World Academy of Science, Engineering and Technology
International Journal of Chemical and Molecular Engineering
Vol:8, No:12, 2014

Evaluation of Biomass Introduction Methods in Coal Co-Gasification

Ruwaida Abdul Rasid, Kevin J. Hughes, Peter J. Heggs, Mohamed Pourkashanian

Abstract**—**Heightened concerns over the amount of carbon emitted from coal-related processes are generating shifts to the application of biomass. In co-gasification, where coal is gasified along with biomass, the biomass may be fed together with coal (co-feeding) or an independent biomass gasifier needs to be integrated with the coal gasifier. The main aim of this work is to evaluate the biomass introduction methods in coal co-gasification. This includes the evaluation of biomass concentration input (B0 to B100) and its gasification performance. A process model is developed and simulated in Aspen HYSYS, where both coal and biomass are modelled according to its ultimate analysis. It was found that the syngas produced increased with increasing biomass content for both co-feeding and independent schemes. However, the heating values and heat duties decreases with biomass concentration as more CO_2 are produced from complete combustion.

Keywords**—**Aspen HYSYS, biomass, coal, co-gasification modelling and simulation.

I. Introduction

DESPITE the fact that coal has been promoted as the best alternative primary energy source due to its abundance and availability [1], heightened concern over the amount of carbon emitted from coal-related processes are generating shifts to the application of biomass. This is because biomass resources are as abundant as coal, if not more, and it is continuously generated. Biomass is said to be carbon neutral, cleaner as they virtually produce no sulfur by-products [2]. Hence, the application of biomass as an energy source would mean the reduction in conventional fuel dependency. Furthermore, the introduction of biomass in coal gasification process is claimed to help reduce the total emissions [3], hence it can be seen as a 'bridging' technology. This is because biomass is not without its own limitations. Biomass is more prone to degradation if stored for prolonged period and would also requires pre-treatment [2] to ensure a more efficient conversion. These uncertainties may be eliminated by co-gasifying coal and biomass in existing coal gasification facilities [4].

Biomass introduction to the gasifier can be carried out either through co-feeding or via having an independent biomass gasifier and adding the produced syngas downstream of the process. Both configurations have their own advantages and disadvantages. For example, biomass co-feeding has an advantage of having lower capital costs as no extra costs for the independent gasifier is required, but operational problems such as excessive slag formation may jeopardize downstream processes and reduce the efficiency of the process [5]. On the other hand, the independent biomass gasification may prevent slagging problems as operating conditions for biomass gasification can be tailored accordingly [5]. But, the capital and operating costs may increase.

The objective of this study is to evaluate the biomass introduction methods in coal co-gasification, either through co-feeding of the biomass or setting up an independent gasifier for biomass. The manner in which biomass is introduced to the gasification process were examined and compared for the base case of 0%, 10%, 25%, 50%, 75% and 100% biomass (B0 – B100) by volume, as well as its gasification performance.

II. The Modelling Approach

A. Base Case

The gasification island consists of an entrained gasifier and an equilibrium water-gas shift reactor, with secondary equipment such as a mixer, coal slurry pump and heat exchangers. The input coal is mixed with water to form coal slurry and pumped in the entrained gasifier represented by the Conversion Reactor in AspenHYSYS. The bottom product of the gasifier is slag and it is sent off to another part of the plant (which is not simulated here), while the raw syngas from the top is cooled. A fraction of the raw syngas is fed to a WGS reactor and mixed with steam to adjust the syngas ratio which the amount of required steam depending on the recycle flow from the flue gas of the downstream GTCC. The raw syngas is subsequently further cooled down before being fed to the amine plant, to remove pollutants produced. In this study, two biomass feed configurations are evaluated; co-feeding and independent gasifiers.

The base case for this study is a coal to liquid (CTL) polygeneration (liquid and power generation) process is based on the values simulated by Kreutz et al. [6]. The coal used is the Pittsburgh #8 supplied at 0.1313 kmol s^{-1} and O_2 from ASU at 7.94 kmol s^{-1}. The coal feed is in slurry form, which was suggested at 64% by weight of solid in the slurry [7].

