Contributions to development of an inertial separation system for suspended solid particles in air

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Abstract. The separation of particles with big inertial mass transported in the air, is most often done with the help of cyclones, due to their resistance to wear at contact with abrasive particles. However, pneumatic conveying of heavy and abrasive granular material mixed with fines, are problematic even for cyclone hardened inlets. The paper studies a new method of dividing the main airflow in two airstreams, one further divided in more smaller streams to achieve the laminar regime, by using a corrugated shaped inlet. Thus generating an improvement in impact resistance, overall cyclone grade efficiency and decreasing pressure drop.

1 Introduction

Cyclones are among most used inertial separators worldwide. Since their invention, in 1885 by John Finch (US325521A Patent), cyclones have been improved and studied in many ways, such as dimensional ratio, separation technic, wear resistance, air pressure and efficiency for separation.Since then, cyclone is preferred for difficult applications where air must be separated from heavy inertial particles and also fines.

The most common type of cyclone is the reverse flow tangential cyclone (figure 1). Fluid is introduced through an inlet section (rectangular or circular), tangential to a cylindrical section. The flow speed will therefore form a vortex along the outer wall, carrying the particles due to the inertial forces, and continued to the lower cone separating particles to the bottom outlet [1]. Filtration of particles occurs by separating the transported elements in the lower exit (D_u). Air and particles which could not be captured in the separation process, are pulled with the air to the center duct, forming an inner vortex, then evacuated outside through the upper exit duct D_0, Figure 1.

The Overall Separation Efficiency of the cyclon is based on proportion of particle mass fractions: the infeed (Mi), the emitted (Me), and the captured fractions (Mc). [2]

Usually, to estimate a cyclone capability we measure the masses of these fractions.
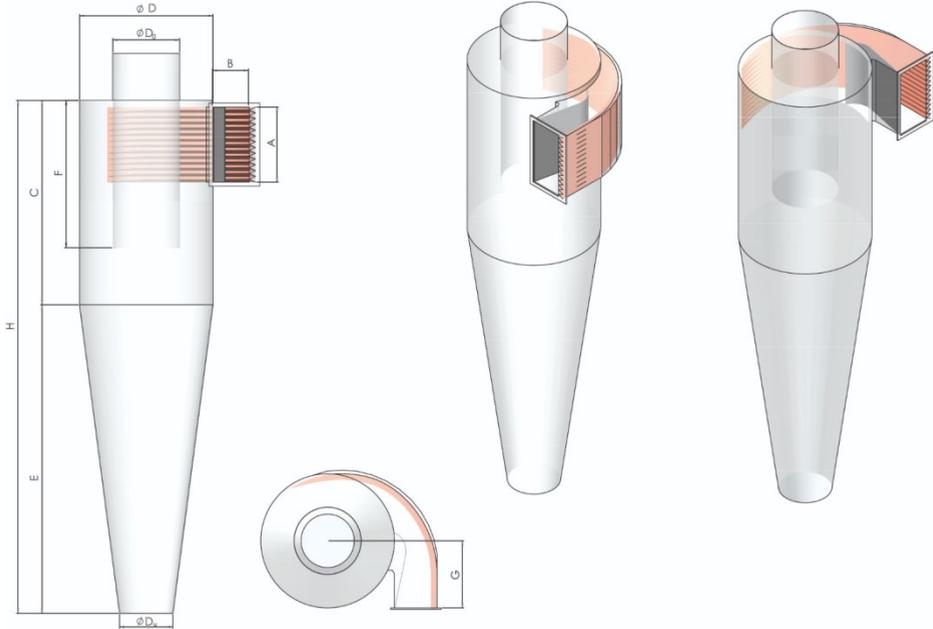
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Fig. 1. Cyclone with corrugated inlet plate example.

Based on the description above:

$$M_i = M_e + M_c \tag{1}$$

The overall efficiency (η) is calculated based on the fraction captured by the cyclone in the lower exit D_u.

$$\eta = \frac{M_e}{M_c} \tag{2}$$

An important cyclone performance parameter, for industrial applications, is the pressure loss, simply defined as difference between pressure measured before and after the cyclone, stating the resistance to air transition:

$$\Delta p = p_i - p_e \tag{3}$$

Some estimations on the pressure drop models are described in equations, others are purely empirical.

In general, pressure loss depends on number of turns, tangential speed in the cyclone, fluid viscosity (dust loading in air) and laminar/turbulent regime.

