

Effect of Co-gasification in Coal and Rice husk on the Pollutant Emission of Gasifier in IGCC Power Plant

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ABSTRACT: A simulation model using ASPEN PLUS was conducted to investigate the effect of co-gasification of coal and biomass (rice husk) on the performance and pollutant emissions of gasifier in IGCC (Integrated Gasification Combustion Cycle) power plants. Influences of feedstock (coal/biomass blending ratio) and operating conditions on specific gasification characteristics (gas composition and cold gas efficiency) are studied. Information on the emission of particulate matters was analyzed. From the simulation results, an optimum range between 6% and 10% was obtained to be a reasonable blending ratio considering on the cold gas efficiency and gaseous pollutant index. The finding from this research confirmed that rice husk is an excellent renewable fuel for co-gasification and provided some valuable reference to the operation of IGCC power plant.

Keywords: Co-gasification, ASPEN PLUS, Blending ratio, Pollutant Emission

1. INTRODUCTION

Renewable energy resources are playing an important role in power generation for sustainability consideration. The use of biomass (either specially grown or waste materials) instead of fossil fuels for heat and power production contributes significantly to the reduction of the net CO₂ emission into the atmosphere. Many studies have been extended on the biomass fuels, such as straw [1], wood chips [2], switch grass [3] and municipal solid waste [4]. Within these researches, co-gasification of biomass with fossil fuels, primarily coal, has received considerable attention. In USA, for example,

tests have been carried out in over 40 commercial plants demonstrating that co-gasification of biomass with coal has the technical and economic potential to replace at least 8 GW of coal-based generation capacity by 2010 and as much as 26 GW by 2020, which could reduce gaseous emissions bulkily. Biomass can be blended with coal in differing proportions, ranging from 1% to 50%. Addition of biomass to coal instead of using pure coal to generate heat and power offers additional advantages: (1) potential availability of large amounts of feedstock (biomass or waste) that can be used in co-gasification applications, (2) relatively small investment is needed compared to an

traditional gasification power plant (such as IGCC), which gives increased process optimization possibilities, (3) gasification of mixtures of coal and biomass shows synergistic effects with respect to char reactivity, tar formation and emission of harmful components.

In the present work, a new co-gasification technology with the feature of fuel flexibility is proposed. The objective of this research is to develop, implement, and demonstrate a capability for evaluating performance of co-gasification characteristics in IGCC systems. Rice husk is chosen as it is cheap and abundant in Asia-Pacific area; energy content is relatively higher than other agricultural sub-products [5]. A simulation model of co-gasification (coal and rice husk) process is created in ASPEN PLUS, which is employed to validate whether the introduction of rice husk to the IGCC power plant can contribute to provide a solution for pollutant emissions. The simulation results are compared with work by others.

2. ASPEN PLUS MODEL

The different stages considered in ASPEN PLUS simulation, in order to show the overall gasification process, are pre-treatment of feed (coal and biomass), decomposition of the feedstock, making slag, volatile reaction, char gasification and gas-solid separation. A description of ASPEN PLUS reactor blocks and simulation diagram are given in Fig.1.

2.1 Fuel Composition

As an effort to demonstrate the validity of the developed model, the syngas composition obtained from the model is compared with that from the experimental studies at various operating conditions using coal and rice husk as feedstock.

Table 1 present the composition of the coal and rice husk used in the simulation study. In ASPEN PLUS, coal, rice husk and ash are specified as nonconventional solid

components. The only properties calculated for nonconventional components are enthalpy and density. Aspen Plus includes special models for estimating these properties for coal, biomass and their derived materials.

