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Study of Solids and Gas Distribution in Spouted Bed Operated In Stable and Unstable Conditions

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Abstract
A spouted bed is a special case of fluidization. It is an effective means of contacting gas with coarse solid particles. Spouted beds should be designed and operated to overcome performance instability and improves the uniform distribution of particles. Steady-state measurements were carried out in the 0.152 m ID cylindrical spouted bed made of Plexiglas that used 60° conical shape spout-air bed. The evaluation of solid and gas holdup in the two regions of spouted bed at stable and an unstable condition was performed using optical probe. The comparison of the radial profiles at the two conditions showed that the variation was in the spout region. The annulus region had similar profiles in both the condition as it acts as a loose packed bed, moving slowly downward. Stable bed was obtained at low gas velocity of 0.74 m/s and instability of spouting was observed at high gas velocity of 1.4 m/s.
The beads can fluidize homogenously at stable conditions, while pulsation of the bed was appeared at unstable spout. Different flow regimes and characteristics can be obtained with minor variations in geometry or operating conditions.
Keywords: Annulus; Fluidization; Solids; Spout; Stability

I. Introduction

Gas-solid spouted beds are either cylindrical bed with cone base or the whole bed is in a cone shape where the gas enters as a jet. The gas forms a spout region that carries the solids upward in a diluted phase, which forms a fountain at the top of the bed where the solids fall down and move downward in the annular region. Among several configurations typical of gas-solids fluidization, spouted beds have demonstrated to be characterized by a number of advantages, namely a reduced pressure drop, a relatively lower gas flow rate, the possibility of handling particles coarser than the ones treated by bubbling fluidized beds.Additionlly,significant segregation is prevented by the peculiar hydraulic structure. A spouted bed can be realized by replacing the perforated plate distributor typical of a standard fluidized bed with a sample orifice, whose profile helps the solids circulation and voids stagnant zones. When the gas flow rate is large enough, the spout reaches the bed surface and forms a "fountain" of particles in the free board. After falling on the bed surface, the solids continue their downward travel in the "annulus" surrounding the spout and reach different depths before being recaptured into the spout (Rovero etal., 2012).

There is increasing a application of spouted such as; coating, desulfurization, CO2 capture, combustion and gasification of coal and biomass (Limtrakuletal.,2004).The spouted bed is a kind of high performance reactor for fluid-solid particles reaction, also it is a hybrid fluid-solid contacting system (Wang etal.2001). Standard deviation of pressure fluctuation was calculated at minimum spouting velocity and at a velocity corresponding to transition from stable spouting to unstable spouting condition. It is shown that standard deviation of pressure fluctuation and PSD varies with various spouting gases and seen to follow a trend with Archimedes number of a given gas–solid system (mollick and Sathiyamoorthy ,2012).

Stable spouting condition is characterized by stable spout and fountain formation in the spouted bed. Unstable spouting condition is characterized by swirling, pulsating and periodic movement of fountain with time in the spouted bed. Such pulsating and periodic movement of fountain may change the flow dynamics and in turn, affect the process (Zhong etal. 2007).Figure 1 explains the flow regime map of stable and unstable regions in a spouted bed (He et al., 1997).

