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Fine classification with vaned rotors: at the outer edge of the vanes or in the interior vane free area?

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Abstract

Based on the physical model of classification in vaned rotors, the fundamental difference between the exclusive use of a forced vortex flow (i.e. classification at the outer edge of the vanes) and the combined use of forced vortex/free vortex flow (i.e. classification in the interior vane free area) is derived.

The classifier used for the comparison is a CFS-HDS model. Results received from this classifier equipped with a Convor-wheel with constant radial velocity of the flow in the interior vane free area are compared with results from a classifier wheel designed for classification at the outer edge of the vanes.

Topics of special interest:

- range of fineness,
- sharpness of cut,
- pressure drop.

Keywords: vaned rotor; outer edge; vanes

1. Theoretical background

Classification in vaned rotors can be described as the equilibrium of two forces acting on an individual particle: the drag force F_W and the centrifugal force F_T. From this equilibrium, within the Stokes-range, the cut point of classification can be derived ([Rumpf, 1939]):

$$d_T = \sqrt{\frac{18 \cdot v_r \cdot r \cdot \eta_c}{\rho_s \cdot v_u^2}} \quad (1)$$

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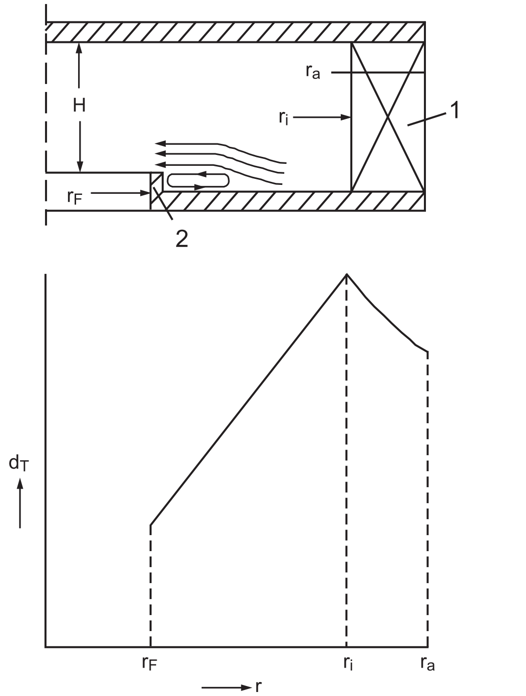

Fig. 1. Cut point d_T in a vaned rotor as a function of the radius; (1) vanes, (2) co-rotating immersion tube.

For constant substance parameters, the cut point becomes a function of geometric and operational parameters (Nied, 1996):

$$d_T \propto \xi = \sqrt{\frac{v_r r}{v_u^2}} \tag{2}$$

From Eq. (1), the cut point d_T can be calculated as a function of the radius r (Nied, 1996; Galk, 1995):

– the radial velocity component follows the continuity law

$$v_r = \frac{V}{A} \tag{3}$$

– the circumferential velocity component develops in accordance with a solid body rotation between the vanes

$$\frac{v_u}{r} = const. \tag{4}$$

and in accordance with a free vortex flow in the vane-free interior area

$$v_u r = const. \tag{5}$$

As Fig. 1 indicates, the cut point d_T initially increases along the vanes and then decreases in the vane-free interior area. The radius r^* in the vane-free interior area that shows the same cut point d_T as observed at the outer edge of the vanes can be calculated as follows:

$$r^* = \frac{r_i^2}{r_a} \tag{6}$$

or

$$\frac{r_i}{r^*} = \frac{r_a}{r_i} \tag{7}$$

Following that, two possible locations for the classification can be defined:

