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Hydrodynamic characteristics in cold model of dual fluidized bed gasifiers

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ABSTRACT

Gasification in dual fluidized bed gasifiers (DFBGs) has proven itself as one of the promising technologies. In DFBGs, the bubbling fluidized bed (BFB) acting as a gasifier and a riser applied as combustor are coupled with the provision of solid transfer between them. The hydrodynamic characteristics of these reactors are very important in improving their performance and achieving better operational control. In the present study, a cold model of dual fluidized bed gasifier of configuration – riser as combustor and BFB as gasifier with loop-seal as the upper connection and L-valve as the lower connection – has been constructed. The influence of operating parameters such as fluidization velocity in the riser, aeration velocity in the L-valve as well as the inventory on the pressure drops and solid circulation rate was inspected. Results show that the pressure drop in the riser decreased with the increase of the riser velocity whereas it increased with the increase of L-valve aeration velocity. Besides, the solid circulation rate was found increasing with the increase of both riser velocity and L-valve aeration velocity. However, the increase of the riser pressure drop and solid circulation rate with the increase of L-valve aeration velocity was limited due to the excessive fluidization in L-valve which disrupted the solid flow. This was termed as the maximum L-valve aeration velocity for the stable operation. The results show that the maximum L-valve aeration velocity increased with the increase of solid circulation rate and riser velocity. Furthermore, a correlation was proposed to relate solid circulation rate to riser velocity and L-valve aeration velocity.

1. Introduction

Gasification is a thermo-chemical process that converts solid fuels such as – coal, petroleum, coke, plastics, biomass and solid wastes – into valuable gas known as syngas through partial oxidation at the elevated temperatures in the presence of a gasifying agent [1,2]. Depending upon the gasification medium, the calorific value of syngas may range from 4 MJ/Nm^3 (air gasification) to 16 MJ/Nm^3 (steam gasification) [3–6]. The syngas can be used to produce gaseous products such as synthetic natural gas (SNG) to generate electric power in gas engine or gas turbine and produce hydrogen for fuel cells. Moreover, they can also be transformed into liquid fuels by Fisher–Tropsch synthesis [6–8]. Gasifiers, equipment of syngas and gas production, are generally categorized as: fluidized bed, fixed (moving bed) and entrained flow bed on the basis of fluid dynamics. Among these categories, fluidized bed gasifiers offer relatively high mixing and reaction rates. Besides, they are capable of being scaled up to the medium and large scales, overcoming limitations of smaller-scaled and fixed-bed designs [9,10]. In recent years, dual fluidized bed gasifiers (DFBGs) have been considered as a simple, reliable and cost-effective method to produce high quality syngas [11] on the ground that DFBGs, using steam as the gasifying agent, can produce a N_2 free syngas of high H_2 and CO and calorific values. Moreover, the quality of syngas in DFBGs can be further improved by optimizing the design and operation of gasifiers, by using catalytic bed materials and finally by a downstream cleaning process [5,12–14].

The basic concept of the DFBGs is to divide the fluidized bed into two zones: a gasification zone and a combustion zone as shown in Fig. 1 with the provision of solid transfer between them. Although several reactors of configuration exist, the riser/circulating fluidized bed (CFB) as a combustor coupled with a bubbling fluidized bed (BFB) as a gasifier has been identified to be the superior technical choice for DFBGs [15,16]. In this type of configuration, gasification of biomass with superheated steam is performed in BFB, which produces the syngas that flows out from the cyclone. The residual char (the un-reacted fuels and the by-products of the gasification process, such as tar and char) and the bed materials are then transferred and combusted along with the additional fuels in the riser to produce heat and flue gas. The heated bed materials from the combustor flow into the gas–solid separators like cyclones and are recirculated to the BFB in order to supply the essential heat required for the endothermic gasification process [17–20]. BFB and the riser are generally coupled with the auxiliary components in order to circulate the bed materials among them. Standpipes, together with non-mechanical valves such as loop-seal and L-valve are mostly employed for these purposes because of their capability to perform under adverse

