An Investigation of the Effect of Process Conditions on the Fluidization Behaviour of Gas Fluidized Beds

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ABSTRACT

This paper reports some of the results obtained from an extensive experimental campaign aimed at studying the influence on fluidization of changing the size distribution of the fine sub-cuts (particles below 45 μm) of Group A powders with increasing temperature. The fluidization behaviour of an alumina powder was monitored at temperatures ranging from ambient to 400ºC and by adding to the material previously deprived of fines two fine sub-cuts of nominal size 0-25 μm and 25-45 μm respectively. Experiments were carried out comparing the fluidization behaviour of the alumina samples when a total fines content was kept at 22% wt and subsequently increased at 30% wt. Fluidization tests such as bed collapse test, pressure drop profiles and bed expansion profiles were performed.

1. INTRODUCTION

The framework that encompasses this work is the understanding of the effect of realistic process conditions, such as temperature and particle size distribution, on the fluidization behaviour of fluidized powders. Process conditions can greatly influence the balance between hydrodynamic and interparticle forces and some times drastically change the fluidization behaviour [1]. In particular, several authors [2-5] have reported on the beneficial effect on fluidization of adding fine particles (<45 μm) to the bed and it is common practice in industry to employ between 10-50% by weight of fine material in order to maximize reactor performance. Fine particles content can affect the quality of fluidization by influencing the distribution of gas between the dense phase and the bubble phase of a freely bubbling bed, therefore showing the unreliability of the "two-phase" theory of Toomey and Johnstone [6]. This states that all gas in excess of that required to just fluidize the particles passes through the bed in the form of bubbles. Newton [2] and Yates et al. [3] based their study on the consideration that the interstitial phase is much more effective in bringing about chemical reaction between gas and solids than the bubble phase. Therefore, they used the chemical conversion for a given throughput of reactant as an indicator of the distribution of gas between dense phase and bubbles. They found that increasing the fines content caused conversion to increase, therefore showing an increase in interstitial gas flow with increasing fines content. Rowe et al. [4] had reached the same conclusion by performing direct measurements of the dense phase voidage using the X-Ray absorption technique. Later, Barreto et al. [5] compared Rowe's measurements with those indirectly obtained with the bed collapsing technique and found good agreement between the two techniques.

However, the relative importance of the various fine sub-cuts (0-25, 25-45 μm) on the improvement of fluidization represents an issue which has not been fully understood as yet.

This work is aimed at looking into this problem by analysing the independent effect on fluidization of adding different fine sub-cuts to a virtually fines free starting material. The study presented here analyses results obtained by adding to the material previously deprived of fines two fine sub-cuts of nominal size 0-25 μm and 25-45 μm respectively and by increasing temperature from ambient to 400ºC. The total content of fine particles used was initially kept at 22%wt and subsequently increased at 30%wt.

2. EXPERIMENTAL APPARATUS AND MATERIALS

All the experiments reported have been carried out using a 140 mm diameter x 1000 mm tall Inconel heated gas fluidized bed. The high temperatures were achieved by means of flexible ceramic heaters wrapped around the vessel. Two solenoid valves were used during the bed collapse experiments, one to cut the air supply to the bed and the other one to vent the air trapped in the windbox section. Most of the experimental information has been obtained using an X-Ray imaging technique, which provides a moving image of the internal flow patterns of the fluids and solids inside the vessel, captured on a video at 25 frames per second.

The starting material for this study was an alumina containing around 50%wt of fines below 45μm and having a particle density of 1730 kg/m^3, measured with mercury intrusion analysis. This was split at 45μm and then the collected fines were separated in sub-cuts using an air classifier. The second step was to create two new powders by mixing the nominal >45 μm (A0) with each of the two fine sub-cuts. Special attention was paid to blending the powders so to obtain two powders with the same total fine content, similar overall particle size distribution (PSD) and differing in the PSD of the fines sub-cut fractions. The mean particle diameters of the two powders resulting from the blending were also kept as close as possible. Figure 1 shows the particle size distributions of the fines free powder (A0) and of the samples A3 and A4 resulting from the blending, which contain 22%wt of total fines but shifted towards bigger or smaller size cuts respectively. Similar procedure was followed to obtain A5 and A6 which contained 30%wt of total fines but shifted towards bigger or smaller size cuts respectively, as shown in Fig. 2.

