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Interactive Effect of Plasma Power and Equivalence Ratio upon Plasma Gasification of Coconut Shell

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Plasma gasification is a promising technology which aids in energy recovery and disposal of organic wastes. A gasification study on effect of plasma power and equivalence ratio on gas composition had been carried out using non transferred DC type plasma torch with air as carrier gas. The experimental trials on plasma gasification were done with varied plasma power (4.8, 8.1, 12.4, 17 and 21.6 kW) and equivalence ratio (0.1 to 0.4). The composition of the produced gas was analyzed and the result obtained from the trials showed that the maximum heating value of the produced gas was 5.75 MJ m^{-3} at higher plasma power 21.6 kW and lower equivalence ratio 0.1.

Key words: Plasma, Gasification, Equivalence ratio, Producer gas

The emission of greenhouse gases has been rapidly increasing due to over usage of fossil fuels**.** The emission of these hazardous gases poses major health issues and is threatening to cause severe global climate change. In addition, the depletion of coal and other fossil fuels makes the extraction of these resources more difficult and energy intensive that resulted in additional burden to the environment. The demand for the energy resources will continue to grow in future, due to increase in rapid urbanization and population. This has initiated a shift towards renewable energy based electricity generation systems (Agon *et al.,* 2015). Among various renewable energy resources, biomass a carbon neutral fuel is the promising energy source that meets the future energy demands and minimizes greenhouse gas emissions as well.

Biomass gasification has become a most suitable technology for electricity generation due to its advantage of using different variety of feedstock's (Guizani *et al.,* 2015). Gasification is a thermo chemical conversion process that converts any organic matter into a combustible gas which mainly composed of carbon monoxide, hydrogen, carbon dioxide and methane.

An important evolution in gasification technology came with introduction of plasma torches during the process (Galvita *et al.,* 2007). The heart of the plasma gasification is the plasma torch that provides very high temperature which aids in thermal degradation of any organic matter into its constituent elements and inorganic portion as vitrified slag. The main advantage of plasma gasification over conventional gasification was increased rate of reaction due to high temperature ionized gas (Janajreh *et al.,* 2013). An important demerit of plasma gasification was necessity of high electric power which reduces process efficiency. Mechanical gasification efficiency was around 70 to 95 % (Agon *et al.,* 2015). In this study plasma gasification trials with biomass as feedstock had been carried out with varying plasma power and equivalence ratio and its effect on producer gas composition and calorific value were discussed.

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Material and Methods

Feedstock characterization

Locally available abundant coconut shell was selected as a feedstock for the plasma gasification study. The proximate analysis using standard ASTM procedures (moisture content – ASTM D-871-82, volatile matter – ASTM D-3175-07 and ash content ASTM D- 3174-04) and ultimate analysis using elemental analyser (FLASH 2000) were performed for the coconut shell. The calorific value of the feedstock was determined using bomb calorimeter (ASTM D – 2015-77). Thermo gravimetric analysis of the biomass sample was analyzed using TGA analyzer (Q50, TA instruments) to determine weight loss with respect to change in temperature.

Plasma gasification reactor

The experiments were carried out in the plasma gasification reactor with feedstock consumption rate of 15 kg h^{-1}. The reactor consisted of a single DC type plasma torch with two graphite electrodes (cathode L-300 mm x D-60 mm and anode L-100 mm x OD – 90 m x ID – 40 mm). One of these electrodes was supplied with DC power source and the carrier gas air from the compressor was made to flow through the torch. The two electrodes were made in contact with each other to develop a huge electric potential to form a high temperature region. The air that passed through the torch got ionized and extended at the tip of the electrode as plasma flame. This plasma flame was used as a heat source for gasification reaction. The produced gas was collected at the top of the reactor and its composition was analyzed using multigas analyzer (3100P portable gas analyzer).

Operational parameters

In this study, two important operational parameters of plasma gasification namely plasma power and equivalence ratio were used to find its impact on gas composition and calorific value.

Plasma power

Different plasma power (4.8, 8.1, 12.4, 17 and 21.6 kW) was used to study the influence of plasma power on gas composition and calorific value of producer gas. Plasma power was varied by increasing plasma current (200 to 600 A) in the transformer.

Equivalence ratio (ER)

Equivalence ratio is defined as the ratio of actual air supplied to the stoichiometric air required for complete combustion. The ER for the plasma gasification in the study was varied from 0.1 to 0.4. Corresponding air flow rate required was supplied to the gasification process. The effect of ER on gas composition and heating value of generated producer gas was studied.

Results and Discussion

Proximate analysis, ultimate analysis, and estimation of calorific value were carried out for coconut shell and their results are given in the Table 1.

