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THE EFFECT OF PARTICLE SIZE AND INPUT VELOCITY ON CYCLONE SEPARATION PROCESS

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Abstract: *Cyclones have been regarded as one of the simplest and cheapest type of separator on account of their high efficiency, adaptability, and relative economy in power. Cyclones have been widely used in different industrial processes. The literature reveals that the cyclone efficiency is dependent on the particle size from the mass of the mixtures heterogeneous solid-fluid. The input air velocity affects both the fan energy consumption and the dust collection efficiency. The objective of this paper is to demonstrate theoretically the influence of the dimensions solid particles and the input velocity into the cyclone over the collection efficiency.*

Key words: *input velocity, particles size, inlet pipe, cyclone.*

1. Introduction

The first cyclone patent was granted to John M. Finch of the United States back in 1885 and assigned to the Knickerbocker Company. Although the "dust collector", as it was then called, contained the essence of today‘s modern cyclones, the dust was allowed to exit out the side of its cylindrical body, rather than out a conical-shaped bottom. It was also a rather complex device and bore little resemblance to today‘s modern cyclones.

Still, the idea of using centripetal acceleration for separating particles from a gas stream was quite a radical idea back in the late 1800's. After all, everyone knows that dust will settle only when the gas stream carrying the dust is quiet and relatively free of motion for a long time.

Most of the early cyclones were used to collect dust created from mills that processed grains and wood products. In the decades that have followed, however, cyclones have found application in virtually every industry where there is a need to remove particles from a gas stream [4].

Cyclones have been regarded as one of the simplest and cheapest type of separator on account of their high efficiency, adaptability, and relative economy in power. Cyclones have been widely used in different industrial processes.

The cyclone separator is a device with no moving parts and virtually no maintenance. It enables particles of micrometers in size to have been separate from a gas moving at about 15 m/s without excessive pressure drop [3].

Although they cannot meet very stringent particulate emission standards, their low capital cost and robust construction make them ideal particle-gas separators. Whereas they have considered as low efficiency

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separators in the past, advanced design principles have significantly improved their efficiency, now in excess of 98% at ambient operating conditions for particle sizes larger than approximately 5 µm when these design principles have adhered [1].

The cyclone has been configuring to accelerate the natural separation of material from air. Cyclonic separation is a method of removing particulates from an air, gas or water stream, without the use of filters, through vortex separation. Rotational effects and gravity have been use to separate mixtures of solids and fluids [8].

Cyclones are particularly well suited for high temperature and pressure conditions because of their rugged design and flexible components materials [2].

The physical laws governing the behavior of today's modern industrial cyclones were firmly established more than a hundred years ago in the works of Sir Isaac Newton and Sir George Gabriel Stokes. Their work provided us with a basis for describing the forces acting on a particle traveling in a fluid medium. Rosin, P., Rammler, E., Intelmann, W. and Feifel, E. especially, established the basis for scientific calculations [4].

The objective of this paper is to demonstrate theoretically the influence of the dimensions solid particles and the input velocity into the cyclone over the collection efficiency.

2. Cyclone Separation Efficiency

The principle of separation in a cyclone is to increase the effect of sedimentation by centrifugal force, which is made by introducing tangential suspension in a device. The efficiency of separation cyclones is much higher than dusting rooms because in a centrifugal force field, the effect of separation is maximized.

In the case of cyclones, the effect of centrifugal force manifests itself differently from particles and gas. Due to centrifugal force the solid particles are thrown to the wall where they lose energy and fall moving under the action of gravity at the bottom of the device where it is discharged (particle mass > gas mass). So, gas is moving downward spiral, solid particles being driven to the top of the gas and then gas (air) is discharged through the central tube of the cyclone due to the circulation effect [5].

Cyclone efficiency characterizes its ability to retain from fluid environment the solid particles of a certain minimum size required. At the same cyclone, changing the particle density and fluid viscosity, changes its efficiency. To retain the minimum of particles diameter required is necessary to align the input speed of the fluid in the cyclone with product characteristics (density of the medium, particle density, and viscosity) and constructive parameters of the cyclone.

Efficiency of solids separation in a cyclone has typical value of 70-80%, but if the fluid is loaded with large amounts of solids, separation efficiency exceeds 99%.

Separation in cyclones is favorable with large particles that would normally be entirely separate, the fluid, in the output will contain only particles smaller than the critical diameter. But, the swirling formed inside the cyclone influence the process of separation [9].

Stairmand (1951) described the collection efficiency curve which indicates the efficiency of the cyclone for separating particles of given density over a range of sizes. This curve is also known as the grade efficiency curve.

Researchers over the years have produced a number of predictive models that use empirical information related to the geometry and operating conditions of specific cyclone designs and are intended to estimate cyclone collection efficiency. Leith (1984) summarized a number of these models. His list included models by

Stairmand (1951), Barth (1956), Lapple (1951) and Leith and Licht (1972). Ogawa (1984) also reviewed a number of predictive models including Lapple and Shepherd (1940), Barth (1956) and Stairmand (1951) [6].