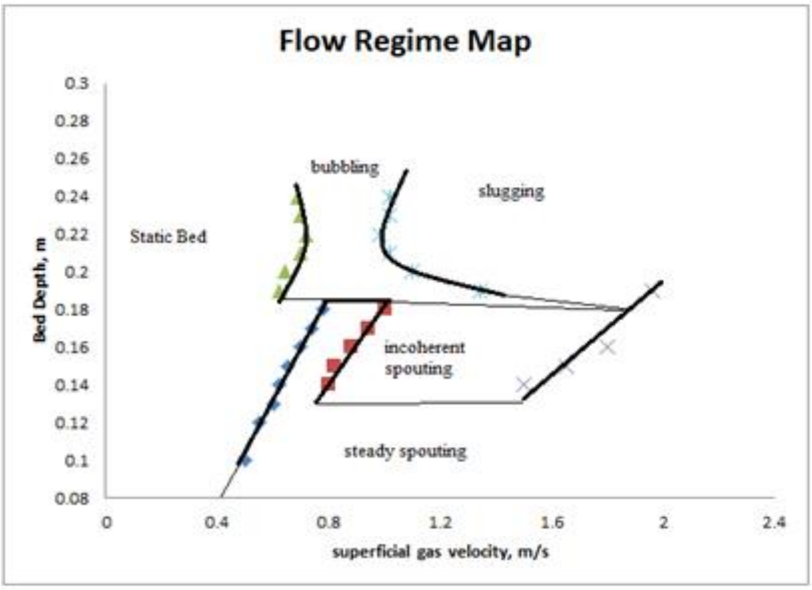


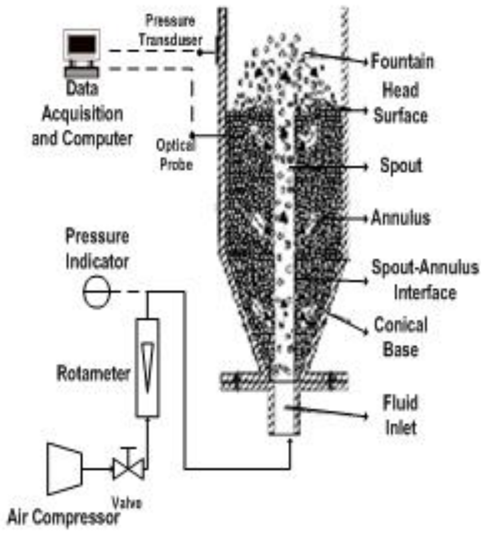
Fig.1. Flow regime map (He et al., 1997).

Stable operation of spouted bed is always advisable to achieve homogeneous solid circulation, thereby heat, and mass transfer. In conventional spouted bed, the stability generally refers a bubble and slug free bed with a straight and pulsation free spout region above the inlet orifice (Deepa etal. 2013).

The present work is devoted to investigation on study the distribution of solids and gas in the spouted bed at stable and unstable conditions using sophisticated newly developed optical probes. Analyzing the solids and gas distribution in the two different regions of spouted bed at stable and unstable conditions.

II. Experimental set-up

The experimental set-up was designed and constructed in the best way to collect the data as shown in Figure 1a.Figure 1b illustrates the 0.152 m ID cylindrical spouted bed is made of Plexiglas. At the bottom of the bed, there is a 60° cone-shaped Plexiglas base of 0.075 m in height. The spouting nozzle (6.25 mm in diameter) locates in the center of the conical base.The gas phase was compressed air supplied from an industrial scale air compressor. Glass beads of 1 mm in diameter was used as solids with density of 2450 Kg/m3. The gas velocity used in the current experimentation was 0.74 m/s (stable spouting regime) and 1.4 m/s (unstable spouting regime).The measurements were taken at 3 different axial heights of H/D = 0.8, 1.5 and 2.5. initial bed height was 0.16 m for both the conditions.



(a)

(b)

