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Enhancing Co-Gasification of Coconut Shell by Reusing Char

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Abstract

Objectives: This paper aims to investigate the influence of char reuse in the gasification process. **Methods:** Co-gasification of biomass (coconut shell) and char was carried out in a downdraft gasifier. Char was produced as a by-product in biomass gasification process which contains a huge amount of concentrated carbon. The simulation was run for the different ratios of coconut shell and char (100:0, 90:10, 80:20 and 70:30) by ASPEN PLUS process simulator software to find out a suitable ratio. **Findings:** The calculated energy is 23703.45 Kcal, 24207.78 Kcal, 24964.28 Kcal and 25468.60 Kcal, where the char ratio is 0%, 10%, 20% and 30%, respectively. Based on the simulation result, gasification was accomplished by adding 30% of char with coconut shell biomass. The simulated and experiment results proved that more energy can be produced by increasing the char ratio. **Application:** Many countries started to find out an alternative source of energy instead of non-renewable energy resources, especially from biomass. Co-gasification of the coconut shell with suitable char ratios is the best alternatives to meet up the world's future energy demand.

Keywords: ASPEN PLUS Simulator, Biomass, Char, Co-Gasification, Syngas

1. Introduction

In this century, energy is the most important political issue for ongoing fuel and economic crisis globally. It is the key components for the development of any country[1]. World economy is still depends on the non-renewable energy sources (natural gas, oil and coal), which are exhaustible, geographically concentrated, limited to reserve, increasingly expensive and very polluting[2]. Therefore, energy generation from renewable sources has attracted the attention of investor and energy scientists. The most abundant renewable energy resource is biomass, which is mainly carbon based. It also contains mixture of organic molecules encompassed with hydrogen, oxygen, nitrogen and small number of other elements. It is mainly derived from biological origins, such as agricultural residue (rice straw, wheat straw, coconut shell, empty fruit bunch of palm oil, etc.), forest residues, municipal solid wastes, etc.[3-5]. Biomass gasification is a promising technique for energy production as syngas afterward that can be converted to synthetic hydrocarbon[6-9]. Nevertheless, co-gasification of char and biomass is a favorable approach to provide both environmental and economic benefits, including significant reduction in CO_2 emission, less waste disposal, and low fuel cost[10]. Co-gasification of coconut shell (biomass) with adding char provides an opportunity to enhancement the gasification process. This gas consists of CO, H_2, CH_4, aliphatic hydrocarbon, benzene, toluene and tars (besides carbon dioxide and water)[3,9]. In this gasification process, some by-product such as char, tar, particle, ash are also produce[4], which are mostly useless as well as they make troublesome to the cleanness of syngas. Therefore, the aim of this study is to utilise by-product materials (mainly char) for further gasification.

2. Experimental Design and Procedure

The experiment of biomass (coconut shell) and char co-gasification has been done by Downdraft Gasifier (DG). The reactor of the experimental DG contains four sep-

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arate zones: (i) upper drying zone, (ii) upper-middle pyrolysis section, (iii) lower-middle oxidation zone, and (iv) lower reduction zone. The design capacity of the lab scale downdraft gasifier used was of 50 kW of thermal output, with cylindrical reactor (height is 1000 mm, and diameter is 400 mm). A necking or throat of slope angle (~ 70°) was provided near the grate of the DG in order to ensure frequently down flow of the feed stocks by gravitational attraction. This DG setup included a Japan made vortex blower which has the flow rate capacity of 950 L per minute (lpm) and working pressure is 30 bar, for the supply of inlet air to the gasifier. The flow rate of inlet air is measured by rotameter fixed with the blower. For monitoring of the gasifier temperature profile is carried out using four (K type) thermocouples which is mounted in the middle section along the gasifier wall, at 200 mm interval. The temperature readings were monitored which display in temperature data logger shown in Figure 1.

