Microwave Plasma Gasification Performance of Sawdust

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Abstract

In this study, the gasification performance of the pine tree sawdust and hornbeam sawdust at varied microwave plasma power is investigated. In each case, 250g sawdust are dosed to gasification reactor. The effects of power on syngas composition and reactor temperature are studied. The sawdust contents are examined by ultimate and proximate analysis. The heating value of the fuels are measured as 21353 kJ/kg for hornbeam sawdust and 17942 kJ/kg for pine tree sawdust by bomb calorimeter. The syngas content is substantially proportional with the content of the fuel. The variation of local temperatures during the gasification is of great importance on the process. The temperature is increased by increasing the power and the conversion performance of sawdust is enhanced. The temperature in gasifier increase %54 in case by increasing power from 3 kW to 6 kW. CO, CH_4 and H_2 conversion increase by increasing the power while CO_2 conversion decreases by power.

Key words: Sawdust, gasification, plasma, microwave

1. Introduction

There are variety of methods to convert the biomass into fuel or energy [1]. One of this method is the gasification of biomass into syngas. In this method, the biomass gasified by absence or oxygen starved media and converted to syngas by partial oxidizations. While the gasification process is a known old process, the process is further improved by using the plasma as heater. By gasification, the biomass decomposed to its components and mainly CO, H_2, CO_2 and simple hydrocarbons [2]. There are several methods to gasify the matters such as depending on reactor type; updraft or downdraft fixed bed, bubbling or circulating fluidized bed, depend on power supply; allo-thermal and auto-thermal process, depending on reaction media; pyrolysis and gasification [3]. The increase of gasifier temperature enhances the conversion of fuel. The plasma gasification method has unique advantages of very high temperature, high response, simple and compact design in comparison with other methods [4]. In this study, the effects of power and air flow rate on gasification performance of hornbeam and pine tree sawdust are investigated. The temperature distribution in the reactor is revealed and the conversion characteristics are examined.

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2. Materials and Method

Microwave plasma gasification system MCw Gasifier (Figure 1) consists of the following sub-components; Microwave plasma system, solid waste feeding and fluid supply systems, gasification reactor, process outputs collection system and the measurement - data acquisition system. The experimental system explanation is also given in the authors papers [5, 6], thesis of the first author [7] and project of authors [8].

2.1 Microwave Plasma System

In microwave plasma system, the generation and transfer of the microwave signal to the reactor are performed. Microwave plasma gasification system consists of Power supplier, magnetron, isolator, stub-tuner, and waveguide and plasma applicator for the plasma. Here the products were purchased from MUEGGE Company which is based on the study of Martin Leins [9].

2.2 Gasification Reactor

Gasification reactor consists of two parts. The first part is the reduction part comprising the head of the reactor where the diameter is reduced for the interaction of the solid waste by plasma. The other part is the main body of the reactor. The main part is formed of 81 mm inner diameter stainless steel pipe which has 3 mm thickness and 500 mm height.

2.3 Fluid (Air) Supply System

The required air flow rate is obtained by using Lupamat LKV 30/8 model screw compressor. It generate compressed air which has 8 bar pressure and 4850 L/min flow rate. The required pressure and flow rate are adjusted by using pressure regulator.

2.4 Flow (Air) Measurement System

The air flow rate is measured by ALICAT MCR-250 L/min-D model mass flow controller. The required air flow rate for plasma applicator varies from 0 to 200 L/min.

2.5 Measurement of Reactor Temperature

The thermocouples which are located at measurement positions along the reactor length in the flow direction of plasma. The first measurement location from plasma applicator's edge is 175 mm away because of the extreme high temperature of the plasma. The location of the thermocouples are $y/h = 0.28, 0.44, 0.6, 0.76$ and 0.92. The height (h) of the reactor which begin from the applicator to the end of the main reactor is 625 mm. 5 thermocouples are located along the axis of the pipe with 100 mm intervals. The B type (Pt18Rh-Pt) thermocouples are used with pure alumina coating. Their measuring abilities are the temperatures up to 1820 ℃ with an accuracy of $\pm$ 4°C.

