

STABILITY ANALYSIS OF DRAFT TUBE SPOUTED BED USING PRESSURE FLUCTUATION ANALYSIS

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ABSTRACT

Spouted bed is widely used in number of industries such as food, pharmaceuticals, petrochemicals, fertilizer, waste treatment, gasification etc. Spouted bed is particularly very useful in efficient drying, coating, mixing, granulation and catalytic conversion for its unique hydrodynamics which favor good heat and mass transfer. Use of draft tube in spouted bed adds further advantage to manipulate solid circulation rates and also leads to favorable hydrodynamics. Experiments were carried out at different gas flow rates in a draft tube spouted bed using argon and nitrogen as spouting gases at various bed heights and draft tube bottom clearances. Experiments were aimed to determine the condition at which stability is achieved. Standard deviation of pressure fluctuation is obtained to determine the stable spouting velocity and draft tube bottom clearance for various draft tube size. Findings report here critical aspects to achieve higher stability in draft tube spouted beds.

Keywords: Spouted bed, draft tube, stability, pressure fluctuation

1. INTRODUCTION

Fluidization is the operation by which solid particles are transformed into a fluid like state through suspension in a gas or liquid. Fluidization is effective for Geldart-A and B type particles. For Geldart-D type particles, fluidization becomes difficult as it gives large exploding bubbles or severe channeling. For countering the poor quality of fluidization with uniformly coarse particles, spouted bed is seen to perform well. The performance of conventional spouted bed is seen to be improved by inserting a draft tube in place of spout region which gives way to greater flexibility in the operation, lower gas flow and pressure drop, solids of any size or nature may be treated, narrower residence time distribution, better control of solid circulation, avoids maximum spoutable bed height and a better control of solid circulation.

Draft tube in spouted bed is typically a mechanical separator between annulus and

spout. Conventional draft tubes are cylindrical in shape and placed at the centre of the bed starting from immediately above the gas inlet nozzle and can be extended up to desired heights. The gap between gas inlet nozzles to the bottom of the draft tubes is known as draft tube clearance which is a significant parameter to control solid circulation rates and thereby heat and mass transfer. Studies on Draft Tube Spouted Bed (DTSB) in last few years report parametric effects of various draft tube configurations in DTSB hydrodynamics.¹

The applications of DTSB in various fields have been reported in the literature. DTSB is used for drying different types of suspensions^{2,3}, in flue gas desulfurization process⁴, as catalytic coal gasifier to produce H₂⁵ etc.. Dynamic models of DTSB have been developed to study the residence time distribution of fluids in annulus^{6,7,8}, effect of operating conditions⁹, reduction of spouted bed drying time etc when it is used as dryer^{10,11}, sensitivity of variables

like gas and particle velocities and voidages in the spout region for a draft tube spouted bed with bottom particle feed¹².

Stable operation of spouted bed is always advisable to achieve homogeneous solid circulation and 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. For the case of DTSB, achieving a straight and pulsation free spout is quite easy as it is thoroughly guided by the mechanical separator named as draft tube. However, the formation of bubbles and thereby slugging near to the bottom of the Draft Tube (DT) is sometimes unavoidable unless interior of the DTSB is properly designed. In order to design interior of a DTSB major design parameters are diameter of the DT and the DT clearance. Over and above, the formation of slug followed by formation of bubbles significantly dependent on the particle size, particle density, static bed height, choice of spouting gas, superficial gas velocity and the cone angle of the apparatus¹.

The aim of our present investigation is to find out the criteria for stable spouting in DTSB using pressure fluctuation analysis. The pressure fluctuation analysis which is believed to be a good technique to analyze various spouting zones¹³ is applied here to

find out stable spouting zone for DTSB. The pressure data which are collected at a frequency of 100 Hz was subjected for statistical analysis and standard deviation of the fluctuation was calculated so as to delineate stable spouting operation in DTSB. The studies were carried out for four important parameters, namely, DT diameter, DT clearance, static bed height, spouting gas velocity and the choice of spouting gas.

2. EXPERIMENTAL

A schematic of the experimental set up is shown in figure 1. The dimensions of the spouted bed apparatus used in the experiments are provided in table 1. The spouted bed apparatus is made of transparent acrylic material to visualize spouting phenomena and particle flow in DTSB. The material of construction of the DT is polyethylene (hard) which was suspended from the top of the bed. The draft tube placement and movement were accomplished manually. Dimension of the DT is also given in table 1. Spherical zirconia microspheres of 500 μm size were used as bed material and argon and nitrogen were used as spouting gases. A dynamic pressure sensor was attached about 20 mm below the gas inlet nozzle of the apparatus.