B. Biomass Introduction Configuration

Figs. 1 and 2 illustrate the schematic diagram of the two configurations for the introduction of biomass in gasification, either through co-feeding it with coal (Fig. 1) or by integrating an independent biomass gasifier (Fig. 2). In Fig. 1, the coal and biomass mixture is reacted with oxygen and/or steam in

Ruwaida Abdul Rasid is currently with the Universiti Malaysia Pahang, 26300, Gambang Kuantan, Malaysia (phone: 603-5492915; fax: 603-5492888; e-mail: ruwaida@ump.edu.my). She was a PhD student in the University of Leeds.

Kevin J. Hughes, Peter J. Henggs and Mohamed Pourkashanian are with the ETII University of Leeds, LS2 9JT, UK (e-mail: k.j.hughes@leeds.ac.uk, p.j.heggs@leeds.ac.uk. m.pourkashanian@leeds.ac.uk).

an entrained flow gasifier. In the base case, 10% of the produced raw syngas is sent to a water gas shift reactor [6], where additional steam is added to adjust the syngas ratio, while the rest of the syngas is sent to the downstream process.

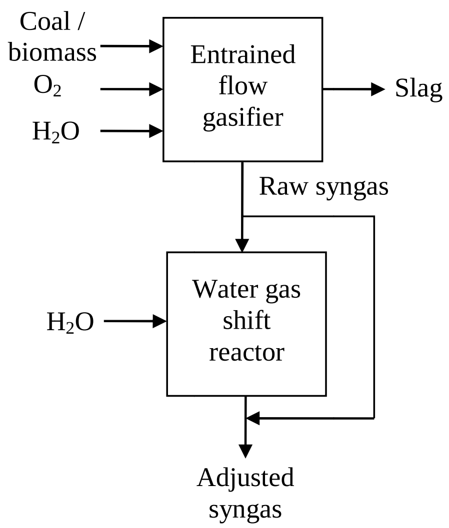

Fig. 1 Schematic diagram for co-feeding configuration for co-gasification process

In Fig. 2, the coal and biomass is reacted with oxygen and/or steam in a separate gasifier, where coal is reacted in an entrained flow gasifier, while biomass in a fluidized bed gasifier, which is a typical type for biomass gasification process. Similarly, in the base case for this configuration, 10% of the produced raw syngas is sent to a water gas shift reactor, where additional steam is added to adjust the syngas ratio, while the rest of the syngas is sent to the downstream process.

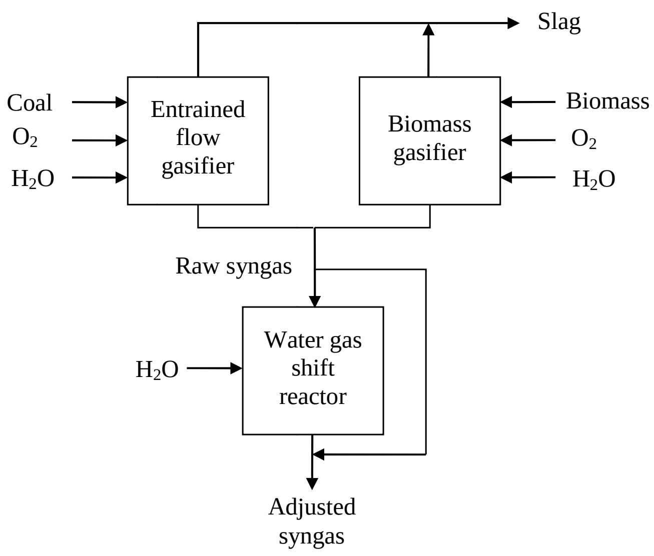

Fig. 2 Schematic diagram for independent co-gasification process

III. Results and Discussions

A. Co-Feeding of Coal and Biomass

Detailed analysis has been modelled for the co-gasification through co-feeding of coal and biomass at the following default values: operating temperature of 1773 K and operating pressure of 72 bar, no additional steam to the slurry feed and the feed ratio of the raw syngas to the WGS reactor at 10%. To ensure reliable results, the ER values are kept constant for each mixture, which is quite a challenging task even in the simulation environment. This is because the stoichiometric requirement for each coal and biomass was determined based on the molar fraction in the input that varies according to each mixture. The input reference value from Kreutz et al. [6] suggested that for B0, the ER value to be 0.33. Other references suggested value between 0.15 and 0.35 [8] or between 0.2 and 0.4 [9], both of which found that lower ER value would give optimum syngas production. In this section, the amount of oxygen flow was adjusted to yield the ER values of 0.25 for each biomass mixtures based on the total stoichiometric requirement of the mixtures.