– the outer edge of the vanes for

$$\frac{r_i}{r_F} < \frac{r_a}{r_i} \tag{8}$$

– the interior vane free area for

$$\frac{r_i}{r_F} > \frac{r_a}{r_i} \tag{9}$$

The fineness index number ξ as given per Eq. (2) finally becomes

– for classification at the outer edge of the vanes

$$\xi = \sqrt{\frac{1}{r_a^2 \cdot H_a} \cdot \frac{V}{n^2}} \tag{10}$$

– for classification in the vane-free interior area

$$\xi = \sqrt{\left(\frac{r_F}{r_i}\right)^2 \cdot \frac{1}{r_i^2 \cdot H_F} \cdot \frac{V}{n^2}} \tag{11}$$

In Eq. (10) the geometric parameters are related to the outer edge of the vanes, whereas Eq. (11) shows an additional parameter-group: r_i/r_F. Hereafter, this parameter-group shall be called “intensification-factor” R=r_i/r_F.

2. Test equipment

Fig. 2 shows the classifier wheel used for classification at the outer edge of the vanes (hereafter called "solid body rotor").

It is characterized by vanes that reach into the area of the fines discharge. This prevents the development of a free vortex flow, the circumferential velocity follows the law of solid body rotation and therefore decreases on its way to the fines discharge.

Fig. 3 presents a Convor classifier wheel. It is designed for the classification in the vane-free interior area. The contour of the rotating walls is such that the surface of the virtual cylinders is a constant for any radius. As a consequence, the radial velocity of the flow should stay constant as well. The fines discharge is equipped with a co-rotating, interchangeable immersion tube. For these tests, three sizes with different diameters had been used (see also Table 1).

The a.m. classifier wheels had been installed in a CFS/HD-S 85 classifier model (Web site Netzsch Condux [Internet]. 2001; Web site Dr. Nied Consulting [Internet]. 2001), produced by Netzsch-Condux. Fig. 4 shows a schematic drawing of this classifier. Table 1 gives a summary of significant geometric and operating parameters.

The restriction to a maximum circumferential velocity of 120.6 m/s has a practical background: this allows the use of standard construction materials (e.g. carbon steel or similar), and even the use of abrasion resistant materials such as ceramics or hard metals, when processing abrasive substances.

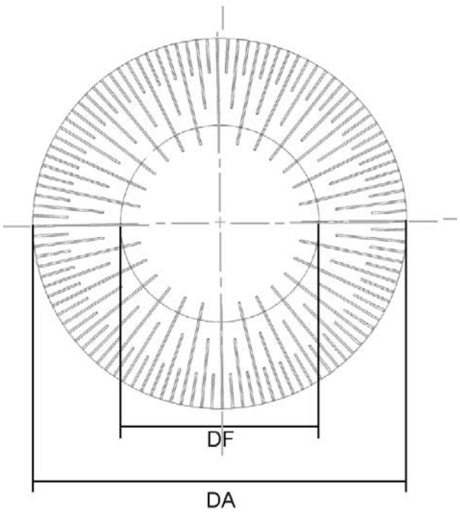

Fig. 2. Classier-wheel for classification at the outer edge of the vanes.

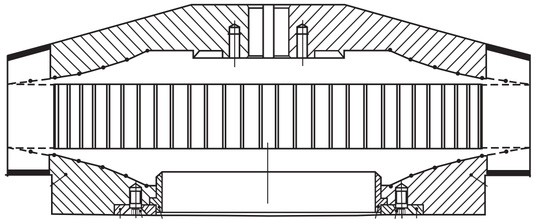

Fig. 3. Convor classifier wheel for classification in the interior vane-free area.

The radial velocity in the classifying zone (outer edge of the vanes for solid body rotation, radius of the fines outlet for classification in the interior vane-free area) has been chosen in such a way, that—for a given geometrical size of the equipment—acceptable air-flow rates can be achieved.

Finally, the range of the product to air ratio was selected in accordance with practical experience for the expected fineness.

3. Experimental results

Test material was limestone with a feed size of d_{97}=16 μm and d_{50}=4 μm. All particle size analyses have been performed on a Cilas 850 B Laser diffraction instrument.

