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Gas leakage between reactors in a dual fluidized bed system

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ABSTRACT

The leakage of gas between two interconnected gas–solid fluidized beds is investigated for 48 operating conditions in a lab-scale dual fluidized bed (DFB) consisting of a riser and a bubbling fluidized bed (BFB). Helium is used as the tracer gas with a spent FCC catalyst bed in ambient conditions. Gas leakage occurs from the riser to the BFB via the downcomer; and from the BFB to the riser via the loop-seal. Gas leakage from the riser to the BFB varied between 0.1 and 0.6%, translating to 1 and 7% of the BFB being contaminated with riser gas. This leakage is dependent on pressure difference across the downcomer and the solids circulation flux. Leakage in the downcomer is proposed to be caused by the riser gas being dragged down by the falling particles in the upper section of the downcomer.

1. Introduction

Dual fluidized beds (DFBs) make use of the fluid-like state of fluidization in order to circulate solids between vessels. An environmentally significant application of DFBs is CO_2 capture by circulating CO_2 sorbents to limit the emission of CO_2 from large-scale industrial gasifiers [1–3]. These DFB looping systems make use of calcium based sorbents and two interconnected fluidized bed reactors: the one being a gasifier/carbonator; and the other being a calciner. In the gasifier CO_2 would be produced and captured by CaO to form $CaCO_3$. The particles are then transported into the calciner where the reverse reaction is performed to drive off the CO_2 and produce CaO. The particles are then looped back into the gasifier for further capturing of CO_2 [3]. This technique sequestrates CO_2 from the syngas (CO and H_2). Chemical-looping combustion (CLC), on the contrary, manages CO_2 by making use of metal oxygen-carriers in an interconnected fuel and air reactors [4,5]. Separate oxidizing air and H_2O–CO_2 streams are produced in the CLC technology, allowing for efficient CO_2 separation. DFBs are also used in hot gas desulfurization, sorption enhanced steam methane reforming and chemical-looping hydrogen generation systems [6].

In these DFB systems, gas leakage may occur between the reaction-vessels which would decrease the efficiency of the CO_2 separation process. To the authors' knowledge, few researchers have examined gas leakage between fluidized beds in DFB systems. Johansson et al. [7] investigated gas leakage in a CLC setup at room temperature using 150 μm silica sand particles and helium as tracer gas. The system consisted of an air reactor (riser) and a fuel reactor (bubbling fluidized bed, BFB) interconnected via the downcomer and a pot-seal, and operated up to a solids circulation rates (G_s) of 8 kg/m^2.s. Between 1 and 3% of the BFB helium was detected in the cyclone outlet of the riser; while, a strong correlation between G_s and gas leakage via the downcomer was noted. In the same study, no gas leakage from the riser to the BFB side was found and attributed to the fact that the BFB pressure was higher than the pressure in the riser-cyclone. Reyes [8] used an interconnected riser and BFB with 438 μm limestone particles to find gas leakage occurring from the cyclone to the BFB via the downcomer. This was an opposite trend to that of Johansson et al. [7] even with the BFB pressure being higher than the riser-cyclone pressure. The main differences between the systems were that Reyes worked with a higher G_s of up to 150 kg/m^2.s; and used a loop-seal between the BFB and riser. Ryu et al. [6] investigated the solids circulation rate and gas leakage between two interconnected BFBs using 150 μm sand and had not gas leakage. This dual BFB system had low particle entrainment rates, with G_s up to 0.2 kg/m^2.s.

Understanding the pathways and mechanisms of gas leakage is important for any DFB system, as gas leakage may reduce the efficiency of a process. From literature it can be seen that gas leakage is system dependent and is a function of operating conditions. Thus, possible pathways and mechanisms of gas leakage according to the operating conditions will be the focus of this investigation. Air will be used as the fluidizing medium with helium as a tracer gas in a cold model dual fluidized bed system.