Fig. 3 illustrates the total molar flow of the produced syngas as well as the variation of the major species at the gasifier exit which are CO, H_2 and CO_2 as a function of biomass content. The produced syngas is shown to increase linearly with increasing biomass content. An interesting observation can be made on the major product distribution whereby increasing biomass content of the fuel mixture has a negative impact on CO, as its composition reduced steadily. CO_2 and H_2 in contrast, were increased with biomass addition. In determining consistent ER values for the mixtures, the molar flow of oxygen was increased with increasing biomass content. Hence, although the ER values were consistent, the impact on the species was different as more oxygen is available to allow for complete combustion. Hydrogen production is shown to be increasing with biomass content, following CO_2 production trend. This is due to the increased amount of hydrogen with increasing biomass content.

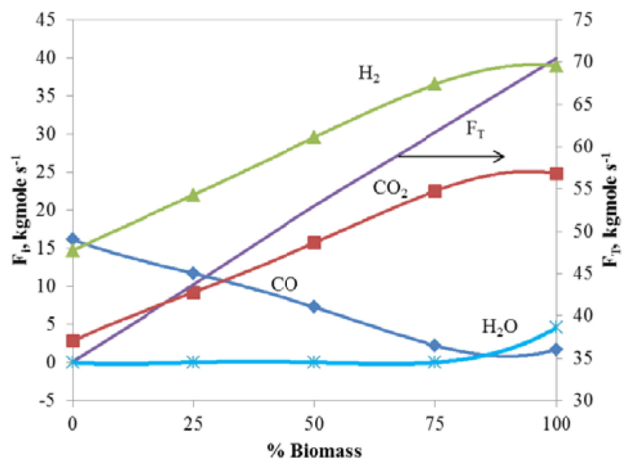

Fig. 3 Total and major species molar flow with increasing biomass content

The minor species that were produced during the gasification process are illustrated in Fig. 4 which are CH_4, N_2, NO, SO_2 and H_2S as a function of biomass content. The figure illustrates that increasing biomass in the feed mixtures collectively is detrimental for all of the minor species. This is because biomass in general could potentially replace coal and other fossil-based fuels, as it can potentially reduce the N and S-based species production and emission to the environment.

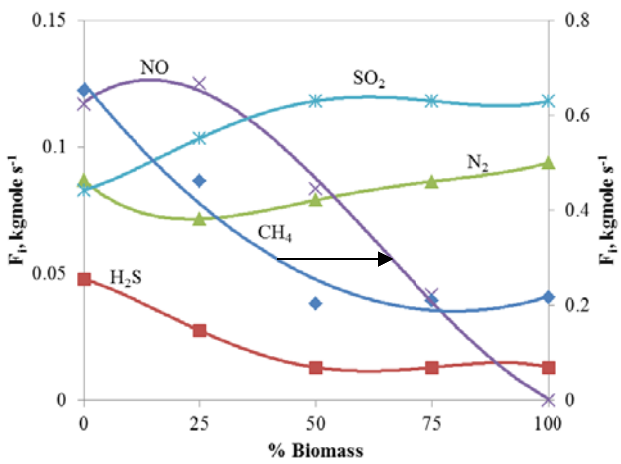

Fig. 4 Minor species molar flow with increasing biomass content

Fig. 5 illustrates the lower heating value (LHV) for the produced raw syngas and it is shown to be decreasing with an increase in biomass content. The LHV value determined was per mass (MJ kg^{-1}), which means that it would be more sensitive towards 'heavier' species that were produced. It was determined that in term of mass, more CO was produced than H_2 and although CO was heavier, it has a lower heating value. Hence, the decreasing trend of the LHV.

