Effects of draft tube height on solid circulation rate and particle residence time in a RCFB

Babu J Alappat* & V C Raneb*

* Centre for Environmental Science and Engineering, Indian Institute of Technology, Powai, Bombay 400 076, India
b Department of Chemical Engineering, Indian Institute of Technology, Powai, Bombay 400 076, India

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Recirculating fluidized bed (RCFB) is a modified form of conventional spouted/spout-fluid bed with a central draft tube/riser tube to contain the spout1. This overcomes the inherent limitation on the maximum spoutable height of the spouted/spout-fluid beds as the maximum spoutable height becomes limited only by the energy of the gas stream entering the bottom of the draft tube2. The use of the draft tube allows accurate control of gas and solid residence time as there is no short circuit between the spout and the annulus. The desired solid circulation rate and particle residence time can also be achieved by adjusting different parameters as reported by Yang and Keairns3. Solid circulation has been studied in detail as it is a critical variable in predicting the performance of a RCFB system2,4-7. According to Yang and Keairns3, the draft tube height affects the solid circulation rate in a RCFB. But La Nauze5 reported that solid circulation was not affected by the length of draft tube or height of bed above it. In that study, the draft tube was short and also the full length of the draft tube was submerged under solids. In a case where draft tube is relatively longer and is not submerged with solids, i.e., when the downcomer bed level is below the draft tube top, height of the draft tube may affect the solid circulation rate.

Experiments have been carried out on a RCFB with different draft tube heights to study its effect on solid circulation rate and particle residence time. This helps in the selection of suitable height for the draft tube of RCFB.

Experimental Procedure

Experiments were carried out on a semicircular, transparent RCFB made of perspex (Fig.1). Madras sand of mean particle diameter 1540 μm (passing through 1680 μm sieve and retained on 1400 μm sieve) and specific gravity 2.6643 was used as bed material. Solid circulation rate and particle residence time were estimated as described by Alappat and Rane8-9. Solid circulation rates were calculated from the amount of solids accumulated over the flap of a butterfly valve when it was closed suddenly for known intervals of time. Particle residence time in the downcomer (t_{pd}) was calculated from the operating downcomer bed height and average particle velocity (estimated using coloured tracer particles) in the downcomer bed. Particle residence time during upward transport (t_{pu}) was calculated from the solids holdup in the draft tube and the measured solid circulation rate. Overall operating voidage in the draft tube was estimated from the true volume of particles settled in the draft tube when the air supply was cut off suddenly using a quick opening/closing valve (Fig.1) and the volume of expanded bed during operation.
1.0 - 2.6 kg
1.5 - 4.7 kg
3.0 - 6.5 kg


Table 1—Experimental details

| Jet diameter | 4 cm |
| Draft tube diameter | 4 cm |
| Area ratio of downcomer and draft tube | 3.59 |
| Draft tube superficial air velocity ($V$) | 11.36 - 15.83 m/s |
| Clearance between perforated plate and draft tube bottom ($x$) | 2.2, 4.0 and 5.2 cm |
| Draft tube height ($H$) | 1.0, 1.5 and 2.0 m |
| Solid inventory | |
| for 1.0 m draft tube height | 1.0 - 2.6 kg |
| for 1.5 m draft tube height | 1.5 - 4.7 kg |
| for 2.0 m draft tube height | 3.0 - 6.5 kg |

Draft tube height ($H$) was varied by attaching sections of length 50 cm. Clearance between draft tube bottom and perforated plate ($x$) was varied using different spacer sections. Details of the set-up and experiments are given in Table 1. The downcomer of the RCFB was not aerated separately. The downcomer bed level was considerably below the top of draft tube even with maximum solid inventory tried.

Results and Discussion

The effects of varying draft tube height for different clearances, draft tube superficial air velocities and operating downcomer bed heights on solid circulation rate, particle residence time in the downcomer and particle residence time during upward transport are discussed here.

Effects on solid circulation rate — Solid circulation rates for clearances 2.2, 4 and 5.2 cm, for different combinations of draft tube superficial air velocity, draft tube height and operating bed height in the downcomer were determined. Fig. 2 shows the trends of variation of solid circulation rate with downcomer bed height for clearance 2.2 cm. Curves for clearances 4.0 and 5.2 cm are similar to that of clearance 2.2 cm but have higher slopes.

For any combination of clearance $x$, draft tube height and velocity $V$, solid circulation rate was found to increase with downcomer bed height (inventory of solid). As the downcomer bed height increases, pressure at the bottom of the downcomer also increases. This enhances the solids movement from the downcomer to the draft tube. But the degree of increase of circulation rate with downcomer bed height is different for different clearances. Clearance 2.2 cm gave relatively lower increase than clearances 4.0 and 5.2 cm because the small clearance between
the draft tube bottom and perforated plate offers relatively higher resistance for the solids flow at the draft tube bottom entrance. With larger \( x \), circulation is smooth and hence the higher increase of solid circulation with increase of downcomer bed height. This is clear from the slopes of curves. Slopes of the curves, \( S_x \) in terms of their magnitudes are \( S_{2.2} < S_{4.0} < S_{5.2} \).

For any combination of \( x \), draft tube height and solid inventory, solid circulation increased with the draft tube superficial air velocity in the range of velocities tested. Increase in the jet air velocity enhances the entrainment capacity, i.e., solids circulation capacity of the air stream.

