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The Effect of Effective Diameter on Fluidization Quality in Compartmented Fluidized Bed Gasifier

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ABSTRACT

Compartmented Fluidized Bed Gasifier (CFBG), consisting of two compartments - the combustor and gasifier, uses air blown instead of pure oxygen for syngas production in bubbling fluidization mode, eliminating the need of air separation unit, and reducing the capital cost, thus distinguishes it from other traditional ones. Fluidization quality is a determining factor in the CFBG to guarantee its well-lifted behaviour. Previous study, without solid circulation at ambient conditions, brought to the fore the necessity of considering the effect of the minimum allowable effective diameter. The study was then performed in the CFBG cold physical model of 0.66m overall diameter (effective diameter for combustor and gasifier is 0.413m and 0.257m) to investigate the fluidization quality and compare it with the results obtained from the previous cold model of about 1.36 times smaller, but with the same compartmented ratio of 65:35. Different inert particles (river sand, quartz sand and alumina) were used, over a range of aspect ratios, for the aforementioned objective. The results showed that the fluidization quality in the gasifier has not been achieved and the degradation of fluidization quality in the combustor is still observed, notwithstanding the fact that the condition of the minimum allowable effective diameter has been met. The reduction of distributor free area, to increase the distributor pressure drop, showed a marginal effect on the quality. The effect of the minimum allowable effective diameter on fluidization quality in CFBG as well as the interplay of geometric and operational parameters require further studies be carried out. The fluidization quality of the binary mixture is also currently under investigation.

Keywords: Channelling, Compartmented Fluidized Bed Gasifier (CFBG), effective diameter, fluidization, fluidization quality

INTRODUCTION

It is of great importance to be able to estimate the quality of fluidization for an efficient and economic use of gas-fluidized beds when the operating parameters are changed. An idealized fluidization consists of a completely lifted and uniform suspension of inert particles. Fluidization quality, Q, is used as a distinctive indicator to show the fluidization characteristic in the compartmented fluidized bed gasifier (CFBG).

The CFBG is a unique compartmented reactor which consists of two reactors, namely the combustor and the gasifier, partitioned vertically inside at a ratio of 65:35, based on the heating requirement during the high-temperature operation. The significance of the CFBG is that it uses air blown instead of pure oxygen for syngas production in bubbling fluidization mode, eliminating the need for air separation unit and thus reducing the capital cost, which distinguishes it from the traditional ones. The idea of having compartmented reactors arises when the construction of several reactors is not economically viable, owing to the need of solids to be circulated through different

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reaction zones in many gas-solid reactions. In this paper, the combustor or gasifier compartment is neither a full cylindrical nor semi-cylindrical, but rather a segment of a cylindrical, as shown in *Fig. 1*. A few studies on non-cylindrical fluidized bed have been carried out elsewhere (Bhattacharya *et al*., 1999; Singh *et al*., 2005; He, 1993; Yan, 1995), but hitherto none has addressed the type of geometry in the CFBG. This has thus invited a strong interest in the study of fluidization characteristics in the CFBG.

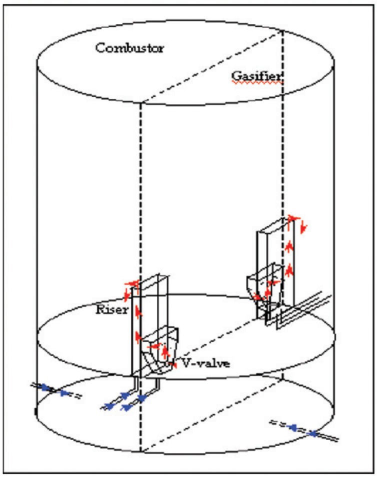

Fig. 1: Isometric view of CFBG

A previous study by Wee *et al*. (2007) brought to the fore the necessity of considering the effect of the minimum allowable effective diameter, without solid circulation at ambient conditions. The study was carried out (in this paper) at the expanded CFBG cold physical model of 36% increment in the overall diameter, compared to the previous one. The objectives of this paper were to investigate the fluidization quality, at each compartment, with different inert particles and sizes being used (river sand, quartz sand and alumina) for a range of aspect ratios as well as to compare it with the results obtained from the previous model.

THEORY

Fluidization is defined as a process, in which particles are transformed into a fluid-like state, through contact with either a gas or a liquid. The fluidization quality indicator, Q, is conventionally defined as the ratio of experimental bed pressure drop to the theoretical bed pressure drop, or in short, Q = Experimental ΔP/ Theoretical ΔP, where theoretical bed pressure drop is simply the weight of the particles over the cross-sectional area of the compartment.