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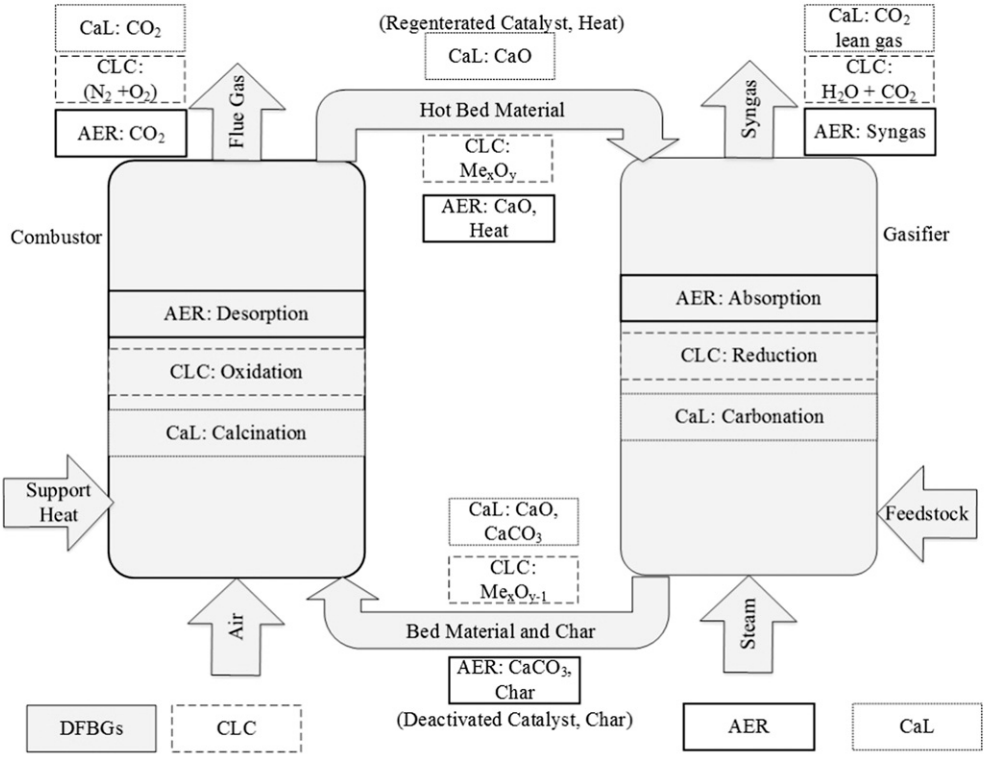

Fig. 1. Concepts of dual fluidized bed, extended from [50].

conditions, to control solid flow and provide gas seal [21–24]. In addition, DFBGs aiming to produce high hydrogen content in syngas as well as in situ CO_2 capture known as Adsorption Enhanced Reforming (AER) or Sorbent Enhanced Reforming (SER) have been under study [25–29]. In this process (Fig. 1), the bed materials such as dolomite and limestone are used for capturing CO_2 apart from transferring heat. CO_2 adsorbent bed material captures CO_2 in situ during gasification according to (R.1). The continuous removal of CO_2 during gasification enhances production of H_2 (R. 2).

$$CaO + CO_2 \rightarrow CaCO_3 \text{ (R. 1)}$$

$$CO + H_2O \leftrightarrow CO_2 + H_2. \text{ (R. 2)}$$

The other promising dual fluidized bed (DFB) technologies are Chemical Looping Combustion (CLC) which offers efficient and low-cost CO_2 capture [30] and Calcium Looping (CaL) process which is employed in post-combustion CO_2 capture [31,32] (refer to Fig. 1). A lot of researches have been carried out to improve the performance of DFBGs. Among them, the hydrodynamics of the DFBGs is one of the important aspects that has been mostly investigated in cold model since they are, comfortable, reliable and easy to handle. Other than that, they have exhibited similar hydrodynamic behaviors [33,34]. A number of researchers dedicated their studies in cold models for the advancement of the hydrodynamics of the DFBGs. The investigations have been performed in order to improve the design and operation of the DFBGs [17,29,35], to inspect the hydrodynamic characteristics as well as their behaviors together with the effect of the operating parameters and the design parameters at the ambient temperature [36–38] and at the elevated temperatures [39,40] and to develop the modeling techniques [11,18,41–44].

Furthermore, for proper operational control of these DFBGs, the connections between the two reactors are likewise important since they ensure the gas leakage between the reactors and contribute towards the control of solid circulation between the two reactors. The upper connection transfers the solids from the riser to BFB while the lower connection executes the vice-versa. Moreover, the hydrodynamics has been found to be highly influenced by the rate at which solids are returned to the riser [45]. Therefore, the study of operational control of solid circulation from BFB to the riser in DFBGs is meaningful. Mostly the connection from BFB to the riser is constructed as an inclined chute placed at a certain angle. Kaiser et al. [17] concluded larger inclination of the connection leads to a higher solid circulation rate. Recently, non-mechanical valves like seal-pot, loop-seal, and L-valve are often used while connecting these reactors because these valves build up necessary pressure drop in a solid circulation loop so that particles can be conveyed from the low pressure zone to the high pressure zone without undesirable inverse gas flow; besides, they offer better control of solid circulation [22,24,46,47]. Goo et al. [36] investigated the effect of aeration velocity in seal-pot on solid circulation rate, and found the solid circulation rate increases sharply with the increase in seal-pot aeration up to 2.5–3 U_{mf} to reach the maximum capacity of seal-pot. Similar results in loop-seal were also shown by Ramirez [48] and Seo et al. [37]; in addition Seo et al. [37] demonstrated solid circulation rate increases with the increase of the aeration velocity in recycle chamber. What's more, designs with loop-seal at the base of the gasifier have also been reported [29]. On the other hand, L-valve is another widely employed non-mechanical valve because of its simple design which is cost effective and requires low maintenance. Apart from that, it is suitable for operating at the elevated temperatures and under the pressure conditions [23,49]. However, the use of L-valve for solid transfer from the BFB to the riser has been least studied. Karmakar and Datta [18] used L-valve to control the solid circulation rate in the DFBG. They suggested the aeration flow in L-valve required to initiate solid movement increase with the particle size and solid circulation rate. In the present study, a dual fluidized bed of configuration – riser as combustor and BFB as gasifier with loop-seal as upper connection and L-valve as the lower connection – was constructed. This study aims to investigate the influence of operating parameters — fluidization velocity in the