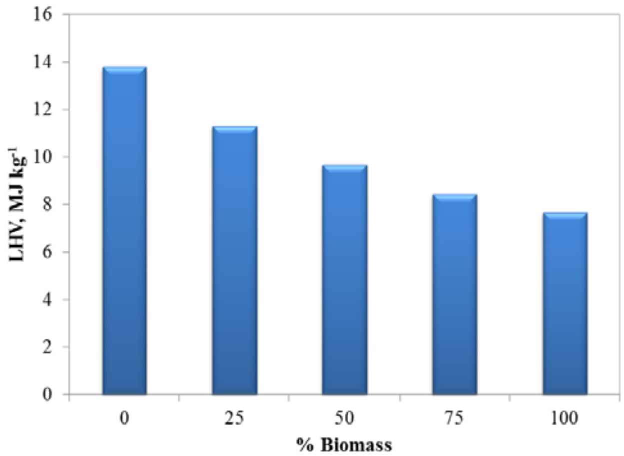

Fig. 5 Heating values for the produced raw syngas

B. Independent Coal and Biomass Gasification

Independent gasification offers the opportunity to adjust individual process operation to get the most optimum output. In this section, ER is fixed at 0.25 for each biomass mixtures. The operating conditions for the entrained flow coal gasifier were maintained as in the co-feeding study as well, at 1773 K and 72 bar. However, for the biomass gasifier, only the operating pressure was set at a similar pressure of 72 bar, while the operating temperature was set lower, at 1123 K to match that of actual biomass gasifier process that has lower operating temperature [10].

The simulation results for the major species production with increasing biomass in the feed mixture are shown in Fig. 6. It shows that similar to earlier findings on co-feeding, increasing biomass content is detrimental towards the production of CO, but the production of H_2 and CO_2 is enhanced, while H_2O production is contributed only from the biomass gasifier. In the co-feeding, H_2O was only detected at B100, while for B0 and the mixtures only a small amount is present. The minor species produced reveals similar trends as the co-feeding study. The main difference is that the changes are linear with biomass increase. This is illustrated in Fig. 7.

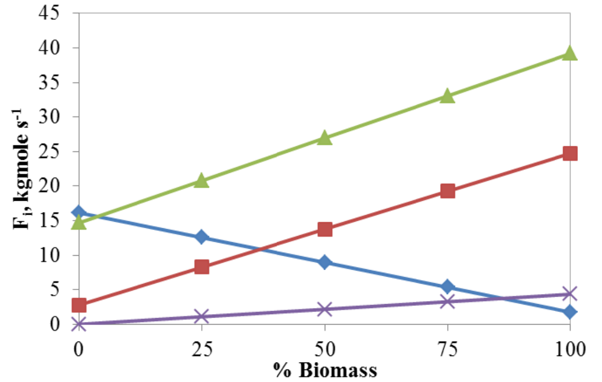

Fig. 6 Distribution of the three major species in independent co-gasification process

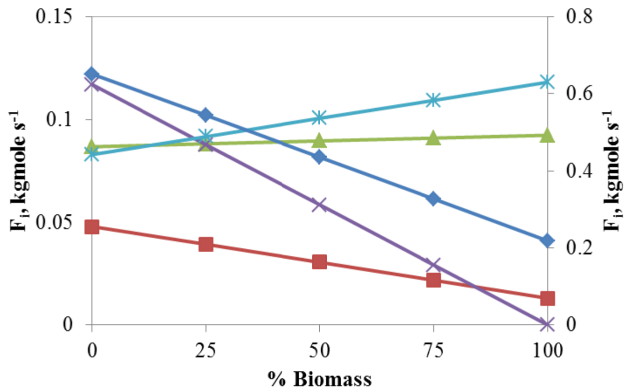

Fig. 7 Distribution of the minor species in independent co-gasification process

On the other hand, Fig. 8 illustrates the LHV of the produced syngas. The syngas produced by the coal gasifier had consistent product distribution, which is about 72% by weight of CO hence its heating values are comparable at 13.8 MJ kg^{-1}. For biomass gasifier on the other hand, the streams are concentrated with CO_2 which is about 83% by weight. Hence, the heating values are a lot lower, as the concentrations of H_2 and CO are lower.