The present work studies the advantages added by attaching a corrugated plate on the slope side of the cyclone inlet. This will increase abrasion resistance of the cyclone inlet, and separate the initial flow (Q_i) in two separate flows:

- one laminar (Q_l), which will carry mostly heavy particles along corrugations;
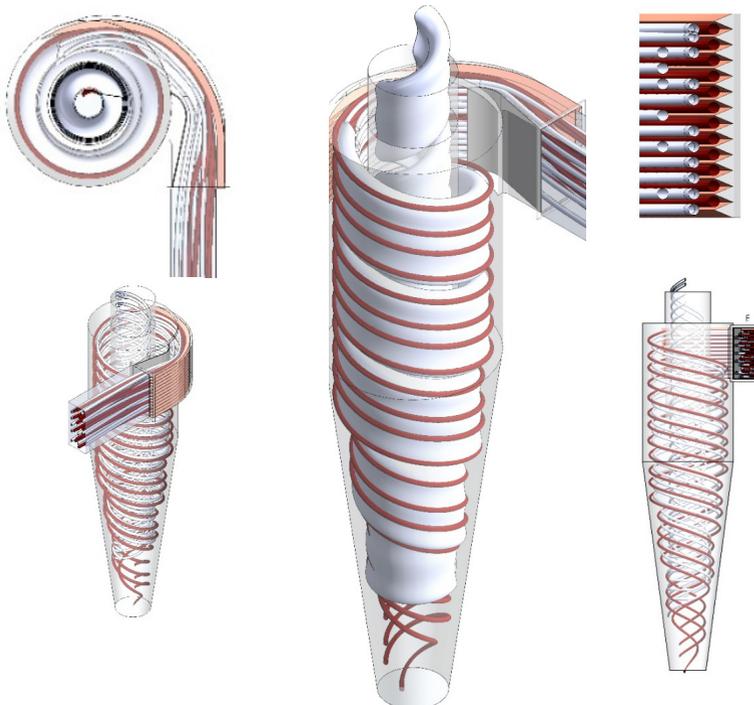- one turbulent (Q_t), in the interior side of the inlet.

Fig. 2. Outer and Inner Vortex.

2 Flow regime

The corrugated plate will be lined lose on the exterior surface of the inlet slope, in a non rigid manner (elastic), for a better resistance to wear. The corrugations are triangular shapes, as per Figure 1-3. This will guide air in the channels formed as shown in Figure 2.
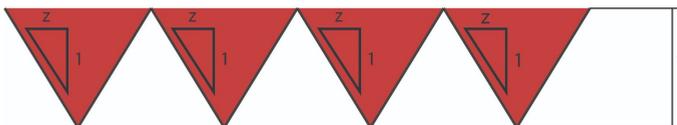

Fig. 3. Corrugation dimensions.

The hydraulic diameter of each channel can be determined with the following relation:

$$d_h = \frac{yz}{\sqrt{(1+z^2)}} \qquad (4)$$

Where z is the slope resulted as variation between x and y:

$$z = dx/dy \qquad (5)$$

This is important for calculation of Reynolds number (Re), based on which we may further establish the settlement velocity regime, according following equation:

$$Re = \rho_g v d_h / \nu \qquad (6)$$

Where:

ρ_g = Air density (app. 1,2 kg/m^3);

v = Air speed;

d_h = Hidraulic diameter;

ν = Air viscosity (app. 1.8 x 10^{-6} Pa s).

When Re < 2000 the flowing regime will be laminar. For Re > 4000 it will be a turbulent.

In case of a classic cyclone with rectangular inlet, the hydraulic diameter is calculated based on inlet dimensions (a,b), according equation:

$$d_h = 2\, a\, b\, /\, (a + b) \tag{7}$$

For cyclones separating air from particles, the flow will be turbulent due to the low air viscosity and large hydraulic diameter combined with high inlet speed.

By using the corrugation plate, a part of the Q_i will be guided along the triangular paths and converted from turbulent to laminar. Each hemi triangular side becomes a separate channel which will guide airflow and particles.

This is possible due to low air speed in proximity of high corrugation surface, very small D_h on corrugation crossection and high concentration of particles in the air (φ) which will increase viscosity due to their inertial mass/speed property.

3 Sedimentation rate

When sum of forces acting on particle are balanced, the movement is constant and the particle falls at unvarying speed. This speed is called "sedimentation rate" and it has a crucial role for the particle separation, therefore contributing to cyclone grade efficiency and cut size. [4]

When Re < 2000 the sedimentation rate is laminar and may be calculated using the equation:

$$v_l = \frac{d^2 v_{Q_l}^2 (\rho_p - \rho_g)^2}{18 v \rho_g} \tag{8}$$

In turbulent regime, when Re > 2100, sedimentation rate is determined with equation:

$$v_t = 1.74\, v_{Qt} \sqrt{\frac{d\left((\rho_p - \rho_g)\right)}{R\,\rho_g}} \tag{9}$$

Where: d is the diameter of the particle; v_{Ql}, v_{Qt} is the average velocity of the laminar flow and turbulent flow respectively; ρ_p, ρ_g is particle, respective air density, R is Cyclone radius, which is approximated equal for both regime types.