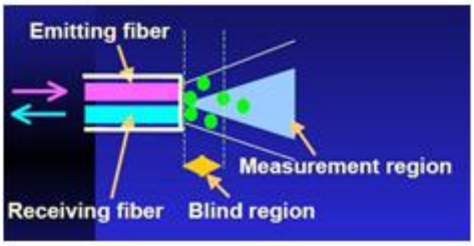


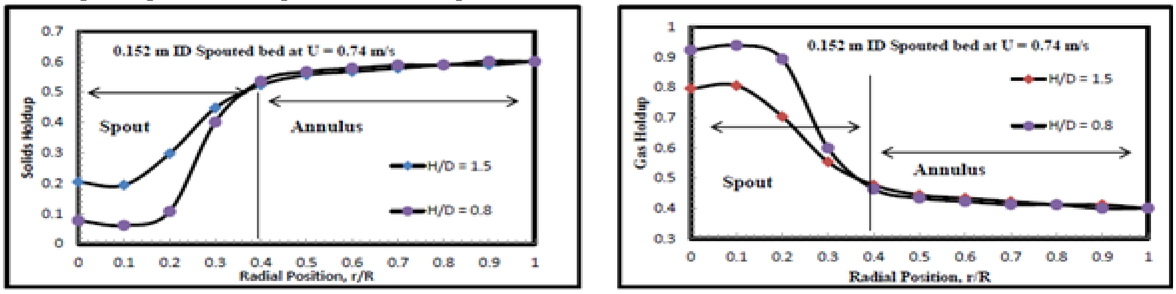
Fig. 2.Experimental set-up. **(c)**

The optical probe (Figure 2c) is used to measure both solids hold up and solids velocity and their fluctuation at radial and axial positions of the spouted bed.Calibration method is used to obtain a relation of voltage (generated by the optical probe) and solids holdup.

The hold up of solid particles are measured by the Particle Analyzer (PV6) which manufactured by the 'Institute of Chemical Metallurgy, Chinese, Academy of Science') .It consists of; photoelectric converter and amplifying circuits, signal pre-processing circuits, high-speed A/D interface card and its software PV6, is adapted to the optical probes. The pressure in the spouted bed adjusting within the desired values by using the inverted circular stabilizer, 60 mm in diameter is installed at the top of the bed column. This is preventing the spout fountain from swaying.

III. Result and Discussion

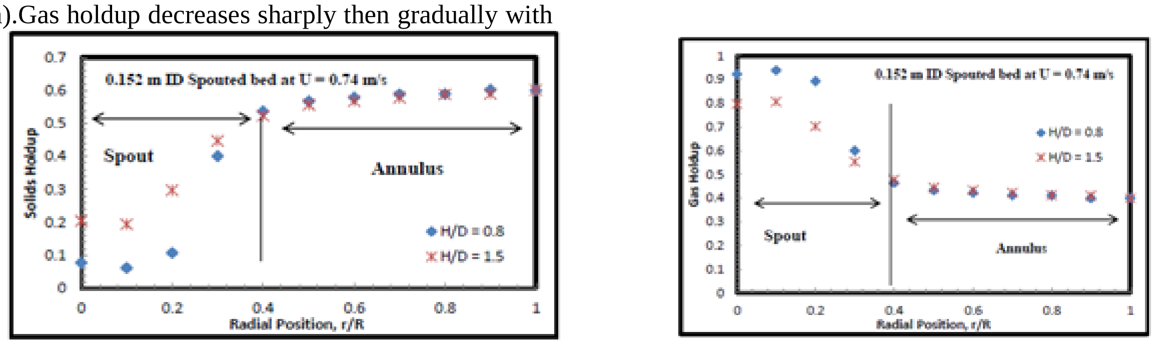
The solids are picked up at the inlet by the gas phase (which comes in as a jet) and are carried to the top as shown in Figure 2. The gas forms a spout region that carries the solids upward in a diluted phase that forms a fountain at the top of the bed where the solids fall down and move downward in the annular region.



(a) (b)

Fig.3. Solids and Gas Holdup at different heights of spouted bed.

The solids holdup at the inlet is low, increases sharply and gradually with increasing H/D, and finally reaches the average value of 0.6 as it reaches the spout-annulus interface. Solids holdup is maximum at the center of the spouted bed for different flow regimes. The solids holdup in the annulus is constant throughout. Annulus acts as a slowly moving loose packed bed, downwards (Figure 3a).Gas holdup decreases sharply then gradually with increasing H/D, and finally reaches the average value of 0.4 at the spout-annulus interface and then remains constant in the annulus region (Figure 3b). Different flow regimes and characteristics can be obtained with minor variations in geometry or operating conditions.The trend reported is in agreement with the results reported in the literature (Zhong etal. 2007).



(a) (b)

Fig.4. Solids and Gas Holdup of Stable Spouting Conditions, U = 0.74 m/s.

Figure 4 illustrates the distributions of solids and gas hold up at stable conditions. Due to stability conditions, the scattering in the experimental data at spout region is low for both solids and gas hold up as shown in Figures 4a and 4b. The stability conditions were appeared in the behavior of the system since the beads in the bed fluidized homogenously. The homogeneity and stability of solid particle observed at low velocity of 0.74 m/s.Decreasing of gas velocity can promote the stability, uniformity of solid particles across the spouted bed (Alwan, 2012).