Table 1
Significant geometric and operating parameters

	Convor	Convor	Convor	Solid body
Outer radius, r_a (m)	0.16	0.16	0.16	0.16
Intensification factor, R	2.2	2.0	1.6	≈ 1
Revolutions n_{max} [min^{-1}]	5.300	5.300	7.200	7.200
Circumferential velocity $v_{u,a}$ (m/s)	88.8	88.8	120.6	120.6
Radial velocity $v_{r,a}$ (m/s)	7.1–8.5	7.1–8.5	5.8–7	7.1–8.5
$v_{r,F}$ (m/s)	7.3–8.8	6.6–8	5.5–6.6	11–13.1
Product/air ratio, v_L (kg/m^3)	0.1–0.25	0.1–0.25	0.1–0.25	0.1–0.25

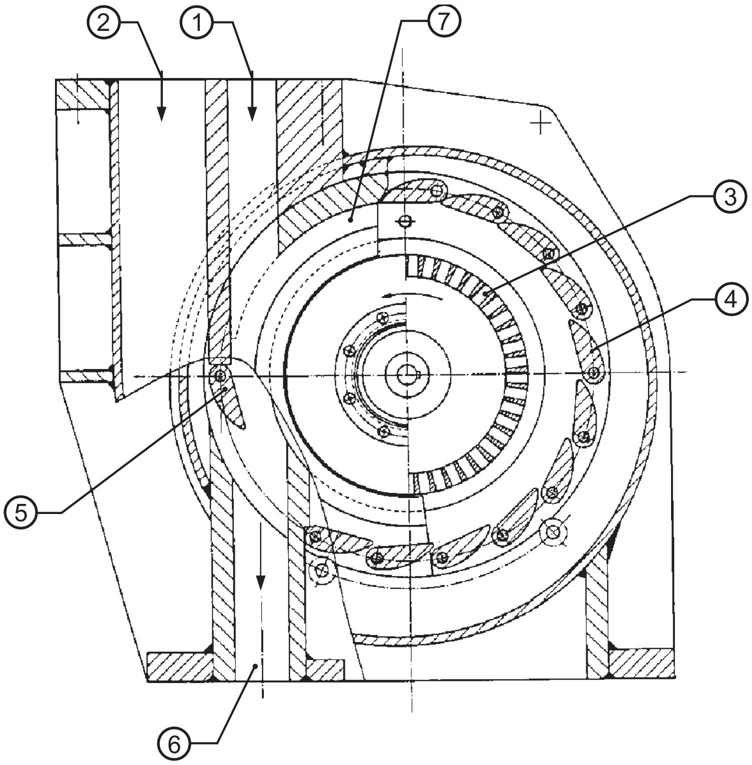

Fig. 4. Schematic view of the classifier CFS/HD-S. (1) Product feed; (2) air inlet; (3) classifier wheel; (4) static vane basket; (5) adjustable coarse flap; (6) coarse discharge.

3.1. Range of fineness

Fig. 5 illustrates the fineness d_{97} in the fine fraction as a function of the circumferential velocity $v_{u,a}$ at the outer edge of the vanes for all four classifier wheel designs. As expected, the circumferential velocity necessary for a desired fineness d_{97} decreases with growing r_i/r_F factors. By far, the solid body rotor requires the highest circumferential velocity: for the same fineness, that velocity is almost doubled in comparison to the Convor rotor with R=1.6. The smallest d_{97} achievable within the

