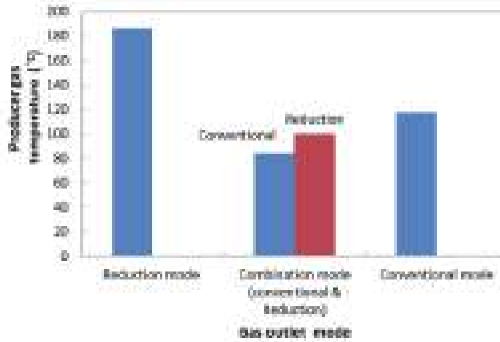

Fig. 3 Producer gas temperature based on gas outlet mode

mode. The total producer gas flow rate of the conventional mode is lower than the other modes. Gas flow rates of each mode of gas outlet are influenced by the temperature of the producer gas outlet. The gas flow rate will increase by the increase in its temperature. The modification to the gas outlet tends to increase the temperature of the gas outlet especially for the gas outlet from the reduction zone. The combination mode shows that the gas flow rate in each gas outlet is approximately half of the values of the conventional mode or the reduction mode. This shows that the total gas flow rate during the combination mode is nearly similar to that in a single outlet operation.

3.2 Producer gas temperature

Fig. 3 shows producer gas temperature for each experimental gas outlet mode. The gas temperature is measured at 1.1 m from the gas outlet pipe attached to the gasifier reactor. The temperature of producer gas at the gas outlet in the reduction zone, in the reduction mode, is higher than the temperature of producer gas, which is measured at the gas outlet at the top section of the gasifier. This producer gas temperature occurs in the conventional mode and combination mode, as well. It is expected that the temperature at the gas outlet is higher due to part of the producer gas from the reduction zone going out without passing through the pyrolysis zone and drying zone. The temperature of the producer gas outlet in the combination mode tends to be lower than in the reduction mode and conventional mode, since it is influenced by the gas flow rate in the combination mode which is lower than in the other modes (Fig. 2).

3.3 Temperature in reduction zone

Fig. 4 shows the average temperature in the reduction zone at each operational mode, as indicated by thermocouple 3 (T3). The average temperature in the

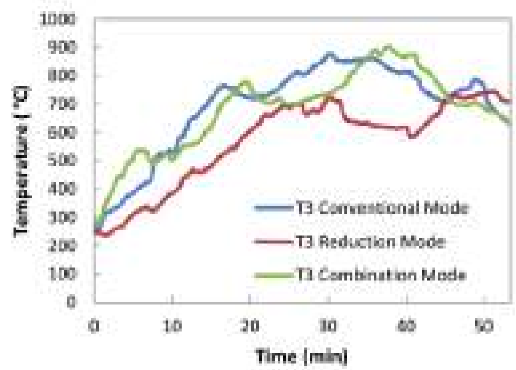

Fig. 4 Temperature average in the reduction zone based on time for three operation modes

reduction zone is higher for the conventional mode in which the gas outlet is at the top of the gasifier. The average temperature in the combination mode is lower than that in the conventional mode due to part of the gas from combustion flowing through the reduction zone gas outlet, thus the temperature decreases in this zone. The average temperature of the reduction mode tends to be the lowest due to the part of the gas flowing in the reduction zone. The gas recirculation from drying and pyrolysis zones that contains water vapor contributes to the low temperature in the reduction.

3.4 Tar content

Fig. 5 shows the tar content of each experimental gas outlet mode. The operation of the gas outlet in the reduction mode results in lower tar content than the operation in the conventional mode (81 and 111 g (m^3-N)$^{-1}$, respectively) because of a secondary tar reaction occurs with H_2O and CO_2 during gas flow in the temperature gradient zone at around 700 °C. The gravimetric tar content in the gas outlet in the reduction mode and conventional mode are