It is essential to find the effective diameter for the CFBG reactor of the non-uniform and uncommon shape. Hence, the effective diameter, D_e (Nicholas *et al*., 1984) was representatively used in this study.

$$D_e = 4\text{x}\ \frac{\textit{mean cross sectional area of flow channels through bed}}{\textit{mean wetted perimeter of flow channels}} \quad (1)$$

Distributor free area is the percentage of the area which is occupied by orifices, as described in equation (2).

$$\text{Free area} = \frac{\text{Total Orificers Area}}{\text{Distributor Plate Area}} \times 100\% \qquad (2)$$

EXPERIMENTAL METHOD

The experimental set up used in this study is shown in *Fig. 2*. The CFBG is custom-made using mild steel as the body structure, and Perspex material as the cover to ease the visual observation during the experiment. The overall diameter of the CFBG is 0.66m, with a height of 1.8m, and partitioned into two compartments, namely the combustor and the gasifier by a vertical diving wall in a ratio of 65:35, respectively. Meanwhile, perforated plate distributor, with orifice diameter of 3mm was used to uniformly distribute the fluidizing agent, ambient air into the beds of the particle, at the free area of 0.27% and 0.32% in triangular pitch arrangement for gasifier and combustor accordingly. The effective diameter for combustor and gasifier is 0.413m and 0.257m correspondingly. Meanwhile, 100 micron mesh was employed on top of the distributor to avoid the particles from weeping through the orifices. The air is regulated in the range of 1 – 2 minimum fluidization velocity, U_{mf}, to maintain the bubbling mode of fluidization. Water manometer is utilized to gauge the pressure drop across the beds and the distributors.

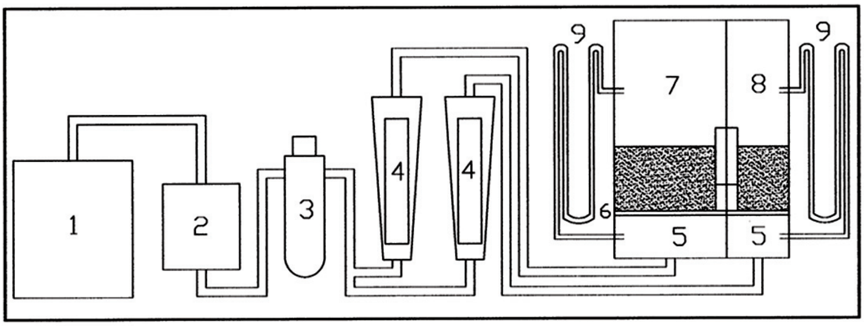

Fig. 2: Experimental set up (1: compressor; 2: dryer; 3: pressure regulator; 4: rotameter; 5: plenum; 6: perforated plate distributor; 7: combustor; 8: gasifier; 9: water manometer)

The particles used in the experiment are mostly natural river sand. However, alumina of different properties, and sized as a perspective heat carrier for pilot plant and quartz sand with free-impurities-surfaces and physical properties were tested on the quality of fluidization. Their physical properties are tabulated in Table 1.

TABLE 1
Physical properties of particles

Particle	River sand	Alumina	Quartz sand	Quartz sand
Size, d_p	272 µm	360 µm	256 µm	362.5 µm
Density, ρ_p	2620 kg/m^3	3992 kg/m^3	2638 kg/m^3	2638 kg/m^3
Theoretical (Wen & Yu) minimum fluidization velocity, U_{mf} (Kunii, 1991)	0.060 m/s	0.154 m/s	0.053 m/s	0.105 m/s

RESULTS AND DISCUSSION

The Effect of Effective Diameter

Fig. 3 compares the fluidization quality at different effective diameters, using river sand at bed height of 0.34m, over a range of free area from 0.27% to 0.32%. The results were then compared with the ones obtained from Wee *et al*. (2007) who obtained D_e = 0.173m, 0.234m and 0.290m. As can be observed from the graph, only the diameter of 0.290m was found to achieve good fludization quality, whereas the rest exhibited the opposite quality. It was also expected that the diameter which was bigger than 0.290m achieved a good fluidization quality (Wee *et al*., 2007); however, the trend of D_e = 0.413m was notwithstanding the fact that the condition of the minimum allowable effective diameter had been met. Further studies need to be done to verify the reasons contributing to it. The flow behaviour of a gas solid fluidized bed is very complex and highly sensitive to scale (Nicholas *et al*., 1984). Hence, the wall effect, which has a strong relationship with D_e, is a determining factor which leads to the fluidization quality. Werther (1968) and other researchers showed that the wall effect became progressively more significant as the bed diameter was decreased. As the diameter was decreased, the friction at the wall was found to support a larger and larger fraction of the weight of the bed, as a result of which the bed became more loosely packed (Srivastava *et al*., 2002). This leads to a decrease in the internal friction and a corresponding decrease in the normal stress exerted at the wall, creating a preferential path at wall side, which facilitates the air to flow through it. This eventually contributes to increasing bed pressure to drop with increasing air velocity which demonstrates the intermediate channelling behaviour (Nicholas *et al*., 1984). Profiles which are below 1.0 indicate channelling bed. This offset suggests that the beds are not completely fluidized.