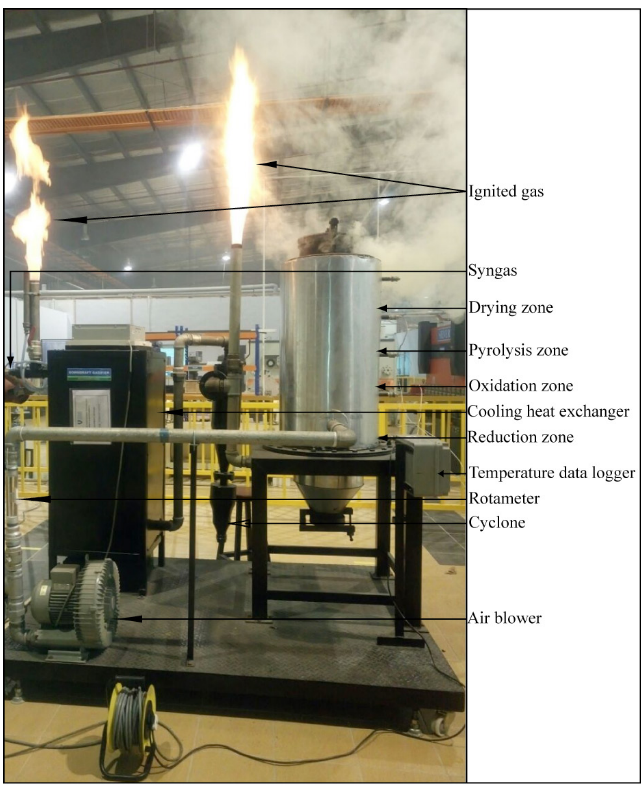

Figure 1. Experimental setup of downdraft gasifier.

In this study, the elemental composition of coconut shell was assumed for C, H, O, as 45.03%, 6.94%, 47.47%, respectively as reported by[11], which is very closer to the composition presented by[12]. However, the carbon content of coconut shell char was considered at 82.66% which was obtained from the average values reported by[13] (87.3%) and [14](78.03%). Based on simulation output, in this experiment, 70% (wt) of coconut shell and 30% (wt) of char were used for co-gasification and the total weight of feedstock was 10 kg. The operation was carried out at the pressure (30 Bar) with atmospheric air[15]. The experimental setup and operational procedure are shown in Figure 1 and Figure 2, respectively.

The drying phase involves evaporation of the moisture contained within the biomass. The temperatures were above 100^{0}C and part of this vapour might be converted to hydrogen during gasification[16] and the rest ends up as moisture in the produced syngas or systhetic gas.

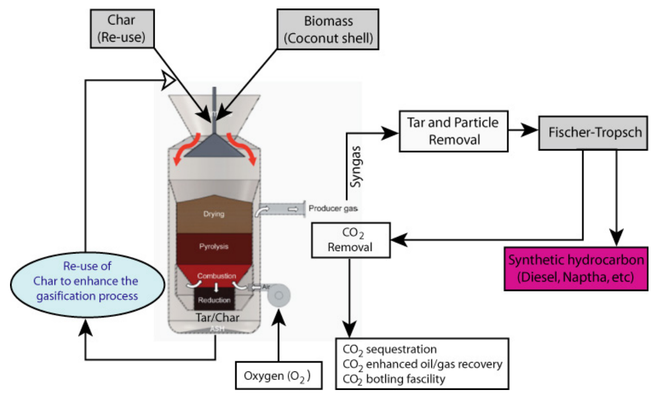

Figure 2. Reusing by-product char for enhancing gasification process.

The biomass begin to pyrolysis at temperature above 200^{0}C[16]. In this stage, thermal disintegration of the biomass into volatile gases and char takes place. The proportion of these components is influenced by the chemical composition of biomass being fed and the operation conditions of the gasifier.

After pyrolysis, there is an oxidation zone where the pyrolysis products move into the hotter zone. Air is inserted into the oxidation zone under starved oxygen conditions. The oxidation takes place at temperatures ranging from 700-1000^{0}C[16] and possible reactions[17] are as follows:

$$C + O_2 \leftrightarrow CO_2 \quad (1)$$

$$H_2 + \frac{1}{2}O_2 \leftrightarrow H_2O \quad (2)$$

$$CO + \frac{1}{2}O_2 \leftrightarrow CO_2 \quad (3)$$

The reaction products of the oxidation zone move into the reduction zone where there is inadequate oxygen, leading to reduction reactions between the hot gases and char. In this zone, the sensible heat of the gases and char is converted into the stored chemical energy in the syngas. Therefore, the temperature of the gases is reduced during this process[16,17].

$$CO_2 + C \leftrightarrow 2CO \quad (4)$$
$$C + H_2O \leftrightarrow CO + H_2 \quad (5)$$
$$CO + H_2O \leftrightarrow CO_2 + H_2 \quad (6)$$

3. Simulation by ASPEN PLUS

To investigate the influence of char on the coconut shell gasification, the ASPEN PLUS Gibbs reactor (RGibbs model) was used for the simulation of reactions (Equation 11, 2 and 5). This model is also used when reaction stoichiometry is not known but reactors temperature and pressure are known. Carbon partly constitutes the gas phase and the remaining carbon comprises part of the solid phase (char) and subsequently undergoes char gasification. The simulation diagram by ASPEN PLUS software is illustrated in Figure 3.