The particle size distribution of the three powders was measured again at the end of each set of the experiments and any elutriated fines were collected. No significant changes in the PSD were noticed and a negligible amount of fines (less than 1% of initial fines content) was lost during the experiments. Table 1 summarises the characteristics of the samples created.

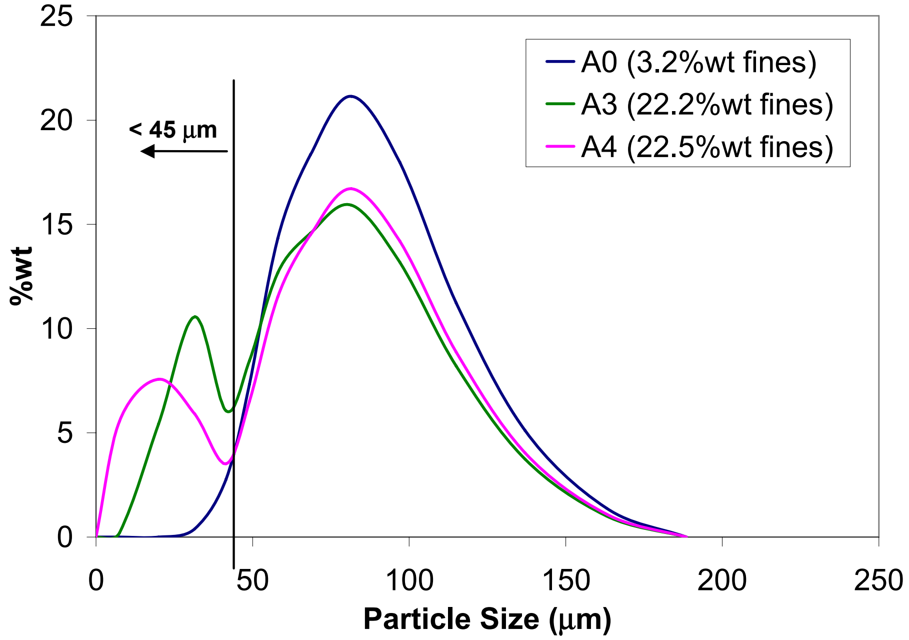

Figure 1 - Particle Size Distributions of A0, A3 and A4 obtained with laser diffraction (Malvern Instrument)

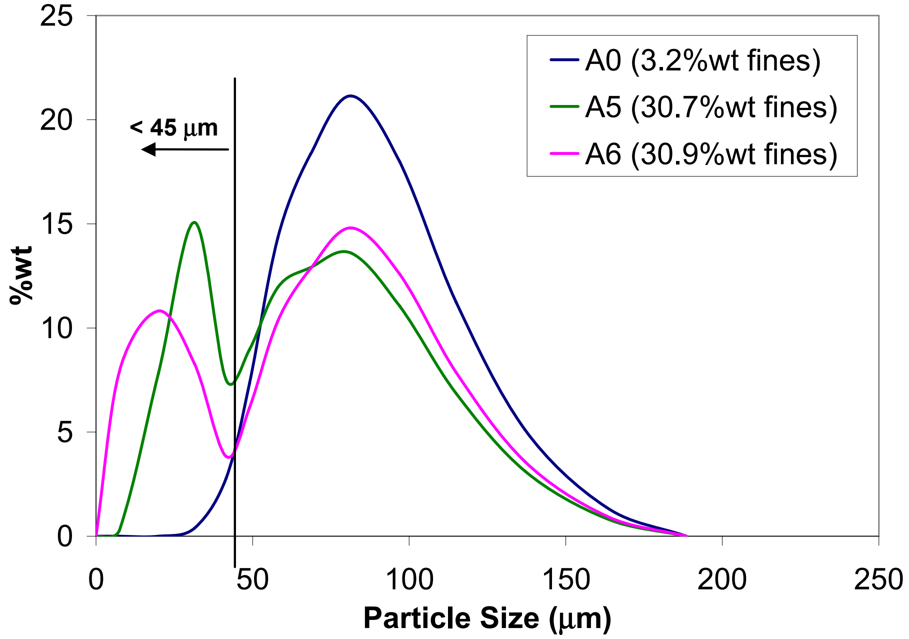

Figure 2 - Particle Size Distributions of A0, A5 and A6 obtained with laser diffraction (Malvern Instrument)