For constant \( V \) and \( x \), as the draft tube height was increased, the minimum downcomer bed level required to initiate solid circulation also increased considerably. Hence solid circulation rate at this minimum downcomer bed level was larger for longer draft tube. High downcomer bed level requirement for long draft tube is because of the increase in solids holdup and the pressure drop across the draft tube with the increase in its length. So, for the circulation to occur, higher pressure differential between the draft tube bottom and downcomer bottom is required. This is possible by increasing the downcomer bed height.

Only in few cases it was possible to compare the solid circulation rates for the same downcomer bed height for different draft tube heights keeping other parameters constant. Because in most of the cases, the minimum downcomer bed height required to initiate circulation is greater than the possible maximum downcomer bed height with the immediate lower draft tube height. However, in general, for the same bed height in the downcomer above the perforated plate, solid circulation rate was lower for longer draft tube when other parameters were kept constant. This is because, for the same bed height in the downcomer, the pressure differential available for circulation through the clearance under the draft tube decreases with increase in draft tube height.

Comparing the solid circulation at maximum downcomer bed level possible, draft tubes of height 1.50 and 2.0 m did not show much difference. However, circulation rate obtained for draft tube of height 1.0 m at this downcomer bed level was considerably lower than the other two.

Effects on particle residence time in downcomer — Residence time of particles in the downcomer bed \( (t_{pd}) \) for clearances \( x = 2.2 \) cm and 4.0 cm for various combinations of draft tube height, \( V \) and downcomer bed height are given in Figs 3 and 4. Curves for clearance 5.2 cm are similar to that of clearance 4.0 cm. For fixed \( x \), draft tube height and downcomer bed height, \( t_{pd} \) increased with decrease in draft tube superficial air velocity. This is because of the decreased solid circulation rate while reducing \( V \). For the same \( V \), \( t_{pd} \) increased with increased draft tube height. This is because, with longer draft tube higher downcomer bed level was required for solid circulation.
Actually when the downcomer bed level increases, the solid circulation increases and also the particle velocity in the downcomer. At the same time particles will have to pass through longer distance. So, variation of $t_{pd}$ is a balance between increased particle velocity and increased distance to travel. Also, increase of the particle velocity in the downcomer with respect to increase of downcomer bed height is different for different clearances as in the case of solid circulation rate. With small clearance the increase of particle velocity in the downcomer will be lesser than that for higher clearances. This is why with $x = 2.2 \text{ cm}$ (Fig.3) $t_{pd}$ increased with downcomer bed height, where as, with $x = 4.0 \text{ cm}$ (Fig.4) and $5.2 \text{ cm} t_{pd}$ decreased with downcomer bed height.

For clearance $x = 2.2 \text{ cm}$, with maximum permissible solid inventory in the unit (the maximum permissible solid inventory limit in each case was set by the level of the butterfly valve), the minimum draft tube superficial air velocities required for maintaining solid circulation were 11.36, 12.13 and 12.70 m/s for draft tube heights 1.0, 1.5 and 2.0 m, respectively. The $t_{pd}$ for 1.0 m long draft tube when operated at this minimum velocity was longer than that for the other two operations at corresponding minimum velocities.

For clearance $x = 4.0 \text{ cm}$, the minimum draft tube air velocities required for maintaining solid circulation were 12.13, 12.70 and 13.36 m/s for draft tube heights 1.0, 1.5 and 2.0 m, respectively. In this case also longer $t_{pd}$ was shown by draft tube of height 1.0 m.

For clearance $x = 5.2 \text{ cm}$, the minimum draft tube air velocities required for maintaining solid circulation were 12.70 m/s for draft tube height 1.0 m and 13.36 m/s for draft tube heights 1.5 and 2.0 m. Here longer $t_{pd}$ was shown by draft tube of height 2.0 m than the other two.

In all the three cases at varying clearances, it was draft tube of height 1.5 m which gave shorter $t_{pd}$ than the other two though it was possible to operate the system with this draft tube at velocities lower than that required for draft tube of height 2.0 m. So, $t_{pd}$ is a balance between the speed of the particle according to the solid circulation rate and the bed depth to travel.

Effects on particle residence time during upward transport — Residence time of the particles during their upward transport ($t_{pr}$) for clearance 2.2 cm for various combinations of draft tube height, $V$ and downcomer bed height is given in Fig.5. Similar trends are obtained for clearances 4.0 and 5.2 cm. However, slopes of the curves for these clearances are higher than that for clearance 2.2 cm.

The $t_{pr}$ was found to be decreasing with increasing downcomer bed height (solid inventory) when other parameters were kept constant. Similarly, $t_{pr}$ decreased with increasing $V$. In both cases solid circulation rate increased increasing particle velocity in the draft tube.

For clearances 2.2 and 4.0 cm, comparing $t_{pr}$ at different draft tube heights for the same $V$, $t_{pr}$ for draft tube of height 1.5 m were smaller than that for the other two draft tube heights. Among the other two, it was draft tube height 1.0 m that showed longer $t_{pr}$. However, for $x = 5.2 \text{ cm}$, it was draft tube of height 1.0 m that showed shorter $t_{pr}$ than the other two. Draft tube height 2.0 m gave longer $t_{pr}$.

For any clearance, the $t_{pr}$ at the minimum draft tube superficial air velocity which can cause solid circulation in the system is longer with draft tube of height 1.0 m than the other two. Among 1.5 and 2.0 m heights, it was 2.0 m long draft tube that showed longer $t_{pr}$.

Conclusions

In a RCFB, height of the draft tube affects the solid circulation rate when the draft tube is not submerged, i.e., when the downcomer bed level is below the draft tube top. Selection of suitable height for the draft tube depends on the residence time requirements also.

References