PNEUMATIC CLASSIFICATION OF ULTRAFINE MINERAL POWDERS

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ABSTRACT

The paper deals with the experimental results obtained in the dry classification of ultrafine powders coming from micronization of an industrial mineral.

The research work has permitted the optimisation of the operative parameters of pneumatic classifiers working in combination with an opposed jet mill.

In particular, the experimental tests have shown that cut-sizes of ultrafine dimensions can be achieved with acceptable imperfection.

INTRODUCTION

Ultrafine particle sizes, namely sizes in the order of a few microns, are gaining increasing importance in minerals processing and in raw materials handling in general. Ultrafine size classification may form the final processing stage of solid materials or the intermediate process for eliminating those very fine fractions that are likely to impair the efficiency of further processing.

Two techniques are currently used for this purpose:

- dry classification using air or other gaseous media as fluid stream;
- wet classification.

Dry classification does entail some difficulties, especially for ultrafine sizes, in particular as far as precision is concerned. Compared to wet classification, the equipment required is generally cheaper though the need to treat material practically devoid of moisture should not be overlooked if satisfactory results are to be achieved.

Dry classification is compulsory in those cases where the need for an additional dewatering stage is not cost-effective, or when the commercial quality of the final product is likely to be impaired by the presence of moisture.

One process in which dry classification plays a primary role is micronisation, where the top-size of the end product is critically important, insomuch as top-size is often not well defined or does not come up to stringent commercial specifications. Almost all micronising equipment is provided with an internal classification system designed to remove the fine particles as they form. The result is that the final product may contain some coarse grains which, depending on the commercial specifications, could well render it unacceptable. In this case, it is necessary to install an air classifier downstream in order to exploit any residual kinetic energy of the micronised product.

Attention also needs to be focused on the possibility of separating the product into two distinct fractions: a fine fraction that forms the final product and a coarse one that is returned to the top of the micronises as circulating load or in certain cases may be used for inferior quality commercial products.

Thus, an efficient classification system allows to obtain a final product characterised by a sharp top size cut and by a rather low d_{50}, while satisfactorily containing the circulating load volume, throughput and hence specific energy consumption, another critical issue in reduction of minerals to micron size [Alfano-1995, Alfano-1997].

Air classifier

Figure 1 shows a schematic diagram of the cross-section of an air classifier operating on the principle of particles settling in centrifugal field [Clyde Orr-1960, Willis-1979, Nautamix-1970].

The device used for the experimental tests described further on, consists essentially of the following parts:

- an outer casing, similar to that of an air cyclone;
- a rotor, replacing the diaphragm outlet in cyclones, in turn composed of two parts:
  1 - a cone, placed in front of and along the feed pipe axis, similarly to the rotor axis;

2 - a rotor, connected to a variable speed motor, solid to the cone whose purpose is to impart a certain acceleration to the ingressing particles;

- a feed pipe through which the particles are conveyed to the classifier. The distance H between the cone apex and the top of the feed pipe can be adjusted to suit classification requirements;
- an outlet for collecting the coarse particles (underflow) and one for the fine particles (overflow).

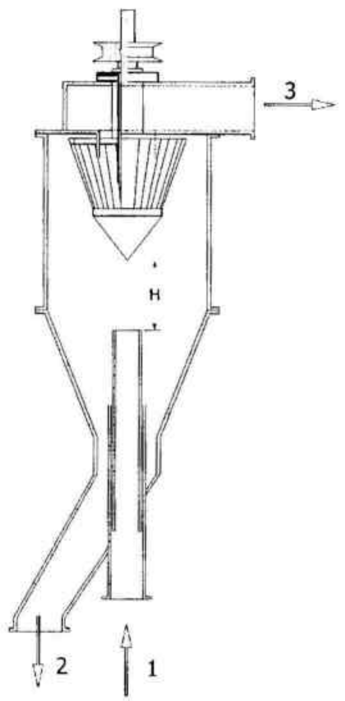

Figure 1 – Air classifier. 1 feed, 2 underflow, 3 overflow.