3. Material and Method

The cyclone dimensions used in theoretical research were derived from dimensional calculation and design using AutoCAD. For dimensional calculating it was chosen an input speed of impure gas in the inlet pipe 15 m/s and a volume flow 400 m^3/s. With this data was determined the size of the cyclone parts according to geometric similarity reports of a cyclone type chosen. In Figure 1 it can be observed the geometry of the cyclone with tangential entry.

To calculate cyclone efficiency have used the relationship given by Leith and Litch (1972). The Leith and Licht (1972) model predicts the grade efficiencies based on the concept of continual radial back mixing of the uncollected particles, and on the calculation of an average residence time for the gas in the cyclone [7]. The Leith and Licht equation proposed and used in this theoretical research is:

$$\eta = 1-\exp\left\{-2\left[\left(\frac{\frac{8\cdot\frac{\pi D^2}{4}\cdot h\cdot\frac{\frac{\pi D^2}{4}(h-s)+\frac{\pi D^2}{4}\left(\frac{\ln+s-h}{3}\right)\cdot\left(1+\frac{d}{D}+\frac{d^2}{D^2}\right)-\frac{\pi D_e^2\ln}{4}}{2}}{D^3}}{a\cdot b}\right)\cdot\left(\left(\frac{\rho d_p^2 v}{18\mu D}\right)\cdot 1.5\right)\right]^{\frac{1}{3}}\right\}\cdot 100, \quad (1)$$

where: η is the efficiency of the cyclone; D - diameter cylindrical body, D = 0.244 m; h - upper height of the cyclone, h = 0.56 m; s - depth of penetration of purified gas hose, s = 0.028 m; ln - natural length of cyclone, m; D_e - outer diameter of central tube exhaust gas purified, D_e = 0.122 m; ρ - solid particle density, a - height of the cyclone inlet, a = 0.122 m; b - width of the cyclone inlet, b = 0.061 m; ρ = 1110 kg/m^3; μ - gas mixture viscosity; $\mu = (37.4 + 0.506\,T)\cdot 10^{-5}$, T = 293 K; d_p - dimensions of particles, m; v - the average inlet velocity, m/s.

For theoretical investigation regarding the influence of the input velocity in the cyclone over the separation process efficiency were used six input velocity values: v_1 = 12 m/s; v_1 =15 m/s; v_1 = 18 m/s; v_1 = 21 m/s; v_1 = 23 m/s; v_1 = 25 m/s and a constant particle size of 0.00004 m.

Known parameters and formulas were introduced in Microsoft Office Excel 2003.

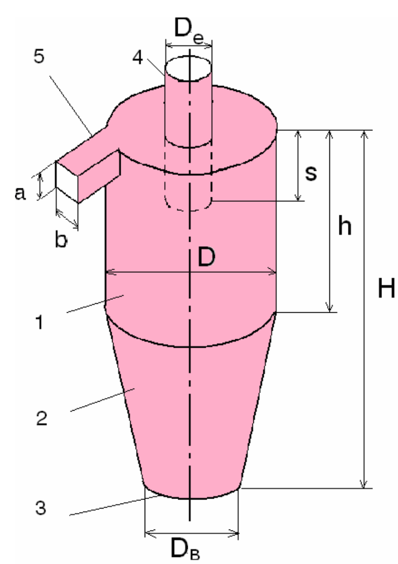

Fig. 1. *Cyclone with tangential entry:*
1 - *cylindrical body;* 2 - *cone-shaped body;* 3 - *outlet of solids particle;* 4 - *outlet of gas;* 5 - *gas supply hole doped*

In Table 1 are recorded the values obtained by calculating the separation efficiency with the relationship given by Leith and Licht (1972) for the six input velocity values listed above according to the five values of the cyclone inlet section: S_1 = 0.001575 m^2; S_2 = 0.002912 m^2; S_3 = 0.004928 m^2; S_4 = 0.006608 m^2 and S_5 = 0.007440 m^2.

For theoretical research regarding the influence of particle size dimensions and inlet geometry on the separation efficiency have used the following dimensions of the intermediate products resulting from the grist: big semolina = 1200 [mm]; middle semolina = 630 [mm]; small semolina = 400 [mm]; harsh dunst = 66 [mm]; soft dunst = 56 [mm]; flour = 40 [mm].

Table 1

Separation efficiency values depending on the input velocity in cyclone

v [m/s]	*dp* [m]	η_1 [%] (S_1 = 0.001575)	η_2 [%] (S_2 = 0.002912)	η_3 [%] (S_3 = 0.004928)	η_4 [%] (S_4 = 0.006608)	η_5 [%] (S_5 = 0.00744)
12	0.00004	75.988	75.78	72.741	67.931	65.896
15	0.00004	78.493	81.935	75.344	70.627	68.614
18	0.00004	80.467	83.772	77.415	72.797	70.812
21	0.00004	82.079	85.256	79.119	74.602	72.647
23	0.00004	83.003	86.1	80.102	75.651	73.717
25	0.00004	83.831	86.852	80.987	76.602	74.689

In Table 2 are recorded the values obtained by calculating the separation efficiency with the relationship given by Leith and Licht (1972) for the same five values of the cyclone inlet section used to study the influence of input velocity in cyclone over the separation efficiency listed above.