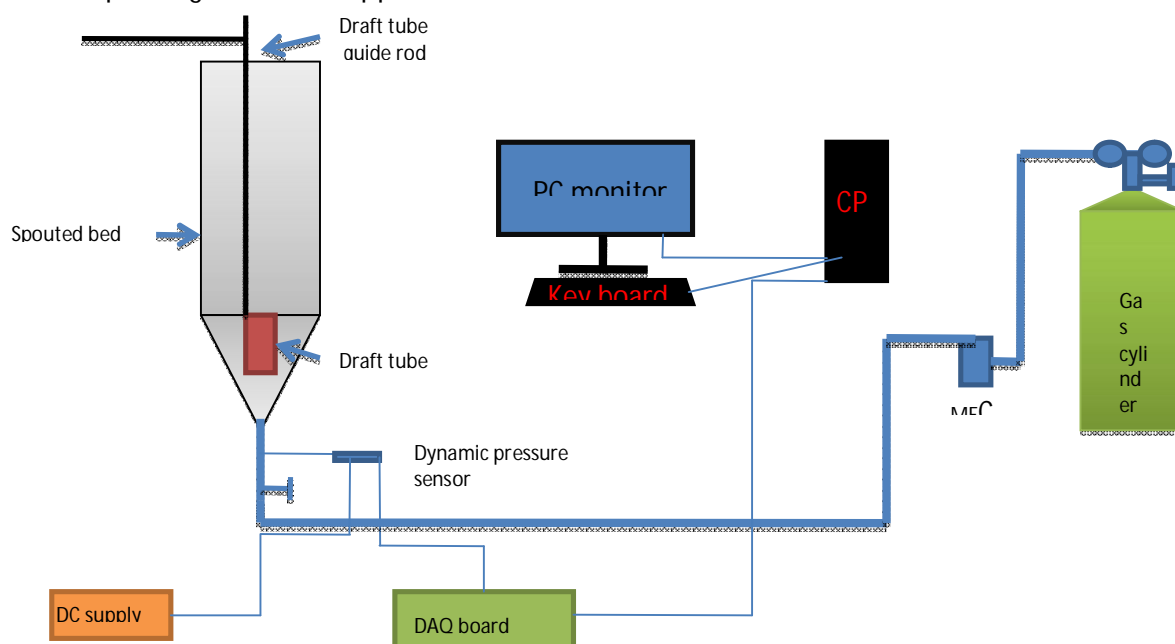


Fig. 1: Schematic of experimental set up

Experiments were performed as per the parameters listed in table 2. The spouting gas flow through the orifice was measured and controlled by a mass flow controller (MFC). Measured quantity of the bed material was charged from the top of the apparatus and the position of the DT was

Table 1: Dimensions of the draft tube spouted bed column

Dimension	
Height of the cylindrical section	400 mm
Height of the conical section	55 mm
Cylindrical diameter	60 mm
Cone angle	4 mm
Diameter of inlet nozzle	8 mm
Diameter of draft tube (1)	8 mm
Diameter of draft tube (2)	6 mm
Height of draft tube	

Table 2: Experimental parameters

Draft tube diameter	Bed height	Clearance
6, 8 mm	40 mm	15 mm
	48 mm	15 mm
	60 mm	15 mm
	48 mm	13 mm
	48 mm	15 mm
	48 mm	17 mm

3. RESULTS AND DISCUSSION

Average pressure drop and the standard deviation of the pressure fluctuation were calculated from the raw data collected from the dynamic pressure sensor for all the experiments. Key findings from the experiments are reported and discussed below.

From figure 2 it can be shown that after a particular superficial gas velocity (close to $U = 20$ m/s), standard deviation of pressure fluctuation does not change significantly and follows the same trend for various bed heights indicating insignificant effect of bed heights on stability of draft tube spouted bed (DTSB). However before a particular gas velocity, the standard deviation appears to change dramatically and it is highly affected by bed height. It is also seen that commencement of relatively stable spouting occurs at a lower gas velocity for higher bed height and vice versa. This could be due to higher solid pressure for higher bed height which favors draft tube spouting at relatively lower gas velocity and vice versa. At the commencement of spouting,

adjusted as required. Spouting phenomena for a wide range of spouting gas velocities was studied and the pressure fluctuation data was collected at a rate of 100 Hz in each case. Pressure fluctuation data was subject to average pressure drop and standard deviation calculation.

standard deviation value is seen to be higher for bed height of 48 mm. This may be due to the maximum possible counter interaction between gas and solids at the interface between DT clearance and annulus. At lower bed height, solid pressure is low and hence standard deviation is found to be low. At higher bed height, solid pressure is high and hence standard deviation is high.

From figure 3, it can be seen that average pressure drop increases continuously with gas velocity irrespective of bed height. Until stable spouting is observed, the standard deviation of the pressure fluctuation is non-linear and it shows a linear variation at relatively higher gas velocity.