Table 1. Proximate and Ultimate Analysis of Coconut Shell

Proximate analysis	
Moisture	6.47 %
Volatile matter (dry basis)	70.42 %
Ash (dry basis)	1.13 %
Fixed carbon	28.45 %
Ultimate analysis	
Carbon	48.63 %
Hydrogen	6.51%
Nitrogen	0.14 %
Sulphur	0.08 %
Oxygen	44.64 %
Lower heating value	17.83 MJkg^{-1}.

The moisture content and ash present in the coconut shell were lower (6.47 % and 1.13 %) and hence it was more suitable for gasification. Coconut shell had a higher volatile matter content of 70.4 % and a fixed carbon of 28.4 % supplementing for higher gasification efficiency. From the ultimate analysis, elemental composition such as carbon, hydrogen, nitrogen, sulphur and oxygen were estimated and found that feedstock contains more carbon (48.63 %) that results in higher carbon conversion. The lower heating value of the feedstock was found to be 17.83 MJ kg^{-1}.

Thermo gravimetric analysis of coconut shell

Degradation of biomass under inert condition was given in three stages (Figure 1). The first stage was dehydration (< 150º C) followed by active pyrolysis

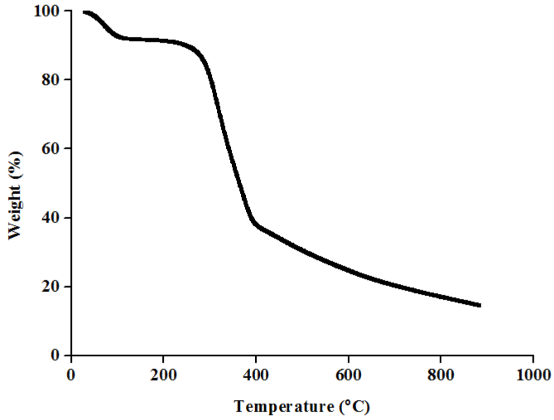

Fig 1. Thermo gravimetric analysis of coconut shell

(150 - 400º C) and passive pyrolysis (> 400º C) (Kumar *et al.,* 2008). From the graph, it is observed that, the initial weight loss (upto 150º C) was due to moisture evaporation and from 200 to 400º C there was a steep decrease in weight loss due to release

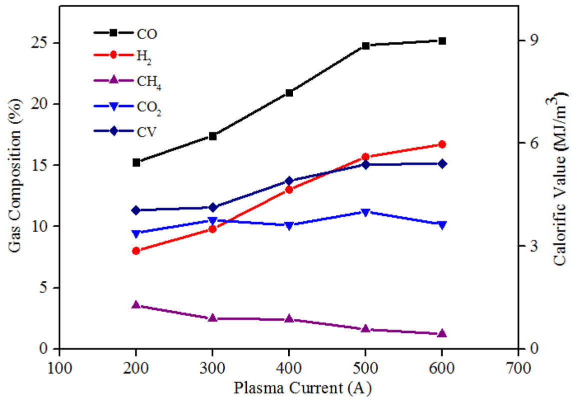

Fig 2. Effect of plasma power on gas composition and CV at ER 0.1

of volatiles. The maximum weight loss was noticed at this stage and revealed that maximum release of volatiles during gasification occurs at 200 to 400º C. Minimum weight loss was occurred during the final stage which represented the passive pyrolysis of char and the left over residues were ash content. The results from the graph showed that the complete thermal degradation of coconut shell was occurred at 900º C.

Effect of plasma power on gas composition and calorific value

The gasification trials had been conducted at different plasma power and ER and their effect on gas composition and calorific value were analyzed. In plasma gasification process more than half of the energy needed for gasification was from the plasma torches. The power of plasma had directly influenced the temperature and producer gas composition. The higher plasma power supplied more heat to the carrier gas air that resulted in higher gasification temperature (Zhang *et al.,* 2012). From the figure 2, it is evident that CO concentration had increased from 16.3 to 26.2 % with increase in plasma current from 200 A to 600 A. The increase in CO concentration may be due to promoted tar cracking with increase in gasification

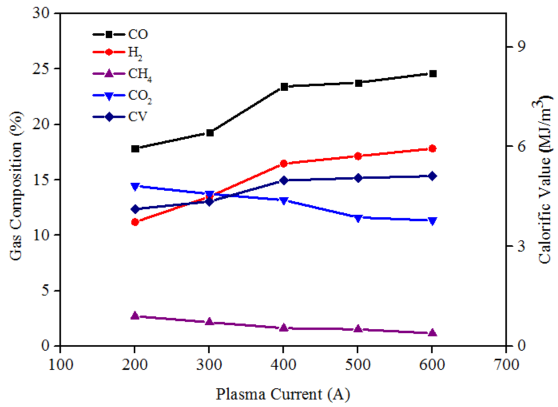

Fig. 3. Effect of plasma power on gas composition and CV at ER 0.2

temperature. The decrease in CH_4 concentration (3.55 to 1.24 %) was noticed which may be because of methane reforming reaction that occurred at higher temperature. Hydrogen concentration had increased from 10.03 to 18.72 % with increase in plasma power. This increase in hydrogen concentration might also