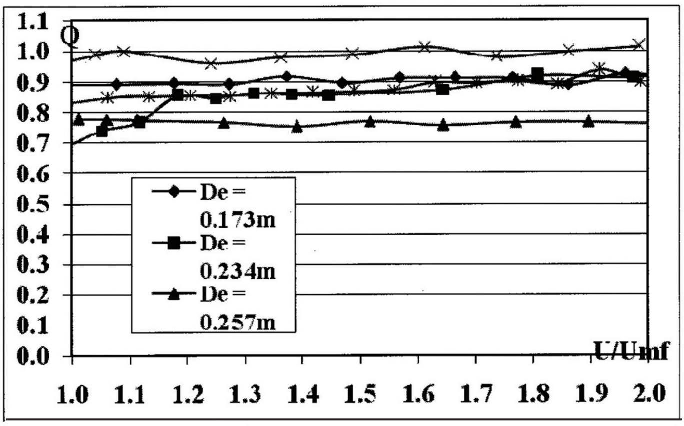

Fig. 3: Fluidization quality, Q versus U/U_{mf} at different effective diameters (river sand, bed height = 0.34m)

The Effect of Free Area

In order to improve the fluidization quality, the study was done to investigate the effect of the distributor free area. *Fig. 4* shows the fluidization quality of different free areas, e.g. 0.23% and 0.32% at the aspect ratio of 1.09 and the river sand was used. The higher free area shows a more satisfactory trend in relative to the smaller free area; nevertheless, the desirable quality of fluidization is still unachievable. The graph shows the inability of the fluidized bed to be fully lifted by the incoming gas rate at U_{mf} and obviously one can observe that channelling occurs in the system studied. Channelling can be a result of the non-uniformities and inhomogeneities in the bed due to the perturbation, where there is a localized higher velocity through the bed, causing a localized expansion. Thus, it changes the pressure drop through that portion of the bed. Channelling becomes more pronounced if the localized pressure drop through the bed-distributor system decreases with the increased velocity (Robert, 1976).

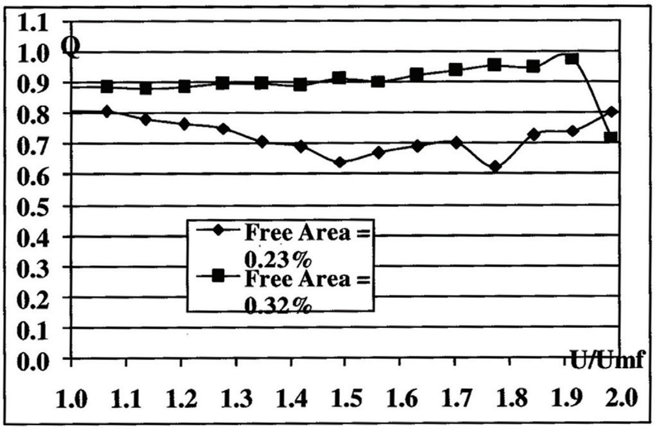

Fig. 4: Fluidization quality, Q versus U/U_{mf} at different distributor free areas (river sand, H/D = 1.09, D_e = 0.413m)

The Effect of Different Particles

A comparison was also done between the alumina and quartz sand of identical size in the gasifier compartment, as shown in *Fig. 5*. It was observed from the fluidization quality curve that the quartz sand showed a better behaviour as compared to alumina. According to Wee *et al.* (2007), the physical properties of the particles play the key effect to the hydrodynamics of the bed.

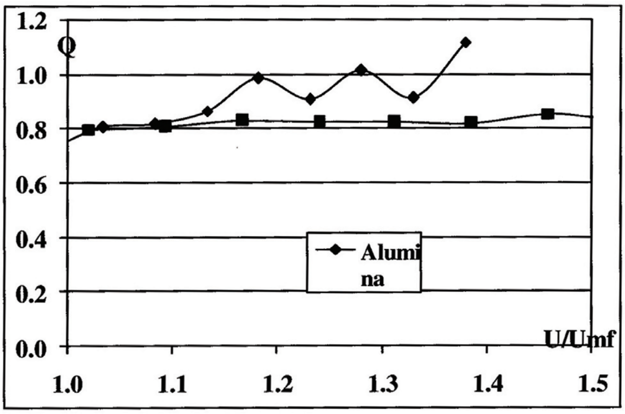

Fig. 5: Fluidization quality, Q versus U/U$_{mf}$, using different particles (free area = 0.27%, H/D = 1.36, D$_e$ = 0.257m)