The operating principles can be briefly described as follows: in a generic cross section of radius r, normal to the rotor axis, a rounded grain of diameter d and specific mass ρ_s is subjected to a centrifugal force F and drag force R, which can be written :

$$F = V(\rho_s - \rho_f)\, u_o^2 / r \tag{1}$$

where V is the grain volume, ρ_f is the specific mass of the fluid and u_o is the peripheral velocity of the rotor.

$$R = k\, \mu\, u_r S/d \tag{2}$$

where μ is the dynamic viscosity of the fluid, u_r is relative grain velocity with respect to the fluid and S is the mean particle cross-section, measured normal to the direction of flow.

The equation for R holds for laminar flow conditions especially when fine particles are present, whatever their shape.

For F > R, the grains shift towards the outer wall of the classifier and viceversa for F < R.

In equilibrium conditions, where F = R we can write, all other conditions being equal:

$$d = k_1\, (u_r \cdot r)^{0.5} / u_o \tag{3}$$

where d is the theoretic size of grains in equilibrium and k_1 is a constant that takes into account grain shape, dynamic viscosity of the fluid and solid and fluid mass.

As d decreases with increasing u_o and decreasing u_r and r, the equilibrium position, on the cross section plane, shifts towards the rotor axis. Under these conditions the cut point d_{50} varies, depending on the direction and of the fluid's axial velocity component. It should be recalled that d_{50} is also a function of feed rate and air pressure and decreases as these are increased. To assess classification efficiency the imperfection I can be used, expressed as the relationship between the probable error and d_{50} [Wills-1979].

Of course, the above considerations rely on a number of approximations that do not allow to correctly evaluate *a priori* the influence on classifier performance of the parameters involved, especially the particles' relative velocity with respect to the fluid, which is difficult to measure.

Thus, in the following we will analyse experimentally some of the classifier's regulating parameters, in particular rotor speed, distance between rotor tip and top of feed pipe, hereafter denoted with H, feed rate, air pressure, particle size characteristics of the feed.

EXPERIMENTAL RESULTS

A practically pure barite, micronised using a Trost jet mill was used in the experiments so as to obviate the adverse effects of feed components specific mass and particle shape on classification.

We have simulated the effects on separation that would be produced downstream from a microniser by introducing a classifier designed to obtain two products with distinct particle size characteristics or alternatively a fine end product and a coarse reject to be returned to the top of the microniser.

For a realistic simulation of the process, the feed materials entered the classifier entrained in an air stream, suitably dehumidified by means of deliquescent salts. Air pressure varied, but in any case represented mean residual pressure observed at the microniser outlet determined beforehand for a variety of mill operating conditions.

Tables 1 and 2 show the grain size composition of both the feed and the product collected at the outlet determined in the laboratory by means of wet classification with sieves and microsieves [Alfano-1993].

Table I - Grain size analysis of jet mill feed

Size class, µm	Weight, %	Cumulative Weight, %
- 300 + 150	60.76	60.76
- 150 + 74	15.97	76.73
- 74 + 37	9.41	86.14
- 37 + 20	5.36	91.50
- 20 + 15	2.15	93.65
- 15 + 10	2.31	95.96
- 10 + 5	1.88	97.84
- 5 + 2	1.35	99.19
- 2	0.81	---
Total	100.00	

Table II - Grain size analysis of micronised product.

Size class, µm	Weight, %	Cumulative Weight, %
+ 30	0.31	0.31
- 30 + 20	4.59	4.90
- 20 + 15	20.44	25.34
- 15 + 10	18.77	44.11
- 10 + 5	31.66	75.77
- 5 + 2	13.87	89.64
- 2	10.36	---
Total	100.00	

Based on the yield-to-weight of the classification products and their relative grain size distribution, determined using a Sedigraph, the cutpoint curve was obtained for all the experimental tests performed, from which the size cuts d_{25}, d_{50} and d_{75} together with the imperfection I were derived.

It should be recalled that for $I < 0.45$ classification is from good to very good, for $I = 0.45\text{-}0.55$ fairly good, fair for $I = 0.55$ to 0.65 and poor for $I > 0.65$.

Rotor speed and distance of feed pipe

Figure 2 shows imperfection versus cut size d_{50} for different rotor speeds and values of H.