Table 1

	d_p (μm)	F_{45} %	%wt 0-25 (μm)	%wt 25-45 (μm)
A0	75.1	3.2	0	3.2
A3	54.9	22.2	5.6	**16.6**
A4	41.7	22.5	**13.1**	9.4
A5	49.1	30.7	8.1	**22.6**
A6	36	30.9	**18.8**	12.1

3. RESULTS AND DISCUSSION

Pressure Drop profiles and u_{mf}

The pressure drop profiles were analysed as a first indication of the quality of fluidization. These were obtained by increasing the gas flow rate in small steps and recording the pressure drop across the bed at each step ("Fluidizing" curves in Fig. 3 and Fig. 4). Once the bed was well fluidized the gas flow rate was then decreased until the bed settled and the pressure drop recorded with the same procedure ("Defluidizing" curves in Fig 3 and Fig. 4). The pressure drops are plotted as ratios $\Delta P / \Delta P_c$, where ΔP is the measured pressure drop and ΔP_c is the calculated pressure drop when full bed support is achieved:

$$\Delta P_c = \frac{Mg}{A}$$

where M is the weight of the bed material, A is the cross section area of the bed and g is the acceleration due to gravity.

Figure 3 reports the fluidizing and defluidizing curves for powder A4 at the minumum and maximum temperatures analysed. A small overshooting in the "Fluidizing" curve is noticeable at both temperatures and was also observed at each intermediate temperature analysed, showing a slight degree of cohesiveness. Similar results where obtained when fluidizing sample A3. Figure 4 reports results obtained for A6 with contained 30%wt of total fines. Similar results were obtained for A5. In these cases, the overshooting in the pressure drop becomes more pronounced, highlighting the increased resistance of the material to flow in order to reach minimum fluidization conditions with increasing the fines content.