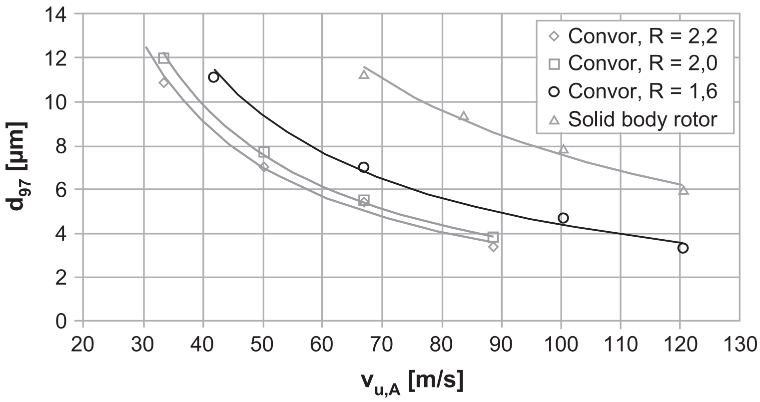

Fig. 5. d_{97} of the fine fraction as a function of the circumferential velocity $v_{u,a}$ at the outer edge of the vanes.

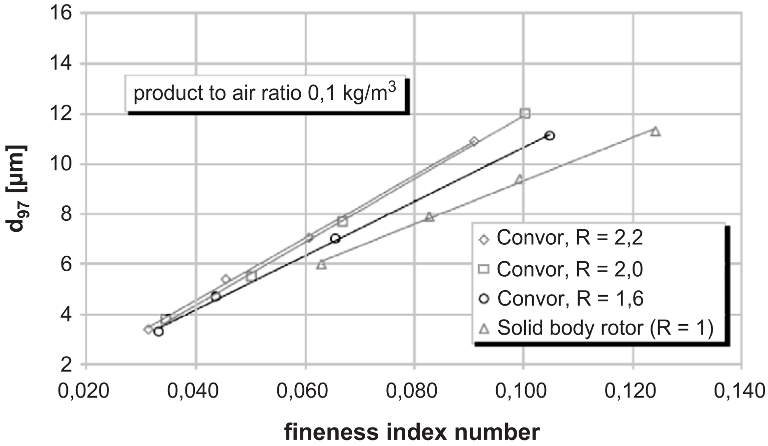

Fig. 6. d_{97} of the fine fraction as a function of the fineness index number ξ.

chosen parameters is approximately 6 µm for the solid body rotor and approximately 3 µm for the Convor rotors.

In Fig. 6, d_{97} of the fine fraction is plotted versus the fineness index number ξ for a product to air ratio of 0.1 kg/m^3. The obtained results follow a straight line for each of the rotors; again it is evident that the Convor rotors achieve smaller d_{97}-values compared to the solid body rotor. However, the gradients of these straight lines show different values.

Linear regressions on the function $d_{97}=a+m\xi$ have been carried out to analyse the gradient's differences, see Table 2. The spread of the a-values of this analysis is around zero; within good accuracy they can be rounded to $a=0$. d_{97} therefore becomes a function of the gradient m and the index number ξ.

Fig. 7 shows the plot of the gradient m versus the intensification factor R. It suggests a dependence of the gradient m on the factor R. The reason for this may be the fact that the assumption to derive the radial velocity, Eq. (3), as well as the circumferential velocity, Eq. (5) was the characteristic of a noncompressible fluid. However, within the range of velocity and pressure drop obtained, gases become compressible. The true radial velocity therefore is higher; the circumferential velocity should be lower than calculated. As a result, higher intensification factors R demand lower ξ-values to achieve the same d_{97}.

Fig. 8 shows d_{97} as a function of the index number ξ with the parameter product to air ratio. Two rotors were compared: the Convor wheel (R=1.6) and the solid body rotor. Both showed the well-known behaviour of vaned rotors: the cut point (here: d_{97}) moves to the fines when increasing the product to air ratio.