The experimental tests were carried out for a feed rate of 30 kg/h and air pressure of 0.2 MPa.

The results obtained demonstrate that for the same H, cut size decreases and imperfection increases with increasing rotor speed. In fact, at higher rotating speeds the force F acting on the particles increases and consequently the equilibrium condition $F = R$ shifts towards a generic rotor section along the device's axis. The result is that some of the finer particles are dragged towards the outer part of the classifier and then exit through the tip. In other words, cut size decreases and imperfection increases, probable error being equal. Furthermore, R also decreases with grain size.

The experimental findings also demonstrate that for the same feed rate load losses increase with rotor speed. Keeping rotor speed constant, d_{50} increases as H decreases, and so too does I, especially at low rotating speeds.

Note too that higher rotating speeds generate greater turbulence near the rotor, enhancing the possibility of particle entrainment. These particles are not separated, resulting in an increase in imperfection, independently of the reduction in d_{50}.

Figure 2 can be used as a nomogram, where rotor speed (keeping H constant the functions $I = f(d_{50})$ are straight lines that converge to a point) and, with a certain approximation, the optimal values of H can be derived at a suitable scale as a function of imperfection and/or cut point.

Lastly, note that in all the tests the top-size of the fine product is less than 15 µm and below 10 µm for rotating speeds of over 1500 rpm and H of 200 mm.

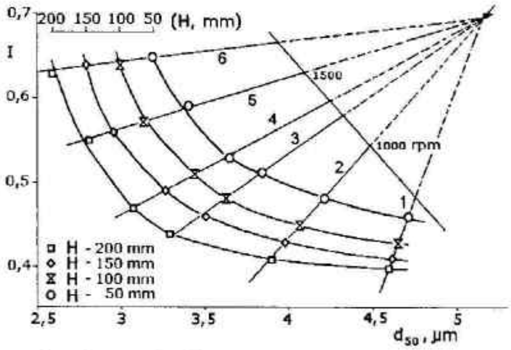

Figure 2 – Imperfection I versus cut off size d_{50} for different rotor speeds and distances H between rotor tip and top of feed pipe. Feed rate 30 kg/h. Pressure 0.2 MPa. 1 - 6 700, 1000, 1200, 1300. 1500, 1700 rpm.

From analysis of the experimental results, not shown here for brevity, it emerged that for I < 0.45 d_{50} are larger than 4 μm. Classification can still be considered satisfactory (I < 0.55) for rotor speeds of less than 1500 rpm. To obtain d_{50} of less than 3 μm values implies values of I ≥ 0.55.

Feed rate

Figure 3 shows I and d_{50} versus feed rate for rotor speeds of 1200 rpm and 1700 rpm, H of 200 mm and air pressure of 0.2 MPa. As can be observed, d_{50} decreases in a practically linear fashion with increasing feed rate.

The gradient is actually lower than that theoretically predicted. This may be attributed to the ingress of grains into the classification zone as a consequence of increased feed rate. In addition to the effect of turbulence, that impairs performance thereby increasing imperfection, this likely produces an increase in R, causing the equilibrium position to shift nearer the rotor axis, bringing about an increase in d_{50}.

Imperfection increases almost linearly up to a feed rate of around 40 kg/h but more sharply for higher values. For the initial tract of the curve this depends on the increase in d_{50} for the same probable error, while in the final portion the greater number of particles entering the classification region produces a significant deterioration in separation precision. Namely an increasing amount of fine particles that should theoretically exit through the cyclone outlet, rises to the top of the classifier.

The top-size of the fine material is in the order of 10 μm at 1200 rpm, decreasing to 9 μm at 1700 rpm.

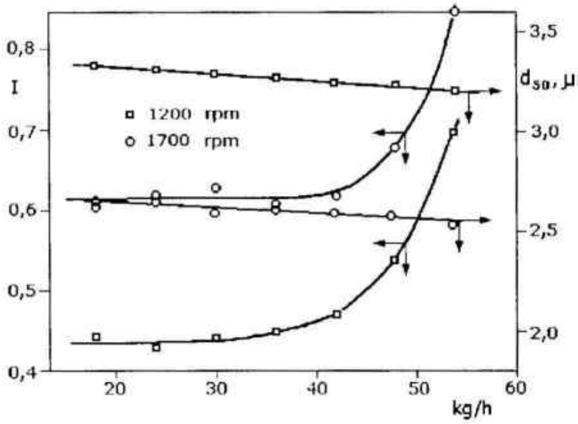

Figure 3 – Cut size d_{50} and imperfection I versus feed rate. H = 200 mm. Air pressure 0.2 MPa.