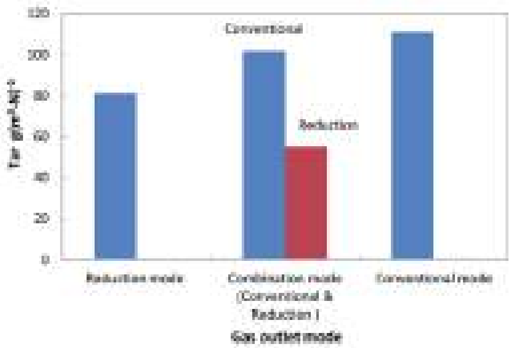

Fig. 5 Tar content based on gas outlet mode

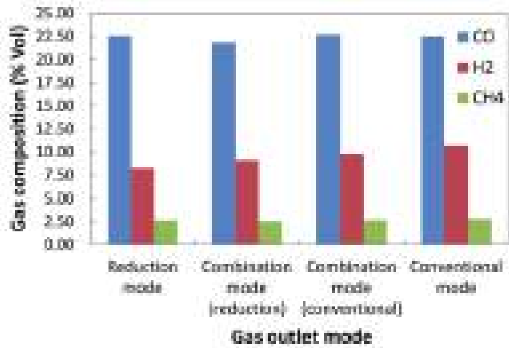

Fig. 6 Gas composition based on gas outlet mode

in agreement with the result of the experiment and model having been conducted and developed by Morfi *et al.* [11] The gas outlet in the combination mode results in a higher total tar content than in the conventional mode because the average temperature in the reduction zone (Fig. 4) is lower than the conventional mode, that makes a secondary tar reaction lower. The tar content produced from the gas outlet in the reduction zone during the combination mode operation is still high, which is about 55 g $(m^3\text{-}N)^{-1}$, due to part of pyrolysis gas from the pyrolysis zone moving downward to the reduction zone. However, the tar content at the gas outlet in the reduction zone is about half of the tar produced from the top gas outlet which is 102 g $(m^3\text{-}N)^{-1}$ in a combination mode operation.

3.5 Gas composition

Fig. 6 shows the gas composition for each experimental gas outlet mode. The percentage composition of CO is in the range of 22-23 % for each mode, but CO is more dominant in the combustion zone [18]. In the combination mode operation, the composition of CO is the same at conventional outlet and reduction outlet. The increasing temperature inside the reactor (Fig. 4) tends to increase the composition of CO. A secondary tar reaction could not be indicated by the increase in CO in this experimental because the pyrolysis gas has passed through temperature about 700 °C. According to Morfi *et al.* [11], CO would experience a significant increase at a temperature over 700 °C in the secondary tar reaction. The composition of H_2 decreases from 10 % to 8 % because of the hydrogen dominantly produced in the reduction zone, where a decrease in the temperature reduction zone influences the decrease in the composition of H_2 (Fig. 4). The composition of CH_4 is quite similar, which is about 2.5 % for each mode because of the lower temperature production of CH_4 [18] becomes a factor influencing its composition.

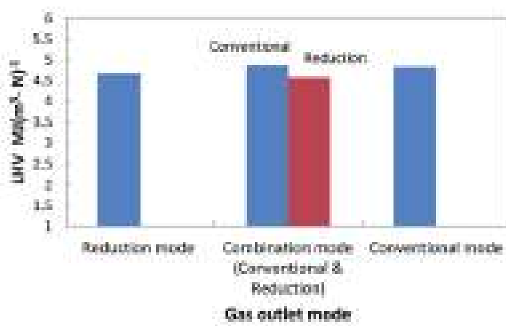

Fig. 7 LHV based on gas outlet mode

3.6 Lower heating value (LHV) of producer gas

Fig. 7 shows the LHV for each experimental gas outlet mode in the range of 4.6 - 4.9 MJ $(m^3\ N)^{-1}$. The lower heating value of the producer gas is influenced by the gas composition (Fig. 6).

3.7 Hot gas efficiency

Since the producer gas does not flow through the gas cooling system, gasification efficiency should be calculated using the hot gas efficiency. Fig. 8 shows the hot gas efficiency of each experimental gas outlet mode. The average efficiency is about 77 % and the maximum is 82 % at the reduction mode operation. The hot gas efficiency of the gas outlet at the conventional mode tends to be slightly lower than other modes due to the influence of operating time, lower heating value, producer gas flow rate and temperature of producer gas. The reduction mode makes operating time longer than the other modes based on the lower temperature inside the reactor (Fig. 4), which results in a lower consumption rate of fuel. The temperature of gas outlet at the reduction mode is higher than the conventional mode (186 and 118 °C, respectively) (Fig. 2). This condition is because part of the gas produced from the combustion (high