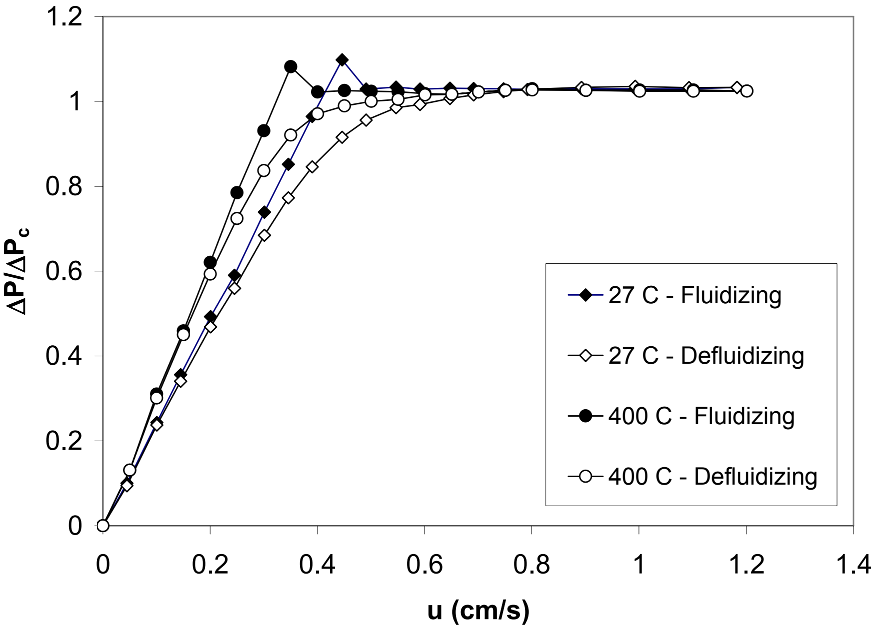

Figure 3 – Pressure Drop profiles at ambient temperature and 400°C. Sample A4

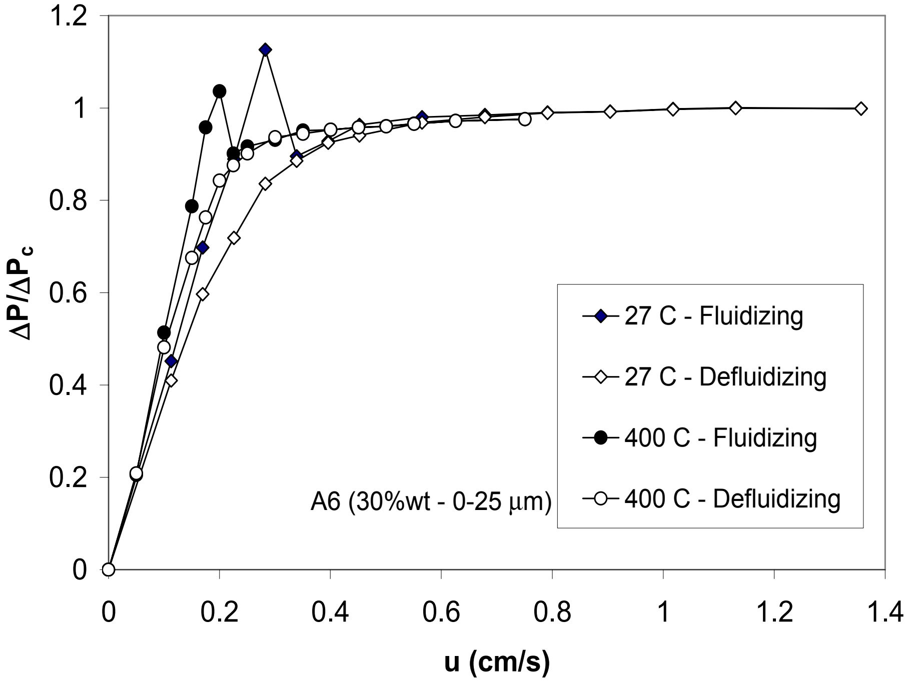

Figure 4 – Pressure Drop profiles at ambient temperature and 400°C. Sample A6

Bed Expansion

Fig. 5 shows the maximum homogeneous bed expansion obtained from the expansion profiles for all powders with increasing temperature. A4, which contains a high percentage of fine particles between 15-25μm, shows a bigger expansion than

A3. Similar results were obtained when comparing A5 with A6. The figure shows also that a greater maximum bed expansion is obtained with increasing the fines content from 22%wt up to 30%wt. However, the analysis of the results with increasing temperature shows a steady increase in the maximum bed expansion for the powder containing small amounts of fines while this remains constant for A5 and A6. This highlights the balancing effect of temperature to the increased aeration of the materials with increasing the total fines content.