Average velocity in turbulent regime is higher, compared with laminar regime, due to parabolic shapes difference as shown in Figure 4.
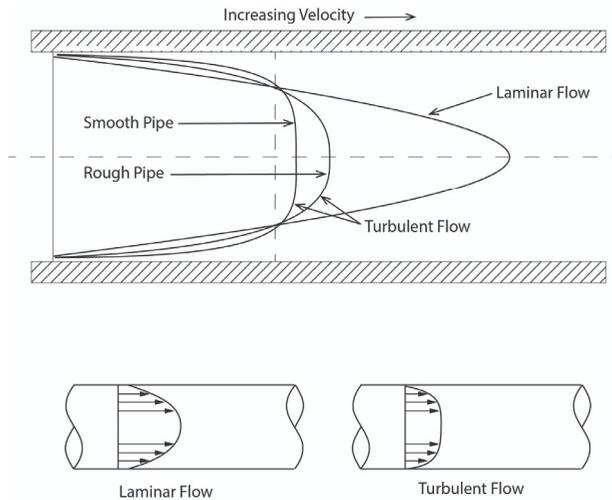
Fig. 4. Laminar vs Turbulent velocity distribution in a duct.

4 Sedimentation time

Average speed, in turbulent/laminar regime, will influence the time of sedimentation - which is depending on sedimentation rate v_l, v_t, cylinder radius (R) and top outlet radius (R_o) with following formulae:

   - the laminar sedimentation time:

$$t_l = \frac{9\vartheta}{d^2 v_l^2} \times \frac{\rho_g}{\rho_p - \rho_g} \times (R^2 - R_0^2) \tag{10}$$

   - the turbulent sedimentation time:

$$t_t = \frac{R^{1.5} - R_0^{1.5}}{2.55 v_t \sqrt{d \frac{\rho_p - \rho_g}{\rho_g}}} \tag{11}$$

To achieve separation of particles from gases, the condition that the sedimentation time is smaller than transit time for particles in study, must be fulfilled.

To calculate the transit time, the length (L) of the flow stream, from entry point until total sedimentation point, must be estimated based on number of turns (n), cylinder radius (R) and upper exit radius (R_o), with following formula:

$$L = \pi (R - R_0) n \tag{12}$$

On this basis, the transit time will be:

$$t_{tr} = \frac{\pi (R - R_0) n}{\vartheta_i} \tag{13}$$

With these in view, the proportion of flow Q_l will have a better separation, due to larger transition time, agglomeration effect and shorter sedimentation time.

5 Cut size

In a group of traditional cyclones connected in parallel (multicyclones), the smaller particle diameter with a collecting efficiency of 50% is calculated from [3]:

$$d_{50} = \left[\frac{9v \left(Qi/N \right)}{\pi \rho_p z_c v_{tmax}^2} \right]^{0.5} \tag{14}$$

Where N signify the number of cyclones in parallel, z_c is the vortex core length, v_{tmax} is the maximum tangential velocity.

In corrugated inlet cyclone, the flow will form several strings, as shown in the Figure 2, each corresponding to a division of the flow Q_l to the number of corrugations.

When these flows are in laminar regime, maximum tangential speed: ($v_{tmax} = 2v_m$) will be higher compared to turbulent regime ($v_{tmax} = \frac{5}{4} v_m$), as shown in Figure 3.

Therefore, cut size d_{50}, will be smaller in the corrugated plate cylinder where laminarity condition is achieved.

6 Abrasion

Cyclones are equipments mainly used to separate inertial particles with large mass. These comes in various shapes, sizes, hardness and rugosity, their impact on cyclone surfaces is therefore of a significant importance.

Since the exposed angle of impact is much smaller and the elasticity modulus is much bigger, compared to the traditional plate inlet, the absorbed energy in the plate is also minimal therefore resulting a good resistance to the abrasion and impact.

The particle initial collision force is decomposed in a normal and tangential force, in relation with the angle of impact to the plate surface.

Main deformation is achieved at large Normal force, therefore a small impact angle will result in less wear of inlet surface [5].

Experimental equipment was made in such manner to allow placing of a removable corrugated plate, fixed in such way to permit elastic deformation on impact with large particles, see Figure 5.

Fig. 5. Practical example of inlet with corrugation plate.

7 Conclusion

Using a corrugation plate at cyclone inlet, will increase grade efficiency due to the division of initial flow in a laminar and turbulent segment.

Resistance on abrasion is highly increased due to the angular exposure of plate surface on particle trajectory.

Cut size of cyclone is reduced due to increase in maximum tangential velocity especially in the laminar flow part.

Construction costs are reduced due to diminishing of materials thicknesses, wear resistance being transferred to the specially designed corrugation plate.

Experimental data and industrial practical tests, showed an increase of above performances, compared with same sized traditional cyclones.

References

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