From figure 4, it is evident that draft tube clearance has a significant effect on the spouting stability. When draft tube clearance is low, the solid flow from the annulus into the draft tube is constricted. At lower gas velocity, the solid flow is further hindered. However, at higher gas velocities, the hindrance in the radial direction is less and hence spouting is smooth with high solid circulation rate. If the clearance is very high, the solid particles will fill up the area between the gas orifice and the draft tube, thereby rendering the situation akin to conventional spouted beds and hence the standard deviation of pressure fluctuation is high. The critical draft tube clearance for the experimental setup has been evaluated to be 15 mm at which the fluctuation in the pressure drop as well as the average pressure drop is less.

As can be seen in figure 5, at lower clearance, the population of the particles inside the draft tube at any instance is low resulting in the particles being pushed along the wall of the draft tube which results in an increase in the average pressure drop and vice versa.

The effect of DT diameter does not show prominent variation in average pressure drop and standard deviation as seen in figure 2-5. However, for a smaller diameter of the DT average pressure drop does not vary much for varying DT clearance. This may be due to the lower population of the particles in a smaller diameter DT which causes less pressure drop variation even if the DT clearance is changed.

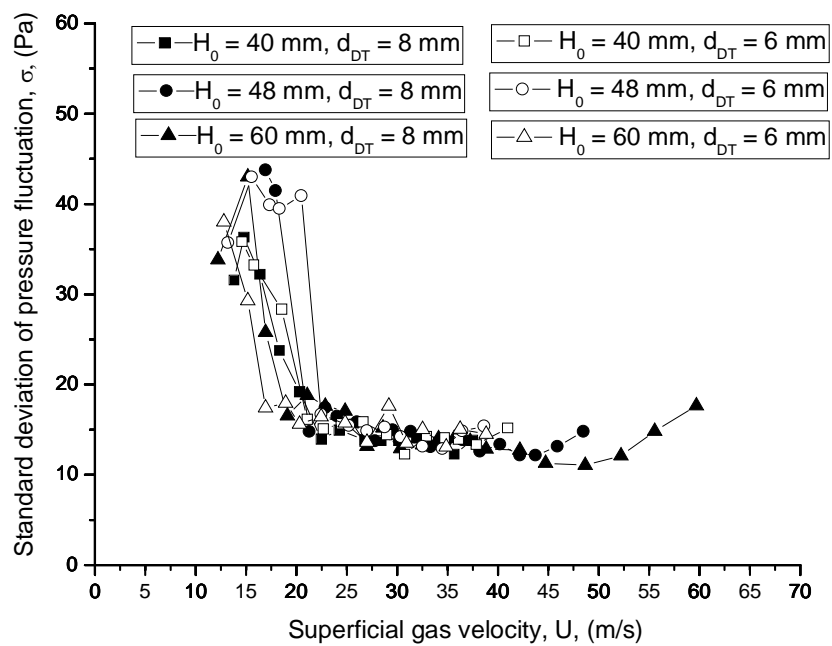


Fig. 2: Variation of standard deviation of pressure fluctuation with superficial gas velocity