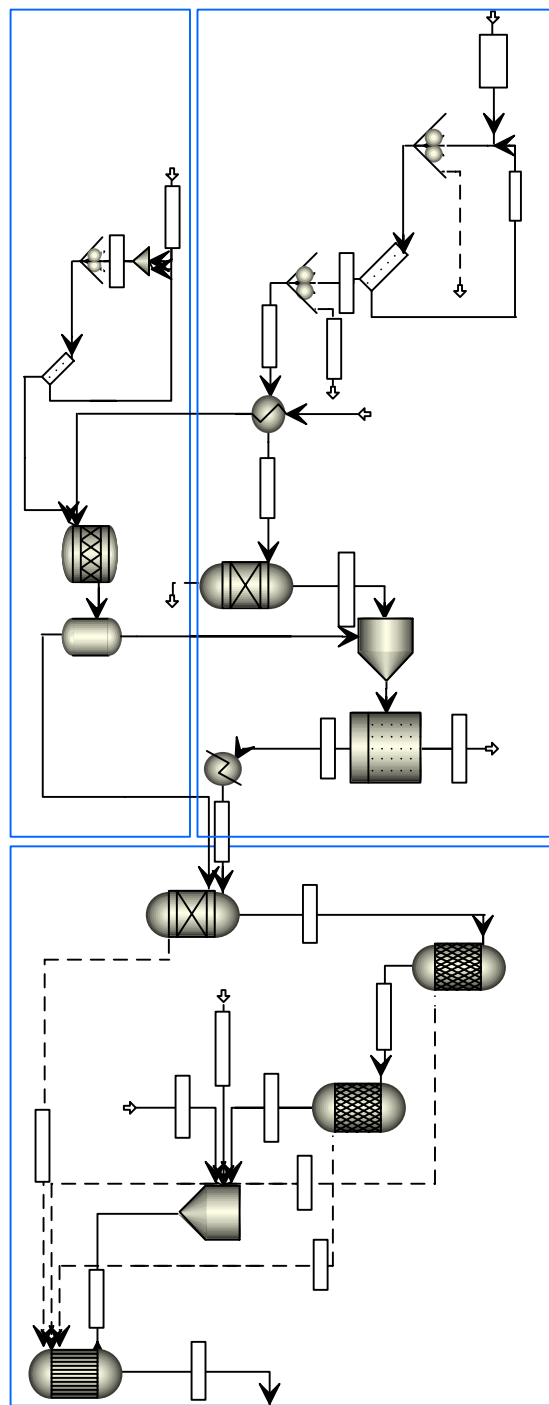


Figure 1: The simulation flowsheet of co-gasification process fed with coal and rice husk in ASPEN PLUS

Table 1. Characteristic of feedstock [6]

	Coal	Biomass
Proximate analysis (wt% dry)		
Volatile	34.41	65.05
Fixed Carbon	57.5	16.02
Ash	8.09	18.93
Moisture	14.6	25
Ultimate analysis (wt% dry)		
C	67.08	36.57
H	4.31	4.61
O	19.26	39.04
N	0.56	0.73
S	0.6	0.12
A	8.09	18.93
Flow rate (ton/h)	85.35	$\alpha \times \text{Coal}$

To investigate the co-gasification characteristics, the simulation was conducted under different operating conditions. The variable was the blending ratio of coal to rice husk (α). By changing the flow rate of rice husk into the gasification zone, different heating values and compositions of raw gas were obtained.

2.2 Feedstock pretreatment

The large coal particles (no less than 1mm), are delivered to the three stage coal crushing and screening area for particle reduction. In Aspen Plus, the processes of crushing and screening are simulated in Crusher and Screen blocks. After crushing, more than 93 % of the coal particles are less than 0.18mm and no particles are larger than 0.36mm. Nitrogen (N₂) is mixed with coal feed to aid conveying and drying, the N₂ phase is separated from the coal before it enters the gasification area.

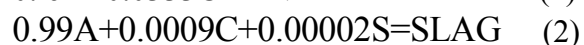
Compared with the coal particles, the biomass average particle diameters are controlled in the range of 0.25-0.75mm by two couples of Crushers and Screens blocks. The moisture of the biomass is dehumidified by the N₂ from the coal heater. Similarly, the N₂ in the biomass is separated in the Bag-House and let the dried biomass alone to enter the gasification area.

2.3 Decomposition

The ASPEN PLUS Yield reactor was used to simulate the decomposition of the nonconventional components in the feed (the mixture of biomass and coal). In this step, coal and biomass are converted into its constituting components including C, H, O, N, S, A, by specifying the yield distribution according to the ultimate analysis of coal and biomass.