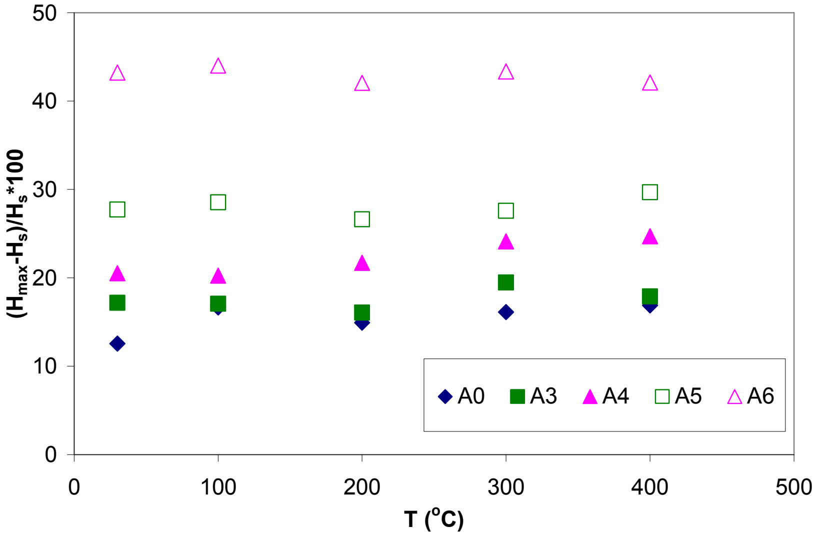

Figure 5 – Maximum bed expansion with increasing temperature for all powders

Bed Collapse Test

The dense phase collapse rate (U_{de}), the standardised collapse time (SCT) and the bed expansion ratio (BER) were obtained from the bed collapse test for all the samples. This test consists of suddenly turning off the gas supply to a vigorously bubbling fluidized bed and recording the deflation of the bed with time. The bed collapse technique was introduced in 1967 by Rietema and was subsequently used by Sutton and Richmond [7] to test the capacity of a powder bed to retain aeration gas. In this work, the bed collapse tests were run at various temperatures and visualization and recording of the bed height with time were obtained by means of the UCL X-Ray imaging technique. Lettieri et al. [8,9] used the bed collapse test to distinguish between powders whose fluidization behaviour was dominated by hydrodynamic and interparticle forces.

A typical bed collapse profile for a Geldart's Group A powder is reported in Fig. 6:

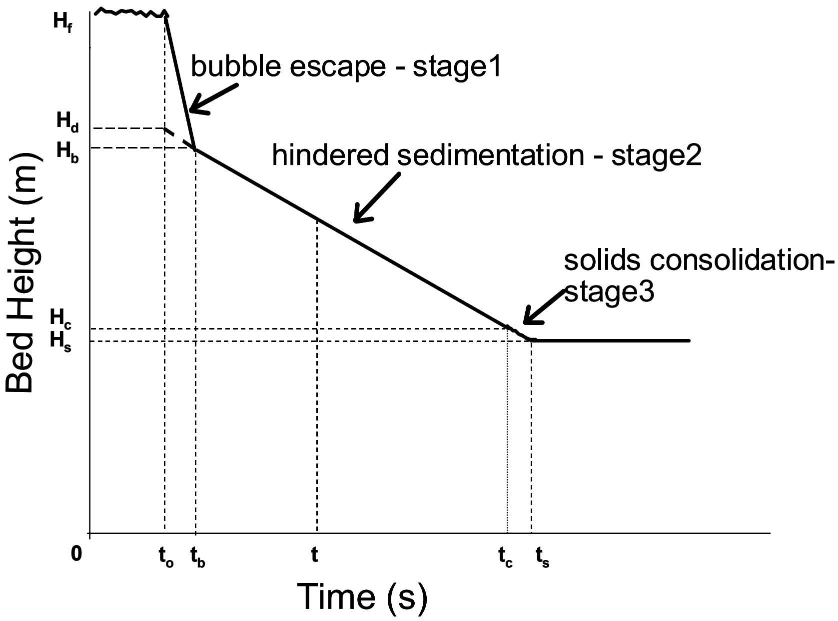

Figure 6 – Typical collapse profile for Group A powders

where:

$$U_{de} = \frac{H_d - H_s}{t_s - t_o}$$ Dense Phase Collapse Rate

$$BER = \frac{H_d - H_s}{H_s} 100$$ Bed Expansion Ratio

$$SCT = \frac{BER}{U_{de}} = \frac{t_s - t_o}{H_s} 100$$ Standardised Collapse Time

where t_o is the time when the gas supply to the fully bubbling bed is cut off and t_s is the time when the collapse is complete and the bed is settled. H_s is the height of the settled bed, whereas H_d is the extrapolated value of the dense phase height at time t_o. Abrahamsen and Geldart [10] reported that the bed collapse test parameters depend on the starting fluidizing velocity when the superficial gas velocity at the beginning of the collapse is below a certain value, which for the powders they examined was found to be 6 cm/s. In this study, however, due to the crucial role of fine particles, the initial velocity was set to 1.5 cm/s in order to minimise elutriation from the bed. This velocity was chosen as to be the highest velocity which would keep the visually observed elutriated fines to a minimum. Lettieri [1] showed that despite the sensitivity of the fluidization parameters on the initial gas velocity, the trends with increasing temperature of these parameters do not change with changing initial gas velocity. This finding suggests that as long as the experiments are carried out in a consistent fashion, i.e. at the same initial fluidizing velocity, a meaningful assessment of the influence of process conditions can be achieved. Therefore, in this work, given the low value of the initial gas velocity chosen, the results from the bed collapses are intended to be comparative and not absolute values.