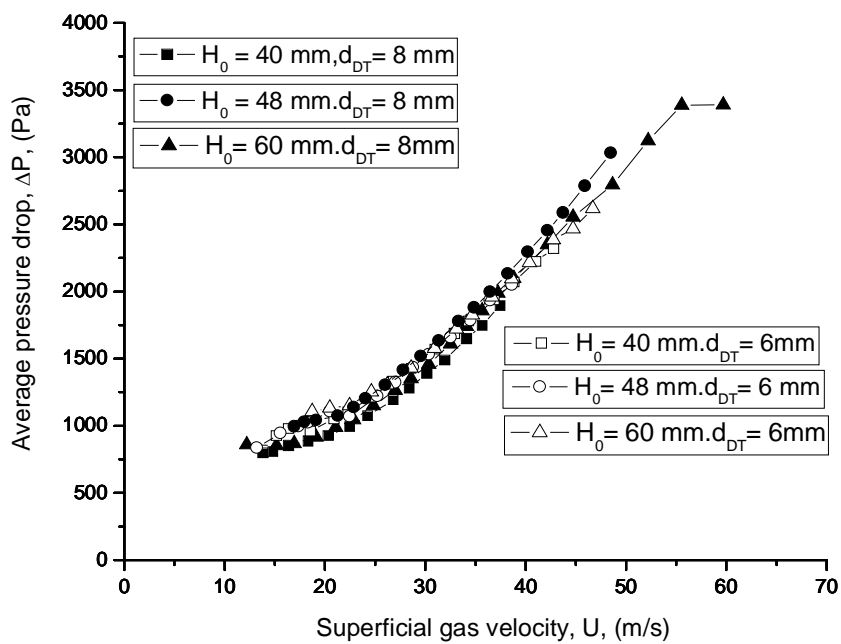


Fig. 3: variation of average pressure drop with superficial gas velocity

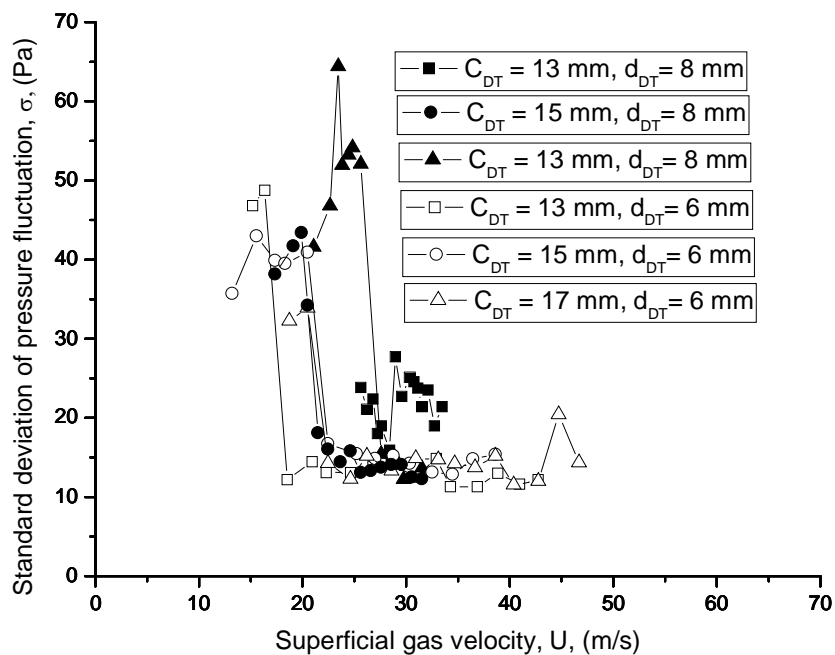


Fig. 4: Variation of standard deviation of pressure fluctuation with superficial gas velocity

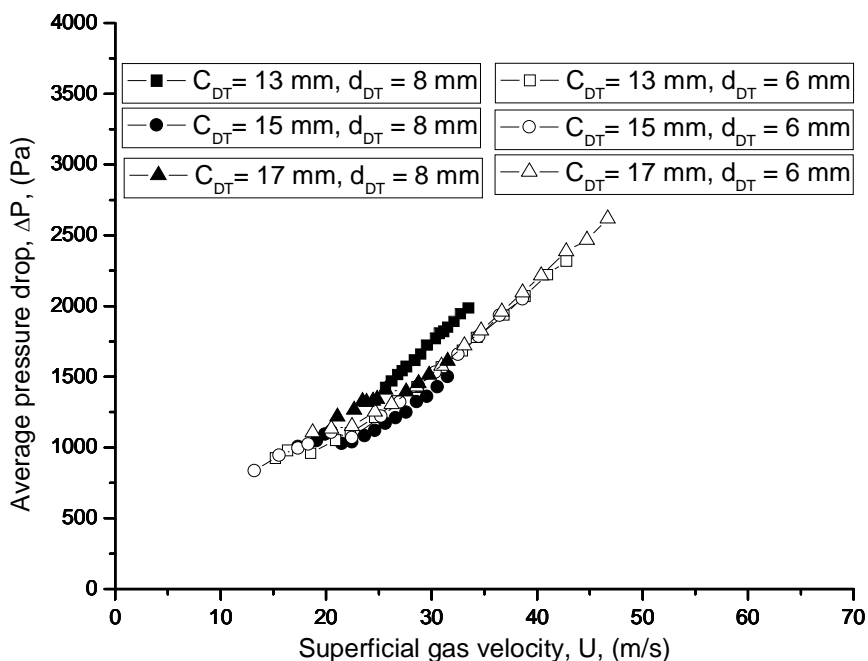


Fig. 5: Variation of average pressure drop with superficial gas velocity

4. CONCLUSION

Stability of the DTSB is successfully studied for two DT sizes and various DT clearances with different static bed heights. Stability analysis using pressure fluctuation technique for a range of gas velocity along with proper DT configuration is confirmed. Critical DT clearance is observed for stable operation of spouted bed. Present study would help in judgment of DT confirmation and DT clearance to establish a stable spouting condition in DTSB.

Nomenclature

C_{DT} – Draft tube clearance (mm)
 d_{DT} – diameter of draft tube (mm)
 DT - draft tube
 DTSB – draft tube spouted bed
 ΔP – average pressure drop (Pa)
 σ – standard deviation of pressure fluctuation (Pa)
 U – Superficial gas velocity (m/s)
 H_0 – bed height (mm).

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