2. Experimental setup

The DFB used in this investigation consists of a 0.1 m (ID) riser with a loop-seal downcomer interconnected to a 0.29 m (ID) BFB, all made of acrylic plexi-glass. The two fluidized beds are interconnected using a bypass line extended from the primary downcomer. Fig. 1 shows a

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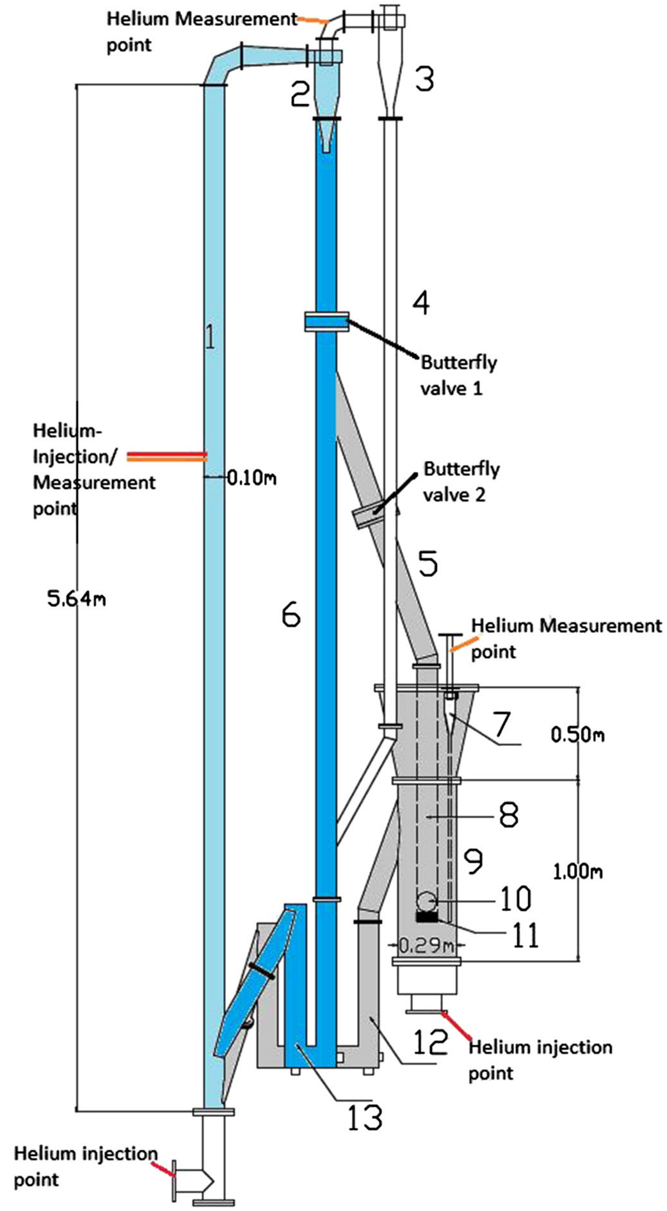

Fig. 1. Schematic diagram of the dual fluidized bed showing the circulating fluidized bed loop in dark and light blue and the BFB-system in grey. Also indicated are: (1) riser; (2) primary cyclone; (3) secondary cyclone; (4) dipleg; (5) upper side-downcomer; (6) primary downcomer; (7) internal cyclone; (8) lower BFB-downcomer; (9) BFB; (10) hole to the side of the lower downcomer; (11) seal at the bottom of the lower downcomer; (12) loop-seal 1; (13) loop-seal 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

diagram of the setup; label 6 represents the primary downcomer, and label 5 shows the second side branch downcomer. The loop is completed via a second loop-seal (label 12) flowing from the BFB to the riser. The loop-seal connecting the BFB and riser is labelled as loop-seal 1 (LS1); whereas, the primary downcomer loop-seal is labelled as loop-seal 2 (LS2). Further details are noted elsewhere [9–11]. Spent FCC particles were used in these experiments having a Sauter mean particle diameter of 78 μm; a particle density (ρ_p) of 1560 kg/m^3 and a bulk density (ρ_b) of 870 kg/m^3. Minimum fluidization velocity (U_{mf}) was determined to be 3.4 mm/s.