Table 2
Statistics of the function $d_{97}=a+m\xi$; parameter: intensification factor R

Classifying rotor	R	m	a
Convor	2.2	124.3	−0.42
Convor	2.0	125.8	−0.67
Convor	1.6	107.6	−0.13
Solid body rotor	1	86.6	0.66

3.2. Classifier efficiency

To characterize the efficiency of the rotors compared, the fines efficiency number $k_{F,97}$ is used. It is defined as the ratio between the fines yield f (calculated from the mass balance) and the fines originally contained in the feed material:

$$k_{F,97} = 0.97\frac{f}{Q_{A,d_{97}}} \tag{12}$$

Figs. 9 and 10 show the fines efficiency $k_{F,97}$ as a function of d_{97} for a product to air ratio of 0.1 and

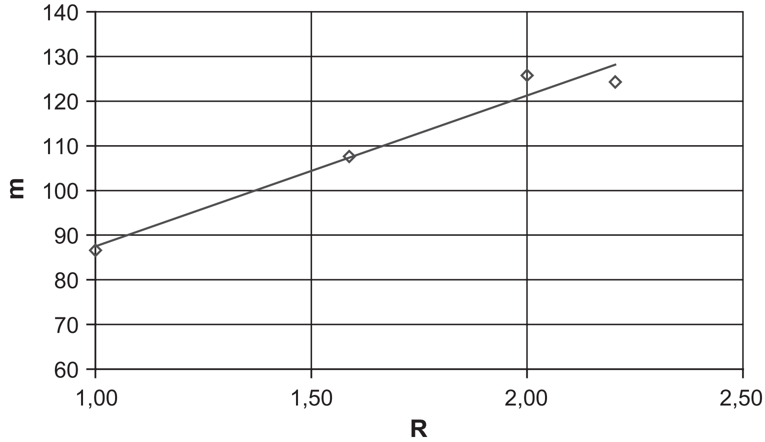

Fig. 7. Gradient m of the function $d_{97}=a+m\xi$ versus the intensification factor R.

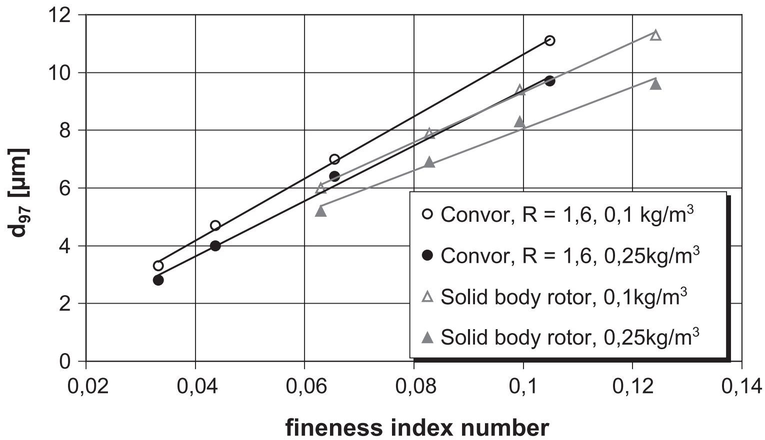

Fig. 8. d_{97} as a function of the index number ξ for Convor (R=1.6) and solid body rotors; parameter: product to air ratio.

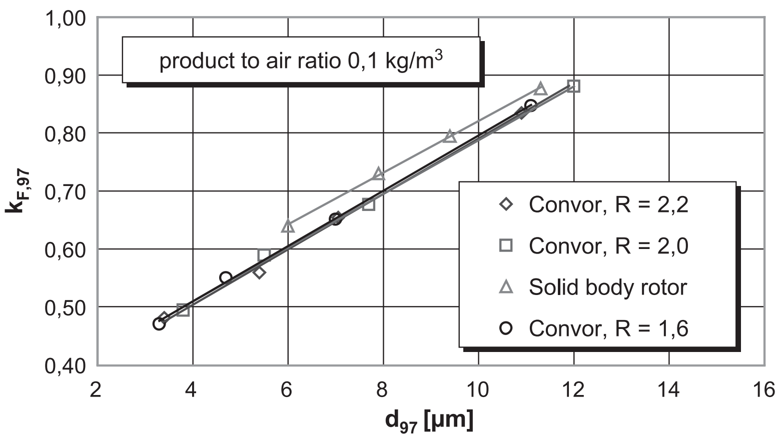

Fig. 9. Fines efficiency $k_{F,97}$ as a function of d_{97}; product to air ratio: 0.1 kg/m^3.