The shape and density of the particles are factors which affect channelling (Nicholas *et al.*, 1984). Channelling always takes place due to the appreciable cohesive force between the particles (Wang *et al.*, 1997). Thus, it is observed that the quartz sand and alumina shows through and intermediate channelling, respectively. The through channelling can be distinguished when the Q is less than 1, whereas the intermediate channelling will have an increasing large fluctuation along the Q=1 (Wee *et al.*, 2007).

The Effect of Different Particle Sizes

A comparison of the different particle sizes was made in the gasifier compartment of shallow bed, as can be seen in *Fig. 6*. None of the sizes showed a quantitatively good fluidization quality. It was also observed that smaller size particles had a tendency to show through channelling, while larger ones show intermediate channelling. Therefore, the increasing of size in diameter would result in a high propensity of intermediate channelling to occur in shallow bed. This is because smaller size particle diameter leads to a less porous bed, leading to a more complex bed structure, and making it more difficult to fluidize and less bed expansion compared to larger size particles.

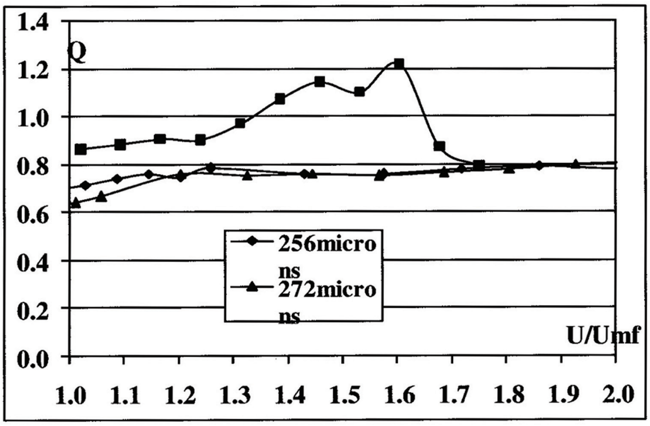

Fig. 6: Fluidization quality, Q versus U/U_{mf} at different particles size (free area = 0.27%, H/D = 0.78, D_e = 0.257m)

The Effect of Aspect Ratio

Fig. 7 shows the fluidization quality in relation to different aspect ratios, using river sand at the distributor free area of 0.27% and a diameter of 0.257m. As can be observed from the graph, no distinctive differences are discernible in progression of the aspect ratio. The average quality which can be obtained over the range of the aspect ratio is approximately 0.8.

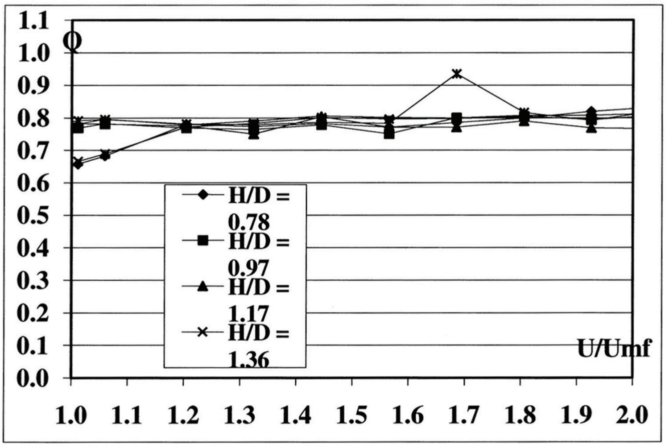

Fig. 7: Fluidization quality, Q versus U/U_{mf} at different aspect ratios (river sand, free area = 0.27%, D_e = 0.257m)

CONCLUSION

The study was carried out to investigate the fluidization quality in the expanded CFBG cold model. One can summarize the findings as below:

1. The expanded CFBG cold model, which results in a bigger combustor compartment (D_e = 0.413m), does not achieve the desirable quality of fluidization, even when the diameter is bigger than the minimum allowable effective diameter (D_e = 0.290m), as obtained in the previous cold model.
2. The effects of different distributor free areas, different particles used, different particle sizes and different aspect ratios to the fluidization quality were also tested; the results showed similar results for all, i.e. the occurrence of channelling was consistent in both compartments.

The effect of the minimum allowable effective diameter on fluidization quality in the CFBG and the interplay of geometric and operational parameters invite further study. In addition, the fluidization quality of the binary mixture is currently under investigation.

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