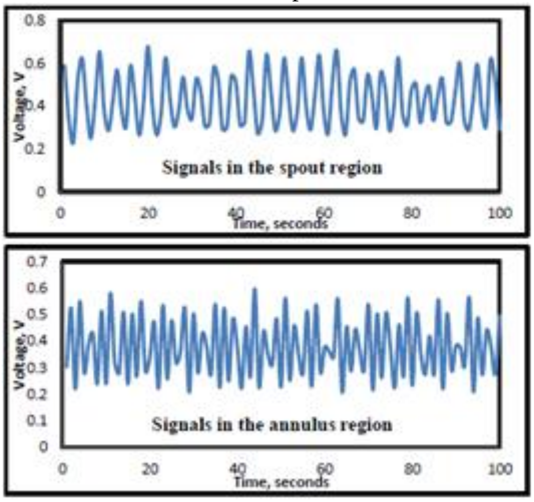
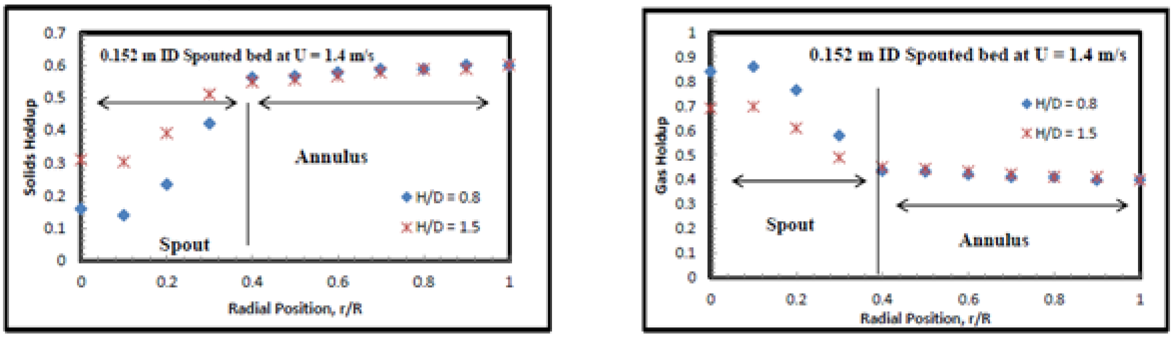


Fig.5.Op signals at stable conditions

Low fluctuations were observed in signals of optical probe at stable conditions as shown in Figure 5.The magnitude and intensity of the voltage fluctuations generated from the optical probes depend on the solids in front of the probe. In spout, the solids holdup is less and hence the voltage generated by the probe lesser fluctuations in terms of magnitude and frequency. The peaks in the signal obtained (Figure 5) correspond to the solids particle reflecting the light and the minima are by the void/air.

In the annulus, the solids move as a loose packed bed and the fluctuations generated by the optical probes is high in magnitude and frequency. Natures of the signals generated also indicate the region of spouted bed being measured. Stability of bed improves the uniformity of solid particles and then enhances heat and mass transfer through the spouted.



(a) (b)

Fig.6. Solids and Gas Holdup of Unstable Spouting Conditions, U = 1.4 m/s.

Unstable spouting is characterized by swirling and pulsation of spout. It was found that flow instabilities can obtained at high spouting gas velocity (Xu etal. 2009) of 1.4 m/s as shown in Figures 6a and 6b. High scattering and fluctuations in experimental data were observed at spout region (Figure 7).Annulus region is still stable for different operating conditions.