Helium is used as a tracer gas with blower air as the fluidizing gas. The stable helium concentration in the BFB, riser and cyclones are measured using a Micro-GC (Varian CP4900). Once the system is set to an operating condition and steady-state operation is reached, five consecutive helium concentration measurements are made, from which the mean is calculated. Each measurement takes approximately 3 min; and helium concentrations are between 0.3 and 3.0%. The gas leakage between the two systems is defined as the volume fraction of helium added which escapes to the second reactor. In order to understand the influence of the operating conditions on the gas leakage, the superficial gas velocity in the riser (U_R) is set at 2.5, 3.0, 4.0 and 5.0 m/s. To simulate a CLC system, the corresponding superficial gas velocity in the BFB (U_B) is varied to maintain a constant volumetric gas flow rate ratio between the two systems. Using an excess air coefficient of 1.1 fixes the volumetric ratio at 11, corresponding to a U_B between 0.028 and 0.056 m/s. The aeration velocity in loop-seal 1 (U_{A1}) is set at 1U_{mf}, 2U_{mf}, 4U_{mf}, or 6U_{mf}; while, the aeration in loop-seal 2 (U_{A2}) is set at 0, 1U_{mf} or 1.5U_{mf}. The permutations between these variables result in 48 operating conditions for which the gas leakage from BFB to riser, BFB to riser-cyclone, riser to BFB and from loop-seals to BFB being explored.

3. Results and discussion

The system pressure loops, total solids circulation flux (G_{sT}) and BFB solid circulation flux (G_{s1}) were measured using pressure probes and the two butterfly valves are shown in Fig. 1. The solids circulation flux was measured by closing a specific valve and measuring the time

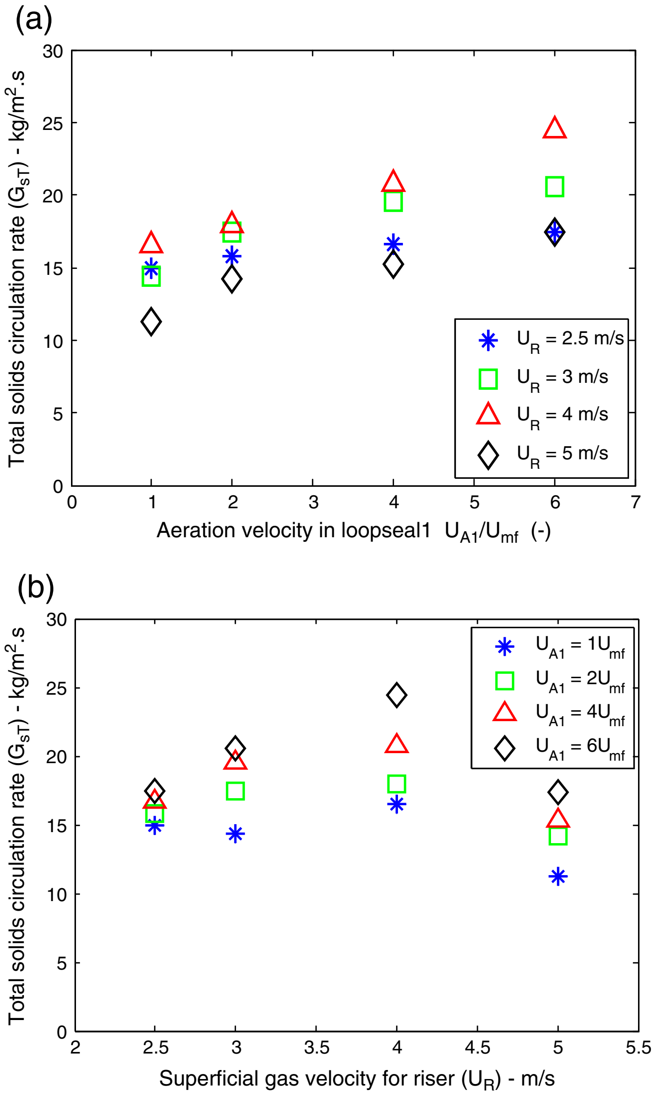

Fig. 2. Effects of (a) loop-seal 1 aeration; and (b) riser velocity on total solids circulation flux (G_{sT}) for $U_{A2} = 1U_{mf}$.