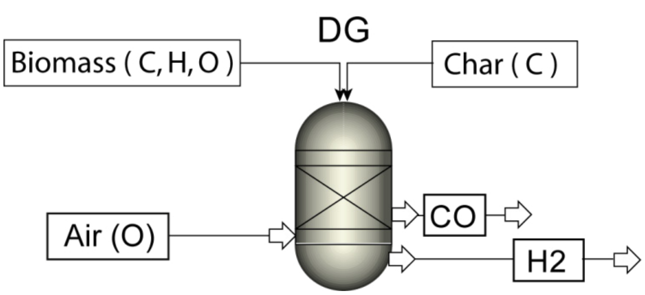

Figure 3. Schematic diagram for simulation by ASPEN PLUS (V 8.6).

4. Results and Discussion

The temperature distribution for the co-gasification of biomass (coconut shell) and char is shown in Table 1. The gasification result indicates that different chemical reactions were took place at different temperature zones. During the drying of feedstock the temperature was below 270^{0}C (T_4). After drying, the feedstock entered into the pyrolysis zone, where the temperature elevated up to 338^{0}C (T_3). Then, the feedstock came in contact with air and some chemical reaction (Equation 2, 3, 4 and 5) were completed, where maximum temperature was 843^{0}C (T_2). The most important reactions take place in the reduction zone of a gasifier between the different gaseous and solid reactants, where maximum temperature was recorded at 1000^{0}C (T_1). The syngas was mainly (with by-product materials) produced in this zone. After the co-gasification of coconut shell and pre-added char, the measured weight percentage of the char was about 2.03% and char dust with minor amount of ash was 1.68%. These by-product materials (specially char) are reusable for the next co-gasification processes. The by-product of CO_2 can be used for enhancing oil or gas recovery in the petroleum sector[18,19], which may reduce the greenhouse gas content by CO_2 capturing[20]. The total energy of syngas, simulated by ASPEN PLUS (V 8.6), shown in Table 2. Four types of biomass to char ratio 100:0, 90:10, 80:20 and 70:30 were simulated. The energy production was more efficient when the char was mixed with biomass. Every batch of downdraft gasification of coconut shell produces char as a by-product material. And, this char can be valorised by using for further co-gasification. The simulation result also indicates that the char is the important factor to enhance the gasification process. The increment of the char percentage in biomass volume will increase the energy exponentially in Table 2 and Figure 4.

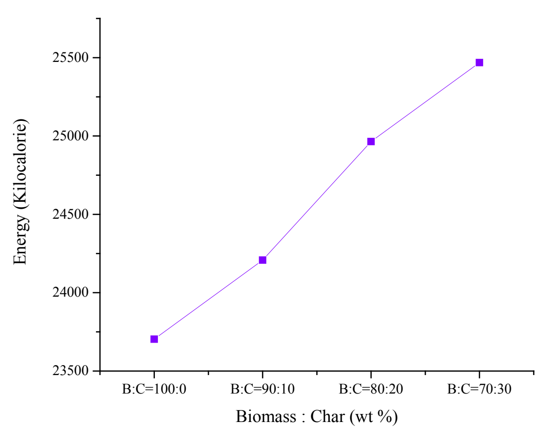

Figure 4. Energy (Kilocalorie) calculated from ASPEN plus simulation for syngas from coconut shell and char (reusing) with different ratio.

5. Conclusion

In this study, a downdraft gasification experiment performed by using biomass of coconut shell with different ratio of by-product char. The obtained simulation results by ASPEN PLUS indicate that, the more energy can be produced by adding char with the biomass (coconut shell). Therefore, by-product char is one of the important gasifying materials that enhance the co-gasification process. The International Conference on Fluids and Chemical Engineering (FluidsChE 2017) is the second in series with complete information on the official website[21] and organised by The Center of Excellence for Advanced Research in Fluid Flow (CARIFF)[22]. The publications on products from natural resources, polymer technology, and pharmaceutical technology have been published as a special note in volume 2[23]. The conference host being University Malaysia Pahang[24] is the parent governing body.

Table 1. Temperature distribution in different reaction zones of DG.

Time (min)	Temperature (^{0}C)			
	Reduction zone (T_1)	Oxidation zone (T_2)	Pyrolysis zone (T_3)	Drying zone (T_4)
0	50	81	29	29
5	880	734	225	164
10	881	735	226	176
15	866	719	228	179
20	894	788	306	256
25	1000	843	338	270

Table 2. Energy produced from co-gasification of coconut shell and char.

Biomass and Char ratio (%)	Energy (Kilocalorie)	
	CO	H_2
100 : 0	12608.22	11095.234
90 : 10	12608.22	11599.562
80 : 20	12860.384	12103.891
70 : 30	12860.384	12608.22

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