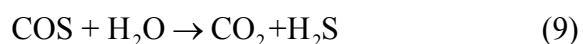
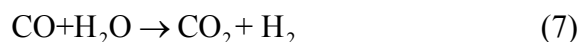
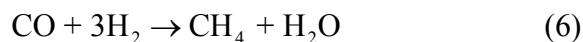
2.4 Making slag and making fine

The ASPEN PLUS Rstoic reactor was used for making slag and fine, in conformity with the equilibrium and the kinetics are either unknown or unimportant. Coal and Biomass consist of mainly C, H, O, N, S, A, and moisture. Carbon will partly constitute the gas phase, which takes part in devolatilization and subsequently results in Volatile gasification. The remaining carbon comprises part of the solid phase (slag and fine). The chemical reactions in this process are very complicated. This model uses a relatively simple approach to represent the reactions. Based on the experimental data, the reaction of making slag and making fine can be expressed [7]:



2.5 Volatile gasification

Gasification is a process that converts carbonaceous materials (such as coal and biomass) into carbon monoxide and hydrogen at high temperatures with a controlled amount of oxygen. The high temperatures and pressures of gasifier mean that a higher throughput can be achieved. All gasifiers remove the major part of the ash as a slag as the operating temperature is well above the ash fusion temperature. A smaller fraction of the ash is produced as a very fine dry fly ash. Some fuels, in particular certain types of biomasses, can form slag also. The mainly reaction in the gasifier are [7]:



Coal gasification is modeled using the Gibbs free energy minimum method in the RGibbs model. This determines the equilibrium composition of the products resulting from the many reactions that can occur. In essence, a limited amount of oxygen or air is introduced into the reactor to allow some of the organic material to be "burned" to produce carbon monoxide and energy, which drives reaction (4) that converts further organic material to hydrogen and additional carbon monoxide.

3. RESULTS AND DISCUSSION

3.1 Residues of Gasifier

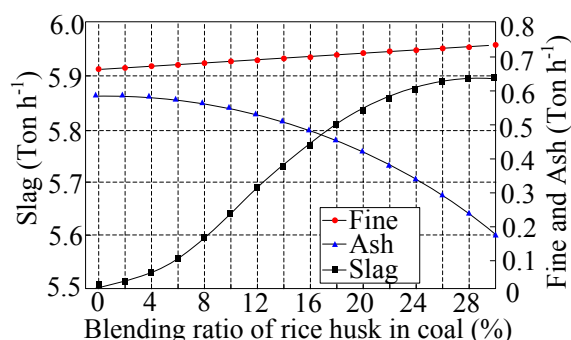


Figure 2: Residue of gasification varied with the blending ratio of biomass in coal

Fig.2 illustrates the output residue of gasifier, such as slag, fine and ash, varied with the blending ratio of rice husk in coal. From the Fig.2, it can be seen that the major contributor to the output residue of gasifier is slag. With increasing the blending ratio of rice husk in coal, the mass flow of slag is increased gradually, which leads to the gasifier yields more residues. The reason

can be explained in the composition of biomass and coal, as listed in Table 1, the rice husk has higher ash content and more moisture than coal. The major difference between biomass and coal ashes is that for the majority of most biomasses the ash consists mainly of salts. As a result biomass ashes have low ash-melting points of, for example, 900°C for rice husk. Because these ashes are extremely aggressive towards refractory materials, which can be used to dissolve minerals before further analysis-biomass does not lend itself for slagging gasification unless it is mixed with large quantities of coal.