The thermocouple sensing edges are immersed at 40 mm perpendicular to the reactor wall such that the measurement inside the plasma flame is possible. The measured inputs are recorded via Elimko E-PR-110 model data acquisition card. The temperature measurements are recorded with 1 second sampling period.

2.6 Gas analyzing system for the syngas

 MRU-Various plus model syngas monitoring system is used to determine the syngas content. It provides continuous syngas monitoring of the process. It can measure the syngas content of CO, CO_2, CH_4, H_2, and N_2 up to 100% and O_2 up to 25%. It uses the nondispersive infrared sensors to measure the CO, CO_2 and CH_4 while it uses the thermal conductive detector and electrical conductive sensor to measure the H_2 and O_2 respectively. It has 1% linearity and repeatability error. It has also %2 span drift and 0.05% detection limit. The measurements are recorded by the device which is connected to computer to monitor and data acquisition. The sampling frequency is adjusted to 2 seconds. The system records the gas composition continuously. The process time is determined from the gas composition changes at the beginning and end of the process.

3. Results

In this study, the hornbeam sawdust and pine tree sawdust are taken as fuel for the plasma gasification. The gasification results of sawdust is taken from thesis of the first author [7]. The proximate and ultimate analysis methods; heating value evaluations and the results of these fuels are explained in detail in the study authors [10].

The temperature distribution at powers between 3 kW and 6 kW, for fuels; pine tree and hornbeam sawdust and 50 sL/min air flow rate is presented in Figure 3. The temperature in the reactor reduces from plasma flame to the upward. The temperature increases by increasing the plasma power. The temperature reduces from plasma flame to upward from 921 ℃ to 515 ℃ at 3 kW, 950 ℃ to 579 ℃ at 3.6 kW, 1046 ℃ to 657 ℃ at 4.2 kW, 1184 ℃ to 712 ℃ at 4.8 kW, 1349 ℃ to 786 ℃ at 5.4 kW and 1476 ℃ to 825 ℃ at 6 kW in case of hornbeam sawdust gasification. The temperature reduces from plasma flame to upward from 937 ℃ to 516 ℃ at 3 kW, 951 ℃ to 578 ℃ at 3.6 kW, 1047 ℃ to 651 ℃ at 4.2 kW, 1205 ℃ to 714 ℃ at 4.8 kW, 1361 ℃ to 779 ℃ at 5.4 kW and 1447 ℃ to 818 ℃ at 6 kW in case of pine tree sawdust gasification. The average syngas temperature increases by increasing plasma power from 3 kW to 6 kW from 759 ℃ to 1175 ℃ in case of hornbeam sawdust gasification and from 766 ℃ to 1169 ℃ in case of pine tree sawdust gasification.
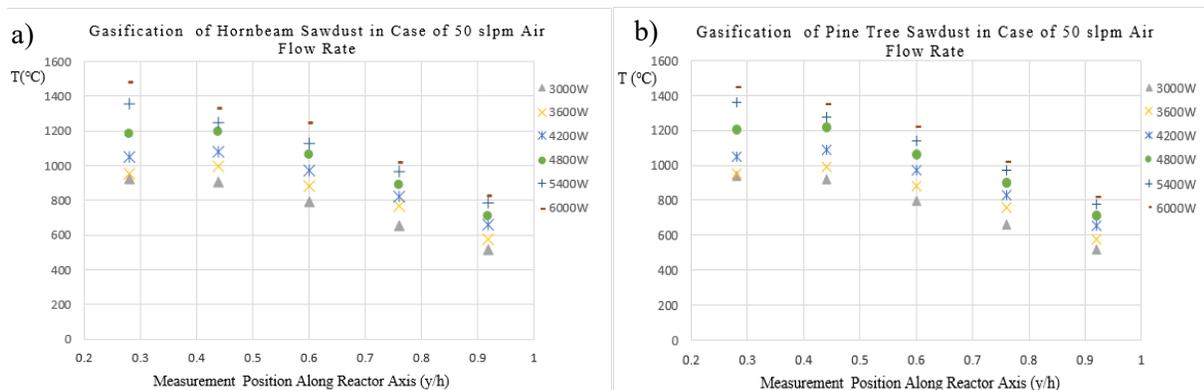
Figure 3. Temperature distribution in the reactor depending on power, air flow rate and sawdust type