Air pressure

Figure 4 shows I and d_{50} versus air pressure again for rotor speeds of 1200 and 1700 rpm and H of 200 mm and 50 mm for a feed rate of 30 kg/h.

Contrary to expectations, d_{50} increases almost linearly as air pressure is increased. This may be explained by the overriding effect of increased drag force R versus the predictable effect of a reduction in cut size, likely producing an increase in relative velocity of the grains with respect to the air stream.

As for the influence of H, for the same air pressure and rotor speed higher values of d_{50} have been observed, in keeping with the indications shown in Figure 2 for small distances. This may be attributed to the fact that for smaller distances the free passage of the particles is restricted causing them to impact against the rotor tip and be deflected towards the classifier walls. This is further confirmed by the higher values of I for smaller distances H.

Imperfection varies linearly with d_{50}, increasing significantly at low air pressures. This may be explained by the fact that the entertainment action of the air stream is inadequate, thus impairing efficiency. The lowest values of I have been observed to coincide with higher air pressure, and at constant air rate, with lower rotor speeds and higher H.

The lowest d_{50} are observed at higher rotating speeds.

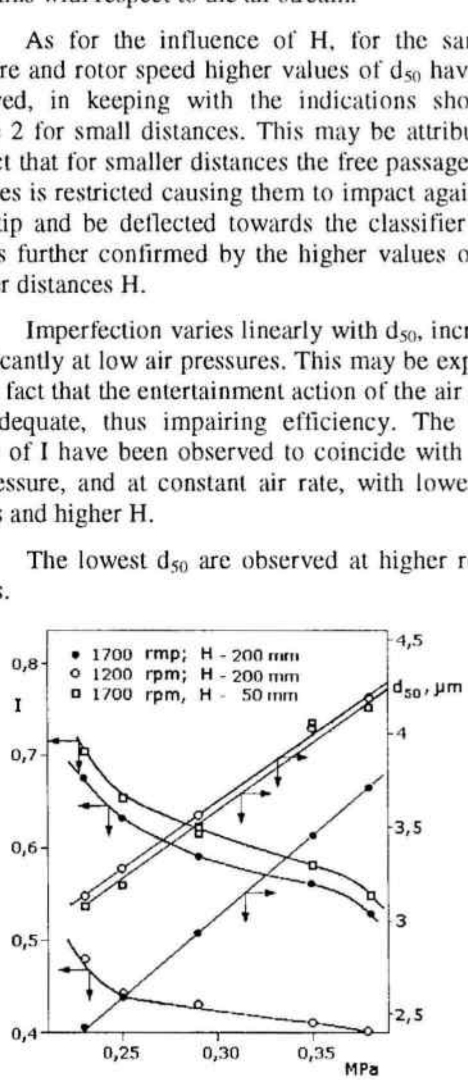

Figure 4 – Cut size d_{50} and imperfection I versus air pressure. Feed rate 30 kg/h.

Particle size distribution of the feed

The influence of this parameter has been examined for a number of barite samples containing from 30 to 70% fines

Table 3. Particle size analysis of air classifier feed.

Size class, µm	Weight, %	Cumulative weight %	Weight, %	Cumulative weight %
+ 30	0.21	0.21	0.24	0.24
- 30 + 20	2.96	3.17	3.95	4.19
- 20 + 15	13.18	16.35	17.60	21.79
- 15 + 10	12.10	28.45	11.27	33.06
- 10 + 5	23.22	51.67	31.72	64.78
- 5 + 2	22.54	74.21	21.55	86.33
- 2	25.79	---	13.67	---
Total	100.00		100.00	

Table 4. Particle size analysis of air classifier feed.