3.2 Composition of syngas

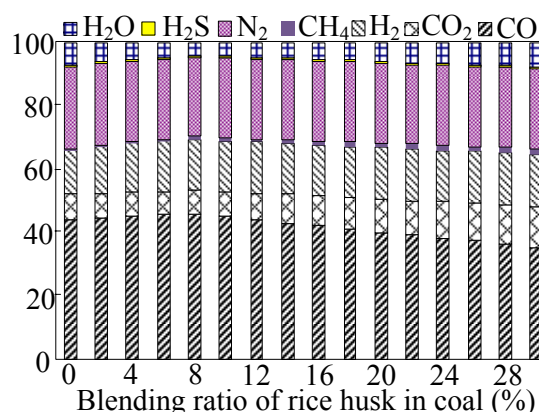


Figure 3: Combustible content in the raw gas produced by the different blending ratio of coal and rice husk

Fig.3 shows the mole fraction of the raw gas varied with the blending ratio of biomass in coal. N₂, as a function of transportation, the percentage remained steady at 23% proximately. H₂S has something in common with N₂, over the range of 0% to 30%, remains at 0.2% level. The mole percentage of H₂O in the raw gas reaches a low point less than 10% blending ratio, a slowly increase occurred from 10% to 30%. It is similar to CO₂, the situation hit a trough at about 8% rice husk mixed with coal and co-gasified. Furthermore, it can be seen that the more rice husk mixed with coal, great changes have taken place in the quantity of combustible content in the raw

gas (CO, H₂ and CH₄). Over the range of blending ratio from 0% to 30%, the peaks of three compositions in the raw gas at around 8% rice husk in coal. Normally, a process that produces a gas with relatively high methane content and therefore has high cold gas efficiency will be good in a power application, but it may not be the optimum choice for a syngas application, in which case the CO yield will provide a better guide to process selection. As the percentage of CO in syngas is more than 40%, the completeness of a gasification process can be reflected by the emission of CO. The reduction of CO is over 9% after blending 30% rice husk, it can be explained that the volatilization behavior of biomass depends on the lignin and cellulose content and fixed carbon is poor compared with coal. All of these may lead to the characteristics of raw gas become weaker. In contrast, an increased by 2% at blending ratio of 8%, this suggests that rice husk can enhance the completeness of the gasification process. Therefore, the optimal range of rice husk blending ratio in coal is between 6% and 10%.

3.3 CGE and CC

There are a number of different criteria that are frequently quoted for gasification process. The most commonly encountered are cold gas efficiency (CGE) and carbon conversion (CC) [8]. The definition is, respectively:

$$CGE = \frac{HHV \text{ of syngas}}{HHV \text{ of coal and biomass}} \quad (10)$$

where the heating value in feedstock is the sum of higher heating values (HHV) of coal and biomass. HHV is estimated by Boie correlation seems to give a better accuracy than the Dulong correlation for HHV of coal and biomass in MJ/kg [7]:

$$HHV = 0.3491C + 1.1783H - 0.1034O - 0.0151N + 0.1005S - 0.0211A \quad (11)$$

where C, H, O, N, S and A are the mass fractions of the elements obtained from the ultimate analysis in Table 1.

Carbon conversion (CC) defined as:

$$CC = 1 - \frac{\text{Carbon in residue}}{\text{Carbon in fuel}} \quad (12)$$

The activity of a catalyst is evaluated by the increase in carbon as CO, CO₂ and CH₄ relative to the available carbon in the volatile fraction according to Eq. (12). Despite the frequency with which these criteria are quoted for different gasification systems, care is required with their interpretation, since both only provide a limited statement about the process efficiencies and gas quality.

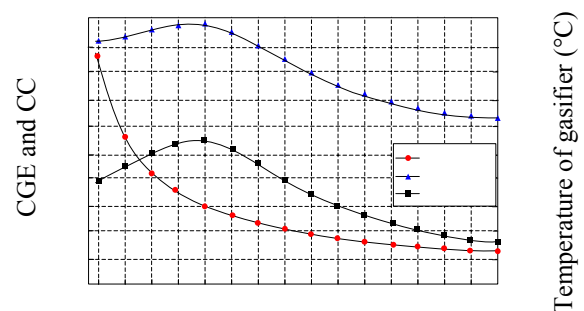


Figure 4: Gasification temperature, CGE and CC varied with blending ration of rice husk in coal