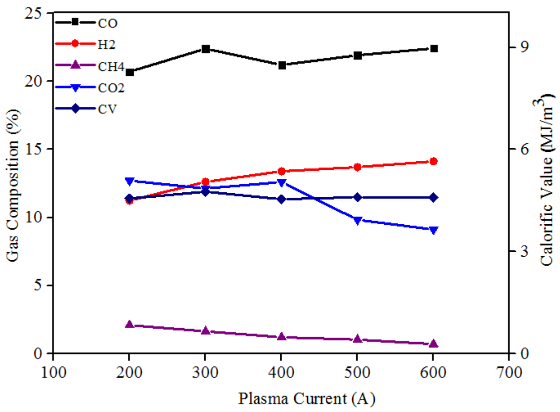

Fig. 4. Effect of plasma power on gas composition and CV at ER 0.3

be due to tar cracking and methane reforming reaction. The heating value of the produced gas increased from 4.39 to 5.75 MJm^{-3} which was mainly due to increased concentration of the combustible gases. Hence it may be that increasing plasma power had a positive influence on producer gas composition. The effect of plasma power on gas composition and heating value had a similar at increasing ER as shown in figure 3, 4 and 5.

Effect of ER on gas composition and calorific value

From the figure 2, 3, 4 and 5 at plasma current 200 A it is evident that at increased equivalence ratio from 0.1 to 0.4, the CO_2 content had increased from 9.49 to 14.81 %. This may be because of oxidation reaction which resulted in decrease in CO content (19.49 %). It is also found that at lower ER (0.1) the CO content was lesser (16.26 %), because the gasification agent was not sufficient to convert all the carbon present in the feedstock to CO. The increased ER provided more chemical heat by combustion which favoured increase in heat supply for the reaction. However higher ER favoured increase in carbon dioxide concentration that resulted in lower heating value (4.51 MJ m^{-3}). It is also found H_2 concentration increased from 10.03 to 13.24 % for the corresponding ER 0.1 to 0.3.

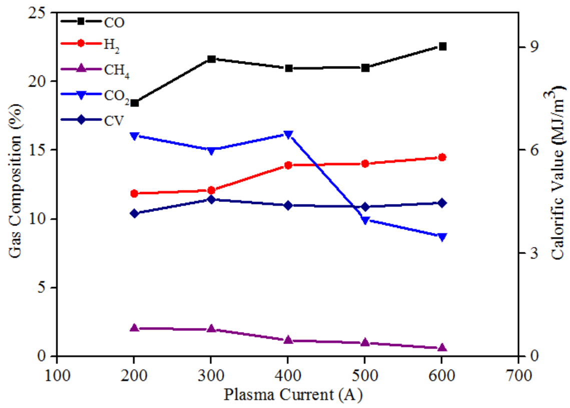

Fig 5. Effect of plasma power on gas composition and CV at ER 0.4

Combined effect of plasma power and ER

In the plasma gasification process, the required heat for biomass gasification is obtained from two sources: mainly by the plasma torch and from chemical heat generated during char combustion. Hence the energy equilibrium of the plasma gasification is controlled by both plasma power and ER. From figures 2, 3, 4 and 5 it is evident that when plasma power was lower (at 200 A), the plasma energy was not sufficient for complete gasification. Hence at lower plasma power, an increase in ER favoured complete gasification by supplying energy needed for the reaction. At plasma power 600 A, the increased ER was not required because the energy supply for complete gasification is sufficient even at lower ER (0.1). The study on combined effect of plasma power and equivalence ratio concluded that when plasma power was higher, lower equivalence ratio was favourable because higher power and higher ER facilitated complete oxidation reactions that resulted in increased carbon dioxide production.

Conclusion

The experimental study on plasma gasification of coconut shell as feedstock was carried out using DC plasma torch. The effect of ER and plasma power on gas composition and heating value showed that plasma power had a positive effect on both gas composition and heating value. Higher heating value (5.75 MJ m^{-3}) was attained for higher plasma power 21.6 kW (at plasma current 600 A) and lower ER (0.1). The interaction between plasma power and ER revealed that at increased plasma power, the requirement of ER will be less for the generation of producer gas with higher heating value.

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