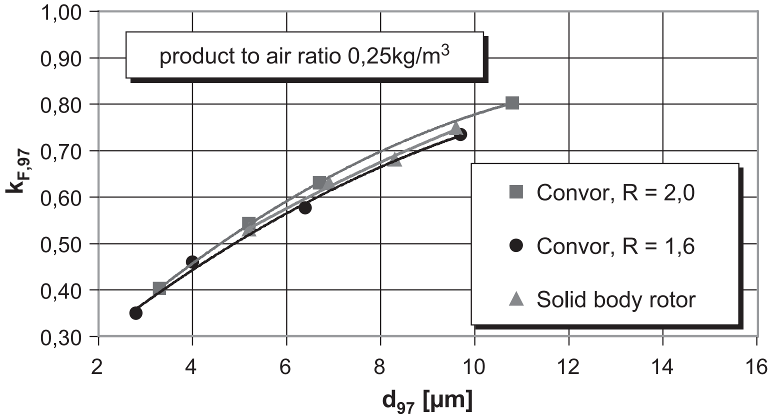

Fig. 10. Fines efficiency $k_{F,97}$ as a function of d_{97}; product to air ratio: 0.25 kg/m^3.

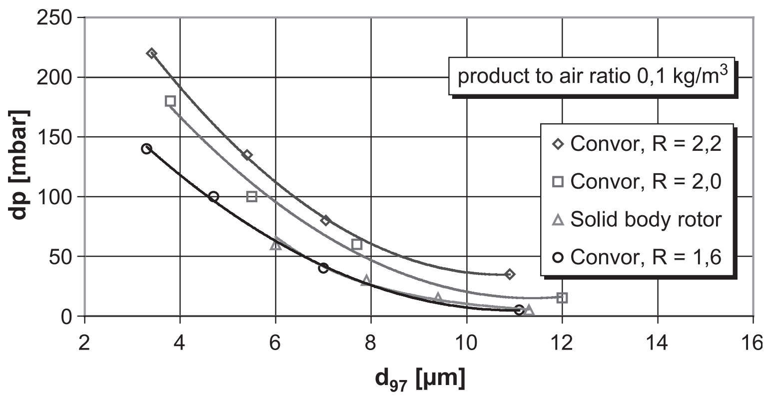

Fig. 11. Pressure drop Δp as a function of d_{97} of the fine fraction; product to air ratio: 0.1 kg/m^3.

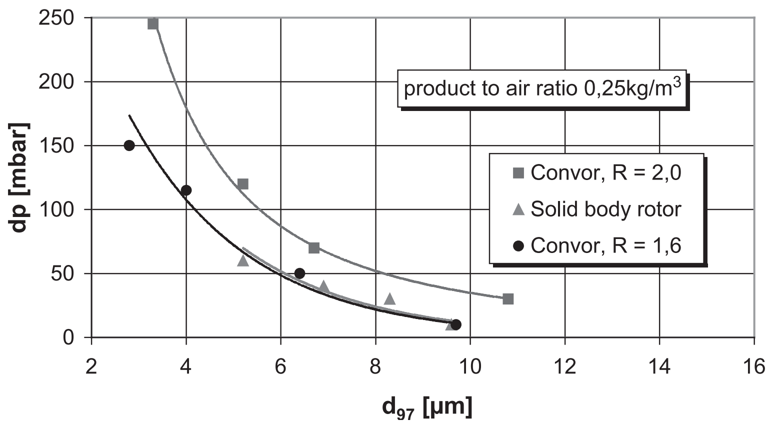

Fig. 12. Pressure drop Δp as a function of d_{97} of the fine fraction; product to air ratio: 0.25 kg/m^3.