The content of syngas in molar base is presented in case of gasification of hornbeam sawdust and pine tree sawdust at power levels between 3 kW and 6 kW in Table 2. The fractions of syngas in case of gasification of hornbeam sawdust (HSD) at power levels between 3 kW-6 kW are presented in first row. As a result of the process, the O_2 in syngas stays below 0.9 % in all power levels. The CO_2 gradually decreases by increasing power from 16.79 % at 3 kW to 10.49 % at 6 kW. In contrast to that, the CO and H_2 increase by increasing the power. The CO increases from 7.33 % to 18.95 % and H_2 increases from 2.35 % to 8.65 % by increasing power from 3 kW to 6 kW. The CH_4 stays in the level of 1.8 % in all power cases. The rest of the mixture is considered as N_2 that reduces by increase of power from 70.97 % to 59.22 %.

Table 2. Syngas distribution depending on power, air flow rate and type of sawdust

Fuel type		Syngas distribution					
	Power (W)	O2,%	CO2,%	CO,%	H2,%	CH4,%	N2,%
Hornbeam sawdust	3000	0.68	16.79	7.33	2.35	1.87	70.97
	3600	0.77	13.80	8.97	4.43	1.83	70.19
	4200	0.81	11.34	9.23	5.12	1.81	71.69
	4800	0.69	11.28	14.2	5.63	1.83	66.37
	5400	0.83	10.89	15.27	6.87	1.8	64.34
	6000	0.88	10.49	18.95	8.65	1.81	59.22
Pine tree sawdust	Power (W)	O2,%	CO2,%	CO,%	H2,%	CH4,%	N2,%
	3000	0.82	18.20	8.30	3.20	2.17	67.31
	3600	0.86	15.91	8.88	4.30	2.13	67.92
	4200	0.85	14.87	9.69	5.6	2.21	66.78
	4800	0.88	13.19	12.7	5.84	2.28	65.11
	5400	0.91	11.27	14.82	6.21	2.25	64.54
	6000	0.90	10.22	17.35	8.98	2.23	60.33

The distribution of syngas content by changing power in case of gasification of pine tree sawdust (PSD) at 50 sL/min air flow rate and power levels between 3-6 kW is shown in last row of Table 2. As a result of the process, the O_2 in syngas stay below 0.91 % in all power levels. The CO_2 gradually goes down by increasing power from 18.20 % at 3 kW to 10.22 % at 6 kW although the

CO and H_2 rise by increasing the power. The CO and H_2 go up from 8.30 % to 17.35 % and from 3.2 % to 8.98 % respectively by increasing power from 3 kW to 6 kW. The CH_4 varies between 2.13 % and 2.28 %. The remainder of the syngas, N_2 reduces from 67.31 % to 60.33 % by increment of power from 3 kW to 6 kW.

Conclusions

In this study, the effects of power and types of sawdust on plasma gasification process are examined. The temperature and syngas content distribution are measured continuously during the process. The magnitude of the temperature in the reactor increases by increasing the power. The conversion performance of sawdust is enhanced by increasing the power. The temperature in gasifier increases % 54 by increasing power from 3 kW to 6 kW. CO, CH_4 and H_2 conversion is increased by increasing the power while CO_2 conversion is decreased by increasing power.

Acknowledgements

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