Attenuation of disturbances using packed bed of nanoparticles

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ABSTRACT

The attenuation of disturbances and shocks is quite important as well as challenging task in a variety of situations. In the present work, the attenuation of disturbance through a packed bed of ultrafine nano-powder that possesses a high degree of void fraction is investigated. Using fast response pressure transducer of response time of 1 ms, both global and local pressure transients were monitored while the packed bed was subjected to flow pulsation of different frequencies. While the local pressure transients show a ten-fold increase in the pressure signal due to the velocity disturbance, the global pressure transients are however quite subdued hardly showing a two-fold increase than that recorded for the steady state pressure drop case. This aspect of the packed bed of nano-powders can be effectively utilized for the attenuation of disturbances.

Keywords: nano-powder, attenuation, disturbances, pressure transients, packed bed.

1 INTRODUCTION

Ultra-fine powders of hydrophilic nanoparticles of metal oxides, SiO2 for example, exhibit tremendously high porosities, which are as high as 0.98 as compared to 0.40–0.50 normally encountered with beds of micro- or macro-sized solids. While most current large-scale applications of nanoparticles are mainly geared towards utilizing their tremendously high surface area for enhancing surface based rate processes which are often compromised due the agglomeration phenomena, the high porosity aspect of the ultrafine nano-powders however remains unaffected by the agglomeration phenomenon. Since pressure drop is strong function of bed porosity, both in laminar as well as turbulent flow regimes, the existence of high bed porosity ensures extremely low pressure drop. It is shown here that this aspect of the nano-powders coupled with their low minimum fluidization velocity can be effectively utilized for the attenuation of strong disturbances. Since the porosities of the bed of nano-powders is substantially higher than those of granular media composed of bigger-sized solids, the propagation of pressure waves could similarly be significantly different [1].

2 EXPERIMENTAL

Details of the experimental set up are described elsewhere [2]. Due care were taken to ensure elimination of entry effects using high density of 0.20-mm perforation drilled on a 12-mm thick plate distributor, which was preceded by 0.50-m long calming section. As shown in Fig.1, the test section was 1.5-m long and 70-mm internal diameter Plexiglas followed by 0.50-m long and 0.10-m internal diameter disengagement section. Fluctuation free compressed air was available at 85-psig pressure. Its flow was monitored using electronic flow-meter that provided an analog output in the range of 0–5V. As shown in Fig. 2, a two-way normally-open solenoid valve was located between the flow meter and the column. The opening and closing of the valve was controlled using a data acquisition system (DAQ) connected to a laptop running Labview software. The valve opening allowed the abrupt start of the flow of the air through the column while the valve closing ensured an abrupt supply cut-off. The air flow rate was carefully recorded by connecting the output signal of the flow meter DAQ.

Flow pulsation in the inlet air was introduced to the test section of the column (packed bed) at a preset air flow. Three different pulse frequencies, namely 0.25 Hz, 0.10 Hz and 0.05 Hz, were used for introducing disturbances in the bed. A pulse of 0.25 Hz means that the air supply was allowed for the duration of 2 seconds and closed for another 2 seconds. The pressure transients of the bed were carefully monitored using fast response piezo-resistive differential pressure transducers with a response time of 1 ms. Local pressure drop was recorded with pressure ports located 110 mm and 230 mm above the distributor using a sensitive bidirectional pressure transducer, Omega PX163-005BD5V. Its measurement range was ±5 inches of water. The global pressure drop was also recorded using a differential pressure transducer (Omega PX163-010D5V) with a range of 0–10 inches of water. The lower port of the global pressure drop measurement was located immediately above the distributor while the upper port was exposed to the atmosphere. The settled bed height of the bed material was approximately 340 mm. Thus, the upper port of the local pressure drop measurement was always below the settled bed height.

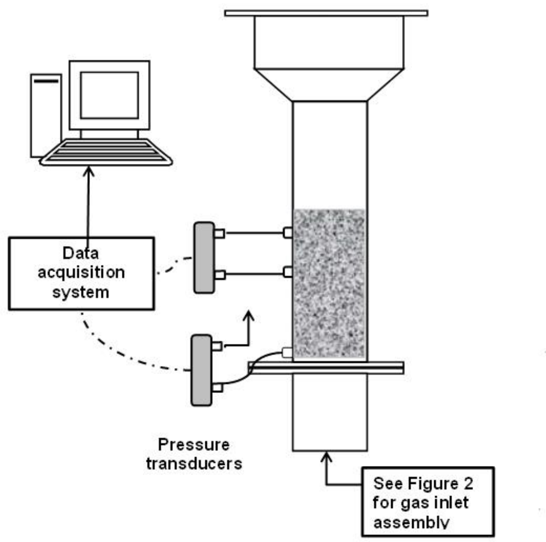

Figure 1: Schematic of the packed bed. Pressure transducers record local and global transients. Air enters enter the test section through perforated plate distributor.