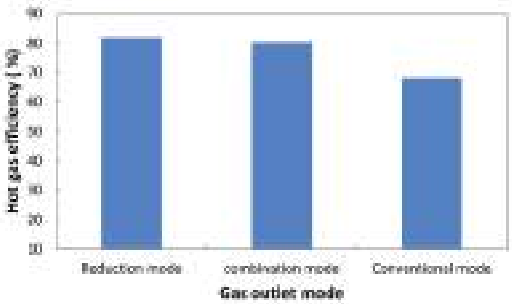

Fig. 8 Hot gas efficiency based on gas outlet mode

temperature gas) zone goes out without passing through the pyrolysis zone and drying zone (low temperature zone). The higher temperature of the gas outlet would increase the gas flow rate and at the same time increases the gas volume as well. The operation of the combination mode has the total gas flow rate of 240 L-N min^{-1}, which is higher than the operation of the conventional mode of 218 L-N min^{-1} (Fig. 2). The LHV of producer gas during the experiment in the combination mode does not indicate much difference compared to other modes as shown in Fig. 7. According to the experimental result, the temperature of gas outlet affect the sensitivity of the heat content in producer gas.

3.8 General discussion

From the experimental result, the modification to the producer gas outlet of updraft gasifier shows a change in the tar content and hot gas efficiency. In the producer gas outlet from the reduction zone (reduction mode) the tar content decreases due to the change in the producer gas flow inside the reactor. The producer gas flows from the top side to the bottom side of the gasifier, this is caused by a high temperature and pressure inside the reactor, which are opposite the ambient temperature and atmospheric pressure outside the reactor, then this forces the producer gas flowing through the zones with temperature gradients. The gas produced by the pyrolysis process that flows through a temperature gradient will encounter a secondary tar reaction [18]. Several studies have been previously conducted to see the effect of temperature gradient on tar reduction when pyrolysis gas of wood flows through the temperature gradient [21,19]. The results are in agreement with this study. The relations of gravimetric tar reduction to changes in temperature is formulated by Morf *et al.* [18] as $Ae^{-E/RT}C_{t0}$ where A is the frequency factor, E is the activation energy, R is the ideal gas constant, T is the temperature and C_{t0} is the initial concentration of gravimetric tar.

Meanwhile, in the combination mode, measurement at the producer gas outlet shows that the tar content at the gas outlet from the reduction zone is still high due to part of pyrolysis gas moving downwardly and then going out of the reduction zone. This is supported by some researchers' reports that the wood pyrolysis process has finished at a temperature of about 500 °C [4,22,23]. In the current work, the average temperature at the gas outlet (reduction zone) is about 700 °C. Another possibility is that the pyrolysis process may still continue until a higher temperature above 700 °C has been reached. This is supported by Grieco *et al.* [20] study, in which tar is released depending on the heating rate of the pyrolysis process. On a heating rate of 0.5 K s^{-1} tar would be released until temperature is above 850 °C, and on a heating rate of 1 K s^{-1}, the tar would be released at a lower temperature of about 800 °C. The tar content might be reduced further, by lowering the pipe line position to the temperature of the reduction zone about 850 °C.

In the combination mode operation, the total amount of tar produced tends to be higher than that at the conventional mode (Fig. 5). It is caused part of oxygen going out before it is reacted with tar that contributes to lower temperature of the reduction zone (Fig. 4) in the modification mode. According to Devi *et al.* [7] tar will decrease by the increase in temperature in the reactor caused by increasing partial combustion of the tar with oxygen at flaming pyrolysis zone.

The modification of the gas outlets results in a higher outlet gas temperature from reduction zone than at the top of reactor, as well an increase in the flow rate of producer gas (Fig. 2). There are no significant differences in the lower heating values of the producer gas (Fig. 7).The differences of hot gas efficiency in this experiment is mostly influenced by the gas outlet temperature and the flow rate of the producer gas.

4. Conclusion

The updraft gasifier with variations of the gas outlets position (top, reduction zone, combination top and reduction zone) has been succesfully tested by the experiment at a laboratory scale. Several modifications reduce tar content at each gas outlet compared to the gas outlet at the top of gasifier (conventional mode). The tar content from the gas outlet at the top of the gasifier is 111 g $(m^3\text{-}N)^{-1}$. The tar content at the gas outlet in the reduction zone (reduction mode) is 81 g $(m^3\text{-}N)^{-1}$, and the tar content at the gas outlets in the combination mode (at the top and in reduction zone) measures 102 g $(m^3\text{-}N)^{-1}$ at the top and 55 g $(m^3\text{-}N)^{-1}$ in the reduction zone. The LHV for each mode is in the range of 4.6 - 4.9 MJ $(m^3\text{-}N)^{-1}$. The average hot gas efficiency is 77 % and the maximum hot gas efficiency is 82 % in the reduction mode operation.

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