Separation efficiency values based on particle diameter Table 2

dp [m]	η_1 [%] (S_1 = 0.001575)	η_2 [%] (S_2 = 0.002912)	η_3 [%] (S_3 = 0.004928)	η_4 [%] (S_4 = 0.006608)	η_5 [%] (S_5 = 0.00744)
0.0012	100	100	100	100	100
0.00063	99.935	99.972	99.876	99.713	99.606
0.0004	99.559	99.762	99.285	98.675	98.326
0.000066	80.439	83.746	77.382	72.769	70.781
0.000056	76.831	80.374	73.610	68.834	66.803
0.00004	68.917	72.778	65.510	60.607	58.569

4. Results and Discussions

The chart from Figure 2 showed the variation of separation efficiency with input velocity in cyclone.

It can be noting that for the cyclone inlet section S_2 = 0.002912 m^2, the degree of separation is higher for any value of the input velocity unlike other sections of inlets cyclone.

The graph shows that the lowest efficiency was obtained to velocity input of 12 m/s and section area inlet S_5 = 0.0074 m^2, while for a velocity input of 25 m/s and a section area inlet S_2 = 0.002912 m^2 cyclone has reached a separation efficiency of 86. 852%. Also, it can be observed that for a input velocity of 23 m/s and a section area inlet S = 0.002912 m^2, the separation efficiency obtained was 86.1%.

To highlight the influence of particle size on separation efficiency in the cyclone has drawn the graph from Figure 3.

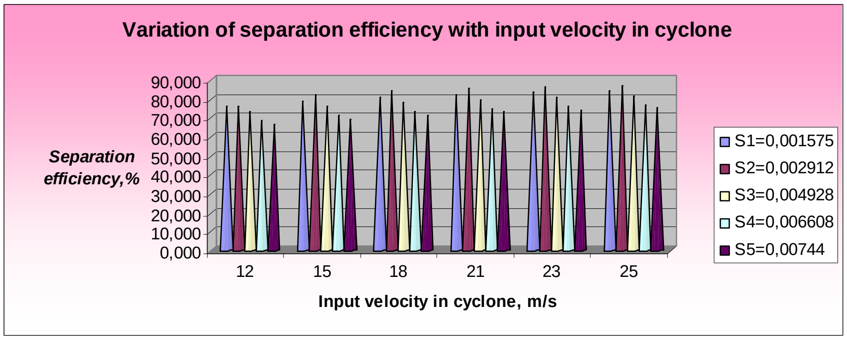

Fig. 2. *Variation of separation efficiency with input velocity in cyclone*

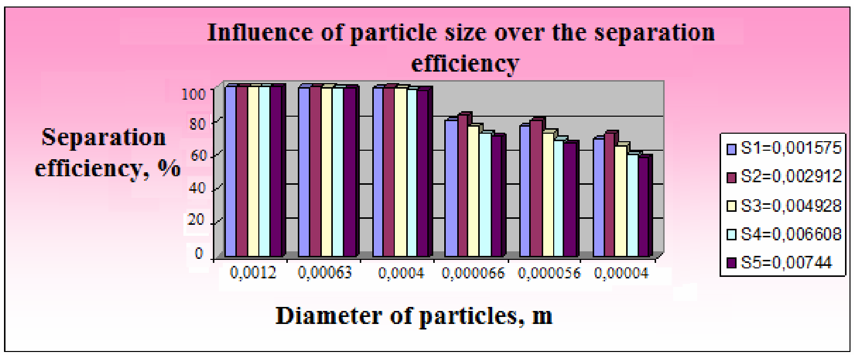

Fig. 3. *Variation of separation efficiency based on particle diameter*

In the graph from Figure 3 it can be observed that separation efficiency increases with the increasing of particle size. Also, it can be observed that for the sectional area of entry into the cyclone $S_2 = 0.002912$ m^2 the separation efficiency is higher, and for the sectional area of entry into cyclone S_5 = 0.00744 m^2 the separation efficiency decreases significantly. It also can be observed that for a diameter of 0.0012 m, separation efficiency is maximized, regardless of the inlet geometry.

5. Conclusions

1. According to the theoretical research, the separation efficiency is better with as the input velocity in cyclone is higher and the cyclone inlet section is smaller.
2. Separation in cyclones is favorable with large particles that would normally be entirely separate, the fluid, in the output will contain only particles smaller than the critical diameter.
3. The efficiency of the separation process increases with particle size solids involved in the separation operation, the size of solid particles which will be separated is a very important factor in choosing the cyclone type.
4. If the particle size is larger and the sectional area of entry into cyclone is smaller, the separation efficiency of the cyclone is higher.
5. To retain the minimum of particles diameter required is necessary to align the input speed of the fluid in the cyclone with product characteristics (density of the medium, particle density, and viscosity) and constructive parameters of the cyclone.

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