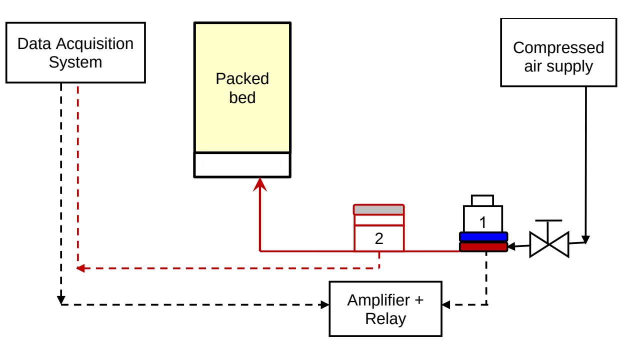

Figure 2: Schematic of inlet flow scheme using pulsed flow; 1-Normally open 2-way solenoid valve as shown in Figure 1; 2- Electronic flow controller for primary flow

Hydrophilic fumed silica (Aerosil 200) was used here. Its tapped density is 50 kg/m3 while the true density is 2200 kg/m3. This results in a very high porosity which is greater than 0.97 for the present ultrafine powder. Its minimum fluidization velocity with flow pulsation was found to be 28.3 mm/s.

3 RESULTS AND DISCUSSION

A typical bed response is shown in Figs. 3a-b. The case of 'no pulse', which means that a steady and non-fluctuating flow of the air is maintained through the bed, is also shown in the figure. This reflected in the steady pressure drop in the bed. It is seen in Fig. 3a that the local steady state pressure drop is almost 10 Pa which sharply rises to as much as 80 to 100 Pa due to the pulse. Thus, the increase in the pressure drop is almost ten times due to the disturbance introduced by the step change in the velocity. In fact, it is the pressure buildup in the air inlet line when the valve is closed that yield a several fold increase in the velocity over that of its preset value. This phenomenon is reflected in the sharp peaks in the pressure transients. It is moreover seen that peak values are higher in the case of higher frequency pulse owing to the larger valve closing time. Once the flow pulse starts, it quickly attains a steady value. The time of attaining the steady value is nevertheless not affected by the pulse frequency. There is another notable feature of the figure. When the valve is closed, both 2-s as well as 5-s pulses show negative pressure drop, which slowly move towards attaining the steady state value. Note that while 2-s time duration is just enough to attain the steady value after the valve opening, the same time duration is not enough for the bed to attain the zero value. The negative value in the pressure drop is caused due the backflow of the trapped air in the packed bed when the air supply is abruptly switched off by the valve closing. There appears to be an exception for the 10-s pulse. At this stage, it is rather premature to attribute it to some kind of bed phenomenon unless the same behavior is repeated at other flow rates.

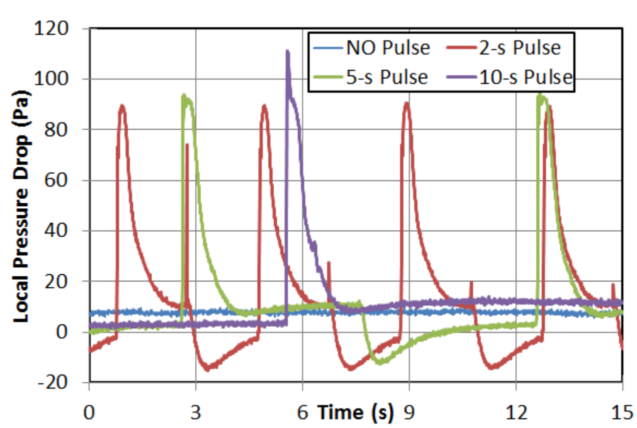

Figure 3a: Local pressure transients for different frequencies at 6.28 mm/s

The case of global pressure drop is depicted in Fig. 3b for the velocity of 6.28 mm/s. The steady state pressure drop when there is no pulse higher than what is seen for the case of flow pulsation. This is due to the fact that the bed was a little non-homogeneous before the start of the flow pulsation. Therefore, 40 Pa can be taken to be a more accurate value of the steady state pressure drop. On the other hand, peak values of global pressure drop hardly exceed 65 Pa. This is not even a two-fold increase in the pressure drop to that of the steady state value. This is big a difference in view of the fact that the peaks values for the local pressure drop were almost ten time greater than the corresponding steady value. This is a clear indication that the bed attenuates the disturbance in the velocity signal which is reflected in the attenuation of the pressure signal.