Table 3
Application matrix for Convor- and solid body classifying rotors

Range of d_{97} of the fine fraction	Feed material	
	Nonabrasive	Abrasive
$d_{97}<6$ μm	Convor, R=1.6	Convor, $R\geq2$
6 μm$\leq d_{97}\leq$15 μm	Convor, R=1.6 (solid body rotor)	Convor, $R\geq1.6$
15 μm$\leq d_{97}\leq$40 μm	Convor, R=1,6 (solid body rotor)	Convor, $R\geq1,6$ (solid body rotor)

0.25 kg/m^3. No significant difference between the Convor- and solid body rotors could be found. The higher product to air ratio, as expected, reduces the efficiency, especially in the very fine range (below 6 μm).

3.3. Pressure drop

Together with the efficiency, the operating costs are crucial for the economic viability of a classification. Expenses for maintenance, especially when processing abrasive substances, and the pressure drop of the classifier represent the most important operating cost factors.

In Figs. 11 and 12, the pressure drop Δp of the classifying rotors compared is plotted against d_{97} of the fine fraction. As expected, for a given fineness d_{97} the pressure drop increases with the intensification factor R. The Convor wheel with R=1.6 shows almost identical Δp-values as the solid body rotor.

The influence of the product to air ratio can be disregarded. The increase of pressure drop for the pneumatic transport of the higher mass flow of product is nearly compensated by the finer d_{97} achieved with higher product to air ratio, compare Fig. 8 (i.e. lower circumferential velocity is required to achieve the same d_{97}).

Thus, classifying rotors can be tailored to a specific application. To reach low pressure drop, Convor wheels with R=1.6 or solid body rotors should be used. To reduce wear, Convor wheels with R>1.6 are recommended as they require significantly lower circumferential speed at the outer edge of the vanes to achieve the same fineness d_{97} (compare Fig. 5).

4. Summary

A comparison of Convor classifying rotors (classification in the vane-free interior area) of varied intensification factors R with a solid body rotor (classification at the outer edge of the vanes) produced the following results:

- Under practical conditions, Convor rotors have a higher potential for finest cuts.
- The efficiency of classification is comparable with both kinds of rotors.
- For Convor rotors, the pressure drop is a function of the intensification factor R. When R=1.6 they reach the same low pressure drop level as the solid body rotor.

From the above statement, an application matrix can be created, see Table 3.

Nomenclature

A (m^2) cross-sectional area
d_T (m, μm) cut point
d_{97} (m, μm) particle size at which 97% of the particle size distribution pass
f fines yield
H (m) interior height
$k_{F,97}$ classifier efficiency
m gradient
n (min^{-1}) revolutions
Δp (mbar) pressure drop
$Q_{A,\, d_{97}}$ (%) portion of material contented in the feed at d_{97}
r (m) radius
R intensification factor
v (m/s) velocity
$\dot{V}$ (m^3/h) gas volume flow
η_c (Pa s) Viscosity
v_L (kg/m^3) product to air ratio
ρ (kg/m^3) density
ξ (s^{-1}) fineness index number

Indices

a outer edge of the vanes
F fines outlet
i inner edge of the vanes
r radial
u circumferential

References

Galk, J., 1995. Dissertation TU Clausthal. 41 ff.

Nied, R., 1996. Int. J. Miner. Process. 44–45, 723 – 731.

Rumpf, H., 1939. Dissertation TH Karlsruhe.

Web Site Dr. Nied Consulting [Internet]. Available from: http://www.drnied.de/server-d/content_text_02.htm [Accessed Febr. 2001].

Web Site Netzsch Condux [Internet]. Available from: http://www.netzsch-mahlen.de/technologie/e_feinstsichten.html [Accessed Jan. 2001].