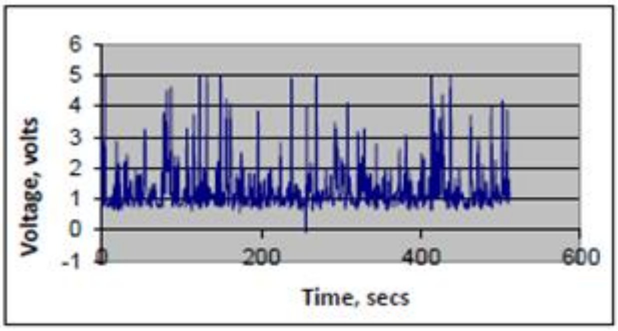
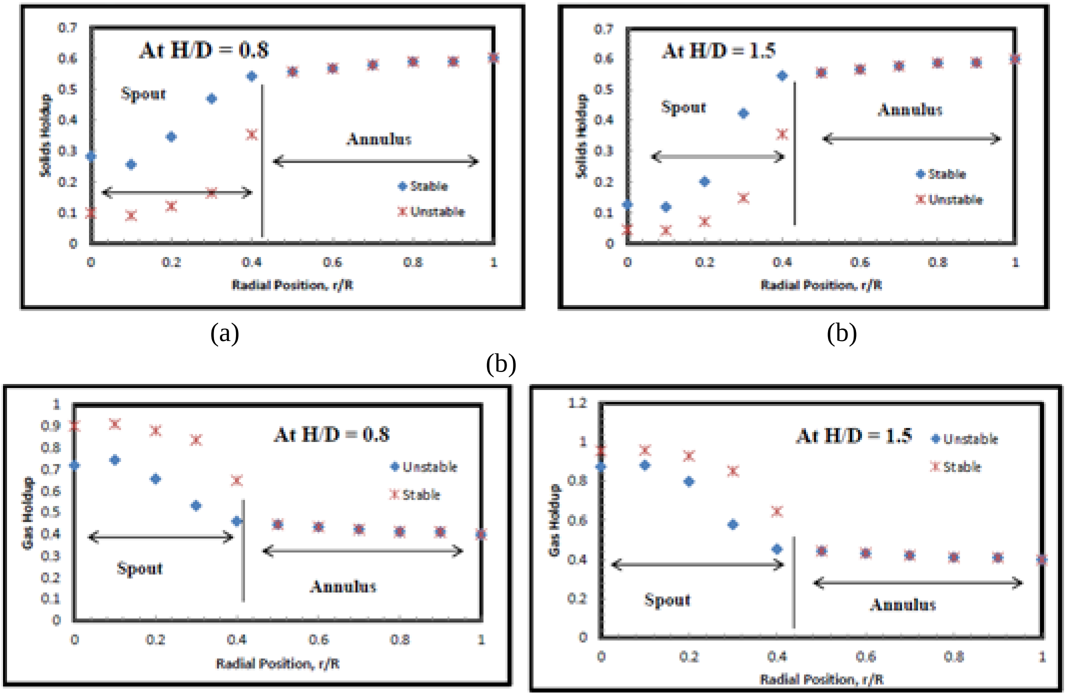


Fig.7.Op signals at unstable conditions in the spout region



(c) (d)

Fig.8. Comparison of Stable and Unstable Spouting Conditions.

The comparison between stable and unstable spouting conditions were explained in Figure 8. At H/D = 0.8, the overall percentage difference between the two profiles is 66.6%. At H/D = 1.5, the overall percentage difference is 54.3%. The annulus had similar profiles due to its nature of moving as a loose packed bed.

It can be seen that the hold up of solids and gas hold up of instable flow (1.4 m/s) in the spouted region is smaller than that of stable flow (0.74 m/s) for different H/D as shown in Figure 8.This indicated that large spouting gas enter into than annular region at instable flow. The spouting gas is poor mixed in the instable flow.

IV. Conclusions

Stable operation of spouted bed is provide uniformity of solid beads, thereby heat, mass transfer and reaction. Solids holdup has maximum value at the center of the spouted bed for different flow regimes and different positions. The solids holdup in the annulus region is constant throughout. Stable bed was obtained at low gas velocity of 0.74 m/s, while instability of spout was observed at high gas velocity of 1.4 m/s.It can be seen that the hold up of solids and gas hold up of instable flow in the spouted region is smaller than that of stable flow for different positions.

The annulus region had similar profiles in both the condition as it acts as a loose packed bed, moving slowly downward. Reasonable agreement has been obtained when compared the experimental results with previous work.

V. Acknowledgments

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