The pressure signal in the case of the global pressure drop is much more broadened as compared to sharp peaks seen for local pressure signals. Since the energy of any perturbation is conserved, the broadening of the peaks reflects the slower rate of energy dissipation.

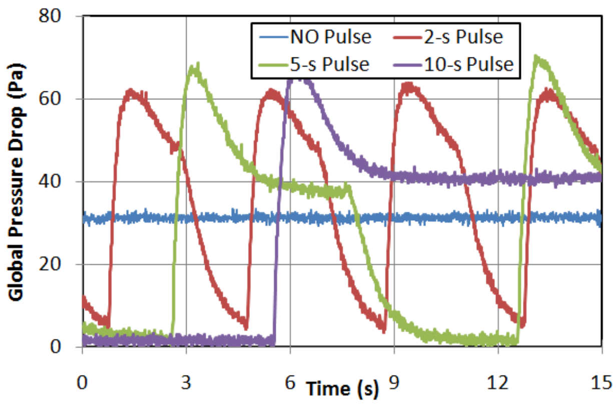

Figure 3b: Global pressure transients for different frequencies at 6.28 mm/s

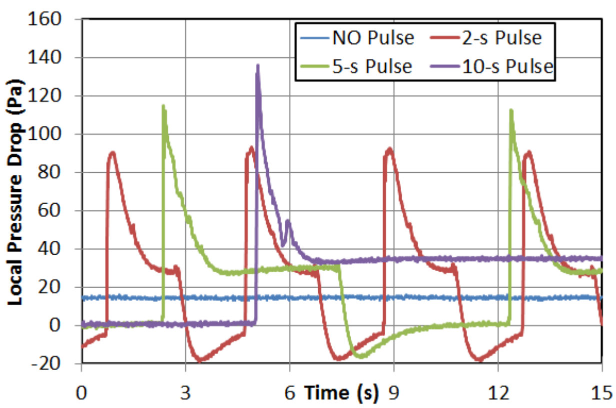

Figure 4a: Local pressure transients for different frequencies at 12.1 mm/s

The case of the 12.1 mm/s is shown in Figs. 4-b. While the case of no pulse show a lower pressure drop as compared to pulsed case owing to greater bed homogeneity. The peaks of local pressure transients are influenced by the frequency. Low frequency pulsation reveals sharper peaks. As seen before that the peaks are quite subdued for the case of global pressure signals and the difference between the peak value and steady value is relative small as compared to what was observed at lower velocity of 6.28 mm/s. It is also seen in Fig. 4b that the pressure signals are also broader than what was seen for the lower air velocity.

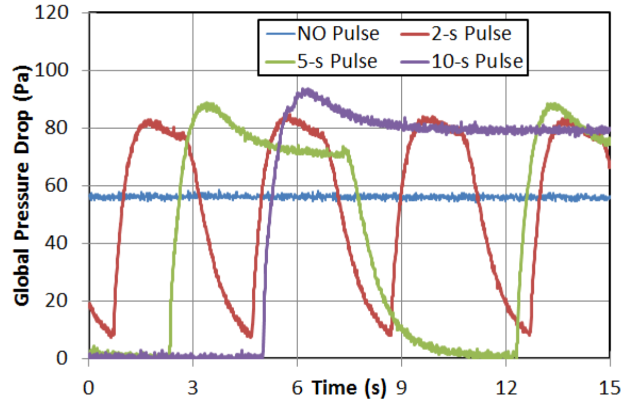

Figure 4b: Global pressure transients for different frequencies at 12.1 mm/s

4 CONCLUSIONS

While the flow pulsation has proved to be effective in promoting the de-agglomeration nano-powders as the velocity fluctuation when introduced impart their momentum to break the large agglomerates [3 − 4], there is clearly an entirely new dimension to this research that can be used to attenuate strong disturbances or perturbations with the help of bed of nanoparticles.

5 ACKNOWLEDGEMENTS

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