Fig.4 exhibited the temperature of gasifier, CGE and CC changing with blending ratio of rice husk in coal. It can be seen that, the two curves of CGE and CC reaches a high point at about 8% rice husk mixed with coal. The maximum of CGE and CC are 78.3% and 99.2% respectively. As to the co-gasification temperature in the graph, a considerable decrease occurred from 0% to 10% of blending ratio. During this period, the temperature falls off from 1350°C at 0% biomass blending (as determined by the ash characteristics of the coal) to 1000°C with 10% biomass blending with coal. From 10% to 30% of blending ratio, the rate of decrease slow down, the temperature remained steady at 970°C. This simulation

result of temperature is reasonable and very agreed with the operating data of the pilot power plant. Biomass ashes have relatively low softening and melting points and when molten are extremely aggressive in terms of corrosion owing to the high salt content. The low temperature of 900-1050°C is often determined by the ash quality of the biomass rather than by the intrinsic reactivity towards gasification.

Whatever, considering the performance of gasifier, the optimal range of rice husk blending ratio in coal is also between 6% and 10%.

3.4 Pollutant emission in gasifier

Biomass offers the benefit of reducing nitrogen oxides (NO_x), sulfur dioxide (SO_x), and CO₂ emissions. The environmental benefits of biomass technologies are among its greatest assets. In fact, in the raw gas from the gasifier, the productions of gasification process are CO₂, NH₃, H₂S and COS et al. To optimize the blending ratio of rice husk in the coal, gaseous pollutant index (GPI) is defined as:

$$\text{GPI} = \frac{\text{Pollutant concentration}}{\text{Energy input}} \quad (13)$$

where the pollutant emission in the raw gas refers to CO₂, nitride (NH₃) and sulfide (H₂S and COS), the energy input in IGCC system is thermal input, HHV of coal and biomass.

Fig. 5 shows the variation of pollutant emission (CO₂, nitride and sulfide) with different blending ratios of rice husk in coal. The formation of carbon dioxide is due to the reaction between carbon molecules and oxygen molecules. Fig.5 (a) provides some interesting data regarding the CO₂ emissions, we can see clearly that overall tendency of CO₂ GPI is first decreasing, later increasing. The minimum CO₂ GPI was at the blending ratio of about 5% -9%, which is affected by the overall fuel carbon content and gasifier feature. Therefore, the curve reveals that the optimum range of blending ratio of rice husk in coal is between 5% and 9%.

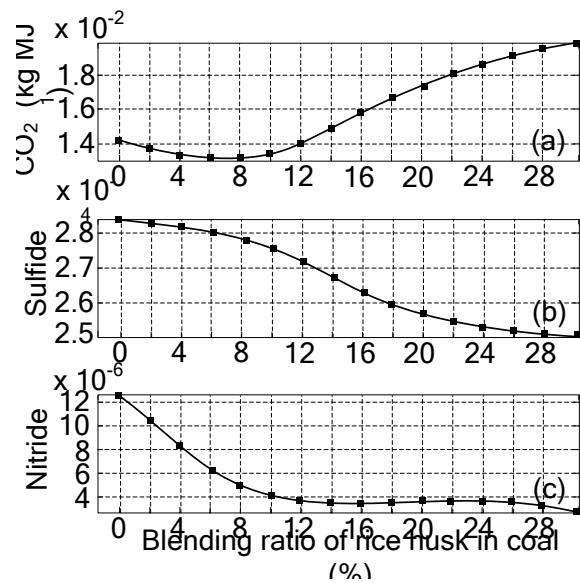


Figure 5: Pollutant emission, CO₂, nitride and sulfide, varied with blending ration of rice husk in coal

Fig. 5 (b) shows the variation of the sulfide GPI in the raw gas with different blending ratios of rice husk in coal. Sulfide emission decreased with the increase of the blending ratio of rice husk in the coal fuel. About 10% of the sulfide emission was reduced after mixing 30% rice husk in coal. It can be explained in the data of Table 1, the sulfur content in coal was about five times of that in rice husk. The reduction of the sulfide emission can be attributed to the decrease in the overall sulfur content in the raw gas.