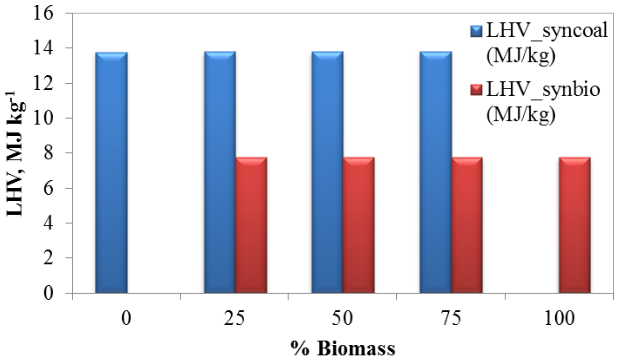

Fig. 8 The LHV of the produced syngas with increasing biomass percentage

C. Comparison of the Biomass Introduction Methods

Comparison of the co-feeding and independent coal and biomass gasification process is through the assessment of the cumulative heat consumed or generated in the gasifiers. As shown in Fig. 8, B0 is the only point in which the amount of heat is at par. However, addition of biomass content caused a reduction in the amount of heat supplied, and with further biomass, the heat input shifted to heat that needs to be removed (below $Q_{gasifier} = 0$). As observed in the figure, independent gasification process was predicted to have larger amount of heat emission, mainly influenced by the biomass gasification process. This suggests that the biomass gasification process has the tendency to proceed to complete combustion, which also explains the high concentration of CO_2 by weight that leads to relatively low heating values found in the previous section.

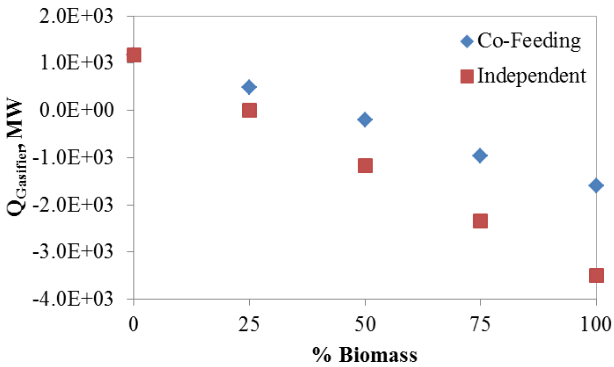

Fig. 9 Heat generated or consumed in the gasifiers with increasing biomass content

IV. Conclusion

In this paper, a process model to represent the co-gasification of coal and biomass was developed and simulated in Aspen HYSYS. The biomass introduction method was evaluated, whether through co-feeding or through independent gasification of biomass. Evaluation of biomass concentration input (B0 to B100) and its gasification performance were also done. It was found that the syngas produced increased with increasing biomass content for both co-feeding and independent schemes. However, the heating values and heat duties decreases with increasing biomass, possibly due to increase in CO_2 from complete combustion, as biomass has larger amount of molecular oxygen.

References

[1] BP. *BP Statistical Review of World Energy*. 2010 June, 2010 (Accessed 2012); Available from: www.bp.com.
[2] Long, H.A. and T. Wang, Case Studies for Biomass/Coal Co-Gasification in IGCC Applications. *Proceedings of ASME Turbo Expo 2011*, 2011: p. 15.
[3] Demirbas, A., Combustion characteristics of different biomass fuels. *Progress in Energy and Combustion Science*, 2004. 30(2): p. 219-230.
[4] Hernandez, J.J., G. Aranda-Almansa, and C. Serrano, Co-Gasification of Biomass Wastes and Coal-Coke Blends in an Entrained Flow Gasifier: An Experimental Study. *Energy & Fuels*, 2010. 24(4): p. 2479-2488.
[5] Abdul Rasid, R. Modelling and Simulation of Entrained Flow Gasification Process. PhD Thesis, University of Leeds, 2013.
[6] Kreutz, T.G., E.D. Larson, G. Liu, and R.H. Williams. *Fischer-tropsch fuels from coal and biomass*. 2008. Pittsburgh, PA, United states: CSREA Press.
[7] Liu, G., E.D. Larson, R.H. Williams, T.G. Kreutz, and X. Guo, Making Fischer-Tropsch Fuels and Electricity from Coal and Biomass: Performance and Cost Analysis. *Energy & Fuels*, 2011. 25(1): p. 415-437.
[8] Mohammed, M.A.A., A. Salmiaton, W.A.K.G. Wan Azlina, M.S. Mohammad Amran, and A. Fakhrul-Razi, Air gasification of empty fruit bunch for hydrogen-rich gas production in a fluidized-bed reactor. *Energy Conversion and Management*, 2011. 52(2): p. 1555-1561.
[9] Skoulou, V., G. Koufodimos, Z. Samaras, and A. Zabaniotou, Low temperature gasification of olive kernels in a 5-kW fluidized bed reactor for H_2-rich producer gas. *International Journal of Hydrogen Energy*, 2008. 33(22): p. 6515-6524.
[10] Higman, C. and M. van der Burgt, *Gasification*. Chemical, Petrochemical & Process: Gulf Professional Publishing. 2008.