Size class, µm	Weight, %	Cumulative weight %	Weight, %	Cumulative weight %
+ 30	0.40	0.40	0.50	0.50
- 30 + 20	5.45	5.85	7.15	7.65
- 20 + 15	24.38	30.23	31.90	39.55
- 15 + 10	22.44	52.67	29.22	68.77
- 10 + 5	26.04	78.71	22.14	90.91
- 5 + 2	14.56	93.27	8.04	98.95
- 2	6.73	---	1.05	---
Total	100,00		100.00	

(- 10 µm), with the particle size distribution shown in Tables 3 and 4.

Experimental tests were conducted setting rotor speed at 1200 rpm, H at 200 mm, feed rate at 30 kg/h and air pressure at 0.2 MPa.

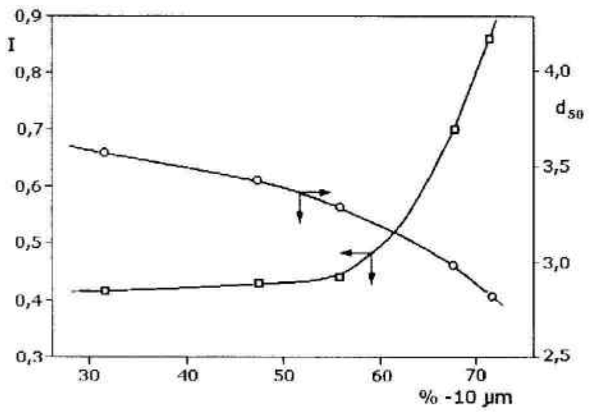

Figure 5 - Cut size d_{50} and imperfection I versus proportion of −10 µm fines in the feed. Rotor speed 1200 rpm. H = 200 mm. Air pressure 0.2 MPa. Feed rate 30 kg/h.

The results, shown in Figure 5 indicate that for increasing proportions of −10 µm fines in the feed, imperfection increases steadily up to fines contents of around 58%, after which it increases sharply on account of the larger number of unclassified particles rising to the classifier tip.

As for d_{50} this decreases fairly steadily suggesting that only separation precision is adversely affected by the larger amount of fines.

CONCLUSION

In the discussion of the experimental results, the performance that can be achieved with the classifier tested here has been described and specifically the possibility of using the diagram of Figure 2 as a nomogram for predicting the results obtainable by adjusting some of the major operating parameters (rotor speed and distance between rotor tip and feed pipe). However, the often decisive influence of feed rate, air pressure as well as proportion of ultrafines in the feed should not be overlooked, bearing in mind that their regulation hinges on the desired objectives in terms of imperfection and cut size.

Concerning the proportion of ultrafines contained in the classifier feed, this aspect is being investigated further in an effort to minimise the negative effect created by large amounts of very fine particles which, among other things, also produce grain agglomeration.

Lastly, it should be mentioned that the present study concerned a homogeneous, non hygroscopic solid, with regularly shaped species of similar specific weight, parameters that warrant further investigation.

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REFERENCES

Alfano G., Dondi M.,Saba P., Surracco M., 1995. Performance of a new jet mill in fine grinding of some industrial minerals. Proceedings XIX Int. Min. Congr., San Francisco, CA, USA, October 22-27, 1995, Vol I pp 105-108.

Alfano G., Saba P., Surracco M., 1997. Top size control in fine mineral grinding. Proceedings of the XX

Int. Min. Congr. Aachen, Germany, September 21-26, pp 337-344.

Clyde Orr Jr, Dalla Valle J.M. - Fine particle Measurement. New York, The Mc Millan Company, 1960.

Wills B,A. - Mineral Processing Technology - An Introduction to the Practical Aspects of Ore Treatments and Mineral recovery. Int. Series on Material Sciences and Technology. Vol 29, 1979, Pergamon Press, New York.

Nautamix NV - Bolletino Tecnico - 1970, Aarlem, the Netherlands.

Alfano G., Saba P., Surracco M., La micronizzazione della barite con un nuovo mulino a getto. II Convegno Minerario Italo-Brasiliano, San Paolo, Brasile, 15-17 sett. 1993, ANAIS, vol.2. pp.827-838.