Fig. 5 (c) shows the nitride emission with different blending ratios of rice husk/coal. Nitrogen content of rice husk was about 30% higher than coal (see Table 1), however, it is very interesting to find that over 60% of the nitride emission was reduced when increasing the rice husk/coal ratio to 30%. The reduction percentage was approximately twice to the blending ratio. The configuration of gasification model was not changed throughout the simulation process. The influence of the gasifier type is thus neglected in the discussion. As the heating value and the gasification temperature of rice husk were lower than

those of coal, the overall gasification temperature decreased with the increase of blending ratio. This reduction of gasification temperature is not favorable for the formation of thermal nitride. As a result, the nitride emission decreased with the increase of the rice husk/coal ratio.

3.5 Simulation results validations

The core of this co-gasification technology is a dry fuel-feed, oxygen-blow, entrained slagging gasifier. The literature survey shows that limited experimental information on such technology is currently available in the open literature. Wiebren [9] has investigated the coal and biomass co-gasification in a pressurized fluidized bed gasifier via lab-scale experiment. Fig. 6 shows the experimental data of NH_3 concentration versus the blending ratio of biomass to coal, α . These results indicate a decreasing NH_3 conversion in the syngas with increasing the blending ratio of biomass in coal. For coal and rice husk, the experimental data obtained are agreed fairly well with the simulation results, no matter how much the rice husk are blended in the coal.

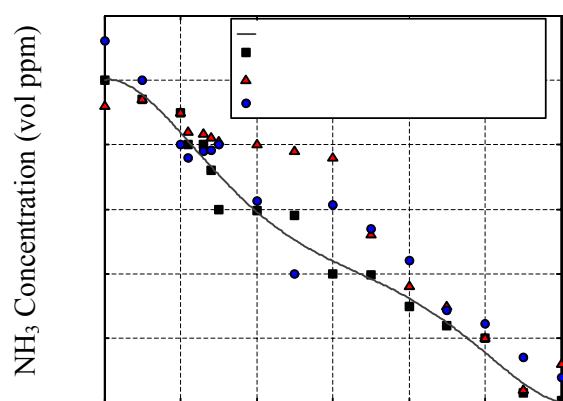


Figure 6: Comparison of the nitride in syngas via experiment and simulation

It should be noted that, although gasification has not reached a commercial status yet, it is widely accepted that, if fully commercialized, it will bring many environmental and economic benefits, i.e.

could reduce nitrogen oxides, sulphur dioxide and other pollutants emissions by 80 to 90%.

4. CONCLUSIONS

An ASPEN PLUS simulation model was created to investigate the performance of co-gasification of coal and rice husk in IGCC power plant. From the simulation results, it can be concluded:

(1) With increasing the blending ratio of rice husk in coal, the mass flow of slag is increased gradually, which leads to the gasifier yields more residues. Combustible content in the raw gas, such as CO , CH_4 and H_2 , reach a peak as around 8% of blending ratio of rice husk in coal. This suggests that rice husk can enhance the completeness of the gasification process. The optimal range of biomass blending ratio was between 6% and 10%.

(2) The two curves of cold gas efficiency (CGE) and carbon conversion (CC) obtain a highest point at about 8% rice husk mixed with coal. The maximum of CGE and CC are 78.3% and 99.2% respectively. The co-gasification temperature, during this period, falls off from 1350°C at coal gasification to 1000°C at 8% blending ratio.

(3) Gaseous pollutant index (GPI) is created and utilized to measure the pollutant emission in the raw gas. The minimum CO_2 GPI was at the blending ratio of about 5%-9%, which is affected by the overall fuel carbon content and gasifier feature. Sulfide GPI decreased with the increase of the blending ratio of rice husk in the coal fuel, which affected by the sulfur content in coal and in rice husk. Over 60% of the nitride emission was reduced by increasing the rice husk/coal ratio to 30%; the gasification temperature plays the important role.

(4) The results of the current research showed that most of the pollutants were reduced when rice husk was introduced. However, 6% to 10% blending ratio of rice husk in coal was found to be the optimum range between pollutant emissions (CO_2 ,

sulfide and nitride) and energy input for CEG and CC. The optimum range for each criteria was the not exactly the same but they were all within the range.

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