Design of Triple Bed Circulating Fluidised Bed Gasifier Model with Cold Gas Efficiency over 80%

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ABSTRACT

Increasing cold gas efficiency (CGE) of low-temperature gasification considering the configuration of triple-bed combined circulating fluidized bed (TBCFB) gasifier that involves steam gasification is critically important to reduce CO₂ emission from power plants. In this study, the TBCFB gasification process was simulated with a commercial process simulator Aspen Plus®. From heat balance calculation between pyrolyser and gasifier (endothermic reactions), and riser (exothermic reaction) and regenerated steam from steam turbines injected into the gasifier, we found that maximum achievable CGE is 95.7% when char conversion ratio in the gasifier is 37.44% at 800 ºC.

[1] Introduction

Coal has been one of major energy resources for power generation globally. Coal utilization leads to CO₂ emissions and is a major contributor to climate change. Hence, more environmentally benign technological approach is required to alleviate this issue. Advanced-Integrated coal Gasification Combined Cycle (A-IGCC) proposed a promising clean coal technology for power generation. A-IGCC uses the concept of exergy recuperation where the exhaust heat from gas turbine is recycled as a heat source of endothermic steam gasification of coal [1]. For this process, a novel triple-bed combined circulating fluidized bed (TBCFB) gasifier has been developed, which consists of downer, bubbling fluidized bed (BFB) gasifier and riser [2,3]. The CO₂ emission from the A-IGCC plants depends on cold gas efficiency (CGE). A little research has simulated the CGE over 80% using different types of gasifier such as dual bed fluidized bed (DFB) and entrained flow gasifier [4,5]. In this study, we estimated maximum achievable CGE of the TBCFB.


The TBCFB gasifier was simulated using commercial process simulator, Aspen Plus®. Redlich-Kwong-Soave (SRK) equation of state was used to determine the thermodynamic properties. Figure 1 shows a block flow diagram for the TBCFB gasifier. Initially, Loy Yang (LY) coal and gasified Loy Yang char (GLYC) were fed into a downer pyrolyser at rates of 19 and 13.2 kg/s, respectively. The GLYC was used as heat carrying particles (HCP) as well as to reduce the amount of volatiles or tar produced from pyrolysis [6]. The products from pyrolysis consist of Loy Yang char (LYC), gases and deposited carbon (carbon attached to surfaces of GLYC). Gases and solid products were separated in a separator before solids (LYC and deposited carbon) were fed into the BFB gasifier, and gasified with steam that was supplied from steam turbines at 600 ºC. The unreacted char from the BFB gasifier was partly combusted in the riser and others were recycled back to the downer. The downer pyrolyser and riser operated at 900 and 950 ºC, respectively. Meanwhile, temperature of the BFB was fixed at 800 or 850 ºC. The properties of coal and char is tabulated in Table 1.

Table 1 Properties of Loy Yang (LY) coal, Loy Yang char (LYC), and gasified LYC (GLYC) [6]

<table>
<thead>
<tr>
<th></th>
<th>Ultimate analysis (d.a.f. wt%)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>H</td>
<td>N</td>
<td>O</td>
</tr>
<tr>
<td>LY</td>
<td>66.90</td>
<td>4.45</td>
<td>0.55</td>
<td>28.10</td>
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<tr>
<td>LYC</td>
<td>91.27</td>
<td>1.48</td>
<td>0.73</td>
<td>6.52</td>
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<tr>
<td>GLYC</td>
<td>96.00</td>
<td>0.70</td>
<td>0.32</td>
<td>2.98</td>
</tr>
<tr>
<td>Higher heating value (HHV) for LY</td>
<td>24 MJ/kg</td>
<td></td>
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</tbody>
</table>
2.1 Heat balance calculation

The generated heat in the riser combustor (exothermic) (R\text{Gibbs2}) was supplied to endothermic parts such as downer pyrolyser (R\text{Yield1,2}) and BFB (R\text{Gibbs1}) by circulating the HCP to meet the heat balance. The required heat of BFB gasifier was determined by varying the supplied steam (600 °C) feed rate.

![Fig. 1 Block flow diagram for TBCFB gasifier](image)

Char conversion ratio in the BFB gasifier was calculated by eq (1).

Char conversion ratio [%] = 
\[
\text{Difference of char molar flow rate (BFB gasifier inlet - BFB gasifier outlet)} / \text{Char molar flow rate (BFB gasifier inlet)} \times 100
\]  

(1)

CGE of the TBCFB was determined by eq (2)

\[
\text{Cold gas efficiency [%]} = \left( \frac{\text{Heating value in product syngas (HHV)[MW]}}{\text{Heating value in feeding coal (HHV)[MW]}} \right) \times 100
\]  

(2)

3.1 Estimation of CGE

Figure 2 shows the relationship between char conversion ratio and CGE at 800 and 850 °C. The maximum CGE was 95.7% and 94.3% at 800 and 850 °C, respectively. At 800 °C, the required char conversion ratio was 37.44% and steam feed rate was 22.8 kg/s, respectively. At 850 °C, the required char conversion ratio was 35.96% and steam feed rate was 20.0 kg/s. At the maximum CGE, the heat received in the downer pyrolyser and BFB gasifier was almost equal with heat generated by riser combustor and supplied by the steam, indicating the overall heat of TBCFB gasifier has reached balance point. To achieve CGE over 80%, char conversion ratio in the BFB should be more than 30.7% and 29.8% at 800 and 850 °C, respectively. In this case, the required steam feed rate can be decreased to 18.7 kg/s at 800 °C and 16.6 kg/s at 850 °C, generating excess combustion heat in the riser. For the design of reactor size, we need to include gasification rate and gas velocity of the steam in the BFB to fluidise the char particles.

[4] Conclusions

Maximum CGE can be achieved at 95.7% and 94.3% at gasifier temperature of 800 and 850 °C respectively. At this conditions, char conversion ratio can be obtained with 37.44% for 800°C and 35.96% for 850 °C. The size of gasifier reactor will influence the amount of steam supplied for fluidization inside BFB gasifier.

[References]


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