Experimental Investigation of Particle Deagglomeration using Turbulence

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Abstract. The effect of turbulence on powder aerosol deagglomeration was investigated. Two impinging jets were used to generate turbulence. Lactose particles, whose fully dispersed fine particle fraction (FPF) - number percentage of the particles whose diameter smaller than 5 μm - is above 90 %, were applied as aerosol powder. The particle size distribution after the dispersion unit were measured by using phase Doppler anemometer (PDA) and turbulence level were quantified at the impingement point of two jets with laser Doppler anemometer. As the turbulence level increases turbulent time and length scales decrease, and the ratio of fine particle fraction (FPF) increases from 36% to 86%.

1. Introduction

Dispersion of particle agglomerates often draw huge interest in many powder related applications, such as food production, particle filters, ink-jet printers, dry powder inhalers etc. In many cases it is desirable to deagglomerate the particle clusters. These clusters are as a result of inter-particular adhesive forces which can be listed as Van der Waals, electrostatic, capillary and mechanical inter-locking forces (Finlay & Berkowitz, 2001; Holzner, 1998). In order to deagglomerate particle clusters, dispersion forces must overcome the adhesive forces. There are various dispersion mechanism which can be applied. In this study, particle deagglomeration using turbulent flows were investigated. The favorable effect of turbulence on dispersion was already shown by Voss & Finlay (2002). Turbulence has effect on particle deagglomeration extensively two distinct mechanisms, first, due to spatial velocity gradients and second, the transient acceleration that is induced by the unsteady of turbulent eddies. In this study the turbulence intensity was measured, the turbulent time scales and powder density function were calculated. Another interesting factor, the exposure duration of the particles to the turbulence was investigated as well.

2. Experimental Set-up

Turbulent flow field is created in a circular duct by means of mutually placed two jets (figure 1). The jet nozzle diameter is 3 mm and they are separated with 5 mm gap. The experiment was

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performed for various volume flow rates which covers jet Reynolds number from 2000 to 13000 (figure 2). The lactose agglomerates are supplied from top of the duct and pass through the turbulent region via gravity. Two different test sections were constructed. One for measuring the radial and axial velocities where the jet flow direction is referred as radial ($w$), and direction of the exit of the powder dispersion unit is referred as axial direction ($u$) (figure 1). The other one for measuring the particle size distribution. The velocity measurements were performed by two-component Dantec Fiber Flow Laser Doppler Anemometer (LDA), with forward-scattering mode and the control volume is located at the midway between the two nozzle exits (figure 3). Fine water droplets, which were produced by ultrasonic fog generator, were used as seeding particles. Particle size distribution were measured by Dantec Fiber Flow Phase Doppler Anemometer (PDA). The control volume of the PDA is located 5 mm at the exit of the powder dispersion unit (figure 4).

**Figure 1.** Schematic illustration of powder dispersion of agglomerates with turbulence flow.  
**Figure 2.** Reynolds number based on the jet and dispersion unit.

Additionally two-dispersion units were connected serially in order to preserve turbulence longer and increase the duration of exposure of the particles to the turbulence. The particle size distribution at the exit of were measured with the same as before.

Powder that were used in the study is a lactose mixture of two batches. Batch I, consists of lactose particles whose volumetrically 90% of them (referred also d90) have a diameter less than 40$\mu$m. Batch II is also comprised of lactose particles, whose volumetric d90 has a diameter less than 5$\mu$m. The presented results here are from the volumetrically mixture of 1% Batch I and 99% Batch II.

### 3. Results

At the highest volume flow rate case, the jet velocity reaches up to 60 m/s. Within few millimeters the radial flow stagnates ($w$-component), and accelerates in axial direction ($u$-component). This strong deceleration and acceleration results, vortex stretching, alignment and intensification of eddies in the axial direction whereas disorientation and abate in radial direction ($u$-direction). This effect finally results a growth in $\bar{w}w$, a fall in $\bar{u}u$ and, consequently, a strong anisotropic turbulence (Davidson, 2004) (figure 5). The abrupt deceleration manifests itself as a sudden drop on the autocorrelation function of the radial velocity fluctuations as
a result of short turnover times even for the high energetic eddies (figure 6). The reduction in the turbulent turnover times have an increase on the transient acceleration that are felt by particle agglomeration. Using the velocity measurements the acceleration that is experienced by a particle in a hypothetical agglomerate of 50\(\mu\)m diameter can be calculated from Reynold stress and the relaxation time of agglomerate, \(\tau\) as follows;

\[
a \approx \frac{\overline{u'w'}}{\tau}
\]

and the relaxation time of agglomerate defined as;
Volume Flow Rate \[l/min\]

\[ \tau = \rho_a d^2 C_c \frac{\mu}{18} \]

where \(\rho_a\) is density of agglomerate, \(d\) is the diameter of agglomerate, \(C_c\) is the Cunningham slip correction factor and \(\mu\) is dynamic viscosity of air. The lactose particles are highly adhesive in nature it necessitates accelerations 200 times that of gravity to deagglomerate. As the flow rate increases not only the total energy of the turbulence increases but also the energy of small scale structures increases (figure 8).

The figures 9 and 10 depict the degradation of the large clusters as the turbulence level increase figure 10. Increase of energy at scales similar to that of particle clusters augments the deagglomeration. The effect of turbulence on FPF can be observed from figure 11. As the flow rate increases so does the turbulence level the FPF increases from 36 % to 86 % which is close to agglomerate-free particle size distribution.

An additional parameter to turbulent deagglomeration might be duration that particles exposed to turbulence. In the figure 12 it might be seen that the same dispersion effect can be achieved with two turbulent dispersion units connected serially than single one with application of less energy. The energy referred here is calculated by;

\[ E = \frac{1}{2} \rho U_j^2 N \]

where \(U_j\) is the bulk jet exit velocity and \(N\) is the number of jets.
**Figure 6.** Autocorrelation function for radial component.

**Figure 7.** Acceleration felt by a hypothetical agglomerate with a 50\(\mu\text{m}\) diameter.
Figure 8. Power Density Function of radial component.

Figure 9. Probability density function (PDF).
Figure 10. Fine particle fraction increase as flow rate increases.

Figure 11. Fine particle fraction increase as flow rate increases.
4. Summary and Discussion

The high levels of turbulence have favorable impact on particle dispersion. The increase in the turbulence intensity also results an increase in FPF. Extending the exposure times to the turbulence also results in higher FPF even with weaker spatial gradients and unsteady inertial effects. The generated turbulence comprises unsteady fluctuations of velocity and high levels of mean shear and mean strain. In a turbulent flow, it is very hard to distinguish the influence of inertia and spatial velocity gradients on the particle dispersion. Our investigations (Asam, 2010) on the influence of strain and shear result in lower FPF than those obtained here. In these investigations, the amount of shear and strain are much higher than those obtained in the present one, the flow is kept laminar and the same powder mixture is employed. Therefore, we presume that the high levels of FPF is due to the inertial effects caused by unsteady fluctuations.

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