Figures 7 and 8 illustrate the trends obtained with increasing temperature for the dense phase collapse rate and the standardised collapse time for samples A3 and A4.

U_{de} measures how quickly the bed would collapse in the absence of fluidising gas. Figure 8 shows that for both powders the dense phase collapse rate significantly decreased with increasing temperature. This is in agreement with the results reported by Abrahamsen and Geldart [10] and Lettieri et al. [2000]. However, no significant difference was observed between the dense phase collapse rate of the two powders having different fine particles distribution, A3 and A4. Similar results were obtained for the samples A5 and A6 containing 30%wt of fines.

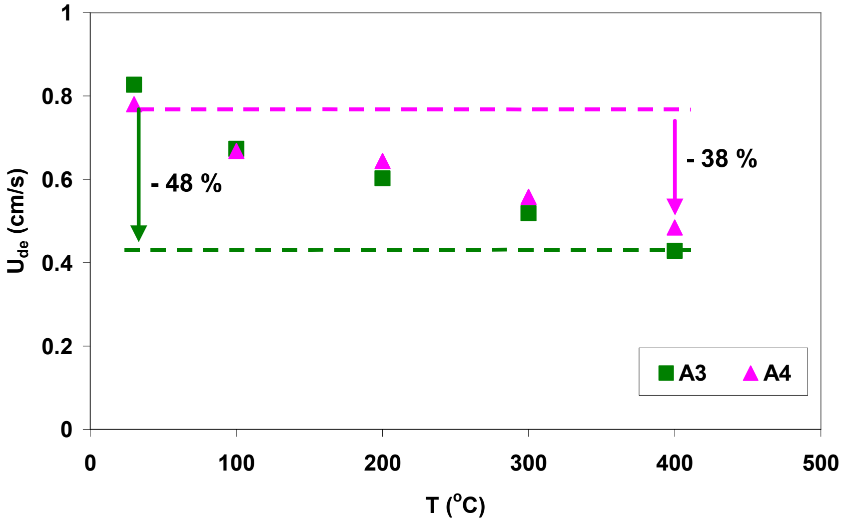

Figure 7 - Effect of temperature on the dense phase collapse rate for A3 and A4 (22%wt fines)

The time required for the powder to deaerate depends not only on the collapse rate, but also on the height through which the bed surface has to fall. The standardised collapse time is therefore believed to be a more discriminating indicator of the changes happening in the fluidization unit at process conditions, as it takes into account also possible changes in the bed structure. Figure 8 shows that the SCT significantly increased with increasing temperature for both powders. This means that for both powders increasing temperature improved the ability to retain aeration. Moreover, at each temperature the powder A4 (containing a higher percentage of the smaller fines) showed a higher SCT than A3 (which contains a higher percentage of bigger fines). The results reported in Fig. 9 show much greater differences between A5 and A6, thus highlighting a greater sensitivity of the SCT (and thus aeration) to the fines distribution when the total fines content is increased to 30%wt. However, while Fig. 8 shows a steady increase in the SCT with increasing temperature, Fig. 9 shows an increase in SCT up to 300°C with values then remaining constant at higher temperatures for both A5 and A6. Thus, the combined effect of increasing temperature and fines content controlled the maximum ability of the powder to expand and retain aeration.

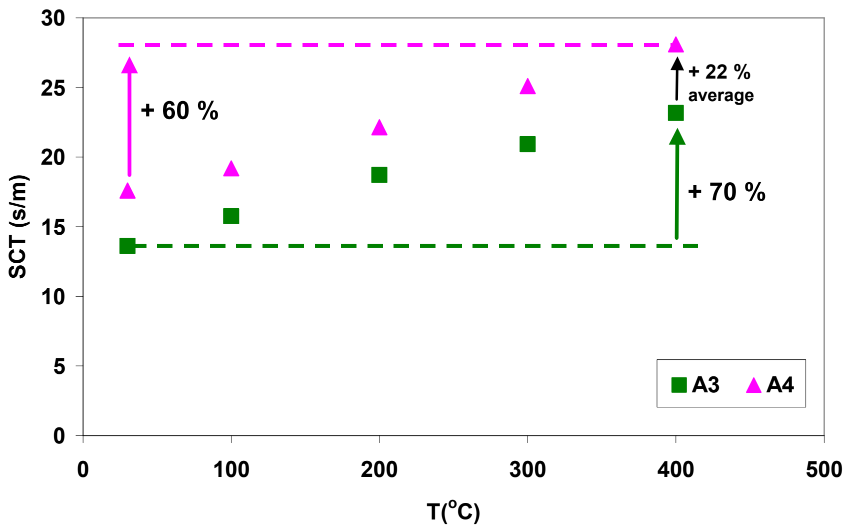

Figure 8 - Effect of temperature on the standardised collapse time for A3 and A4 (22%wt fines)

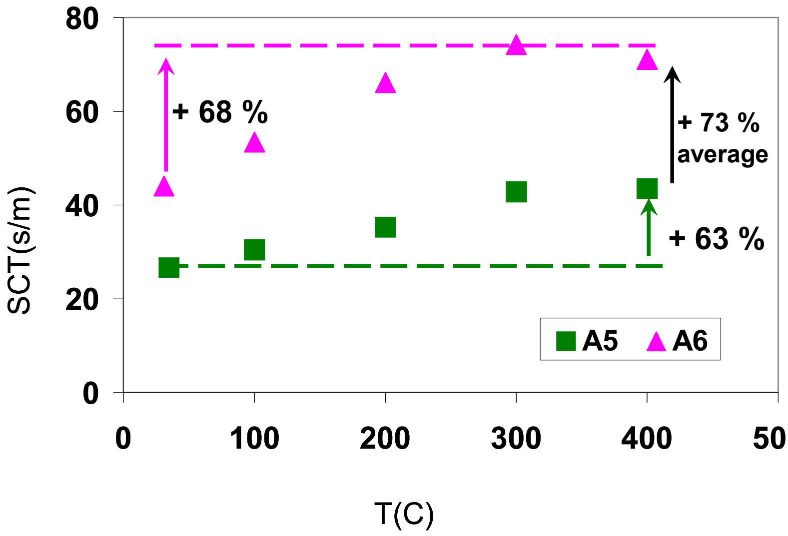

Figure 9 - Effect of temperature on the standardised collapse time for A5 and A6 (30%wt fines)

CONCLUSIONS

Fluidization tests were carried out on alumina powders containing 22%wt (A3 and A4) and 30%wt fines content (A5 and A6) and differing in fines size distribution. A3 and A5 being richer in “bigger” fines and A4 and A6 being richer in “smaller” fines. The effect of temperature and of fines content and fines size distribution on the fluidization behaviour (pressure drop and bed expansion) and on the parameters of the bed collapse test were investigated.

The pressure drop profiles showed that increasing content of fines increased the resistance to flow of the powders in order to achieve minimum fluidization. Bed expansion increased with increasing fines content and greater differences between the samples containing the small fines sub fraction (0-25μm) or the bigger one (26-45μm) were observed when the total fines content was 30%wt. Increasing temperature however played as a balancing effect on the capability of the powders to reach maximum expansion when the total fines content was 30%wt.

The bed collapse test showed that even small changes in the fines size distribution caused some significant changes in the standardised collapse time, SCT, of the powder investigated. In particular, at each temperature examined the alumina powder richer in smaller fines (A4, A6) was found to be more aeratable (greater SCT) than the alumina powder richer in bigger fines (A3, A5). The dense phase collapse rate U_{de} did not discriminate between powders having different fines size distributions.

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NOTATION

A	bed cross sectional area (m^2)
BER	bed expansion ratio (%)
F_{45}	mass fraction <45μm
g	acceleration of gravity ($m\ s^{-2}$)
H_d	dense phase height (m)
H_s	settled bed height (m)
M	mass of powder (kg)
SCT	standardised collapse time (s/m)
t_o	start of collapse time (s)
t_s	end of collapse time (s)
U_{de}	dense phase collapse rate (m/s)
GREEK SYMBOLS	
ΔP	pressure drop across the bed ($N\ m^2$)
ΔP_c	calculated bed pressure drop ($N\ m^2$)

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