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THE INFLUENCE OF INLET SECTION OVER THE CYCLONE PERFORMANCE

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Abstract: *Due to constructive simplicity, low cost of use and a good adaptability to various working conditions, cyclone has become one of the most important devices for solids particles separation from the mass of mixtures solid-fluid. In this paper is presented the dependence of the efficiency of separation process in cyclone for heterogeneous system such as solid-gas, according to the geometrical characteristics of the inlet. For the theoretical research it was used the relation of Leith and Licht (1972), and the experimental research it was made on laboratory pilot plant that permit the modification of the cross section inlet in the cyclone. Finally the theoretical research results were compared with those obtained experimentally.*

Keywords: *inlet section, cyclone, separation efficiency.*

1. INTRODUCTION

Cyclones are static devices that allow the separation in centrifugal field of heterogeneous gas-solid mixture. They are simple to construct, of low cost, and can be made from a wide range of materials with an ability to operate at high temperatures and pressures [1].

Cyclones have become ubiquitous in technological processes that generate heterogeneous mixtures of solid - gas: for environmental protection (power generation, industries for processing the plant), supply systems of motor (the intake air by the turbines of trains and helicopters). Even in domestic applications, is now often used as vacuum cleaners that have the dust bag replaced by a small cyclone [2].

Over the past 100 years, the main research directions of the separation process in cyclone were focused on study of his geometry influence (cylindrical body, conical body, central tub and dust outlet). Only very few researchers carried out relevant research aiming at the inlet geometry of the cyclone [3].

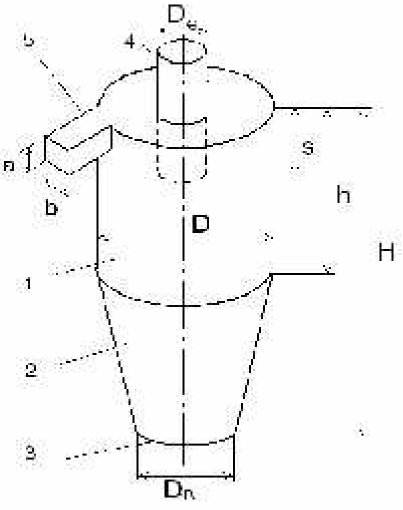
2. THEORETICAL RESEARCH OF THE INFLUENCE OF INLET SECTION IN THE CYCLONE OVER SEPARATION EFFICIENCY

For theoretical research regarding the influence of sectional areas of the cyclone inlet on the separation efficiency were used the cyclone dimensions arising from the application of the principles of dimensional analysis and 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 0,111 m^3/s. On the basis of geometric and cinematic similarity, with this data was determined the size of the cyclone parts according to geometric similarity reports of a cyclone type chosen. Thus, parts of the cyclone size used in theoretical research are shown in figure 1 [4].

The influence of sectional areas of the cyclone inlet on the separation efficiency in cyclone was demonstrated theoretically from the relationship given by Leith and Licht (1972):

$$\eta = 1 - \exp\left[-2\left(C\Psi\right)^{\frac{1}{2m+2}}\right]\cdot 100\left[\%\right], \quad \textbf{(1)}$$

where: η is the efficiency of the cyclone; C is an parameter that depends on the size of the cyclone; Ψ - Inertial impact parameter which depends on the nature of gas-solid; m - Alexander's criterion of similarity, which is consistent with the size and temperature gas cyclone: m=0, 5 [5].



D – diameter cylindrical body, D = 0,244 m;
D_e - diameter of central tube exhaust gas purified, D_e = 0,122 m;
D_b – diameter exhaust side solid particles (dirt), D_b = 0,061 m;
H – cyclone height, H =1,06 m;
a – height of the cyclone feed inlet, a = 0,122 m;
b - width of the cyclone feed inlet , b = 0,061 m;
h – upper height of the cyclone, h = 0,56 m;
s – depth of penetration of purified gas hose, s = 0,028 m;

Figure 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.

The inertial parameter value which is depending on the nature of gas-solid heterogeneous system is determined by the relationship:

$$\Psi = \frac{\rho_s \cdot d_p^2 \cdot \upsilon_{t_2}}{18\mu \cdot D}(m+1), \tag{2}$$

where: ρ is the solid particle density, ρ=1110 kg/m^3; μ - gas mixture dynamic viscosity, Pa·s; v_{t2}- velocity of the gas to the entry into the supply: v_{t2} =15 m/s; d_p – average diameter of particles, d_p = 0,00004 m.

Dynamic viscosity depends on temperature and is calculating with the relationship:

$$\mu = (37.4 + 0.506 \cdot T) \cdot 10^{-5}\text{; T = 293 } [K]; \tag{3}$$

In the theoretical research it was considered variable value of the parameter C depends on the size of the inlet section, and other terms of the relationship will remain constant.

To achieve its purpose, have considered the following values for sectional areas of the cyclone inlet: 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.

The C parameter that depends on the size of the cyclone can calculated with next relation ship:

$$C = \frac{8 \cdot K_C}{a \cdot b}, \tag{4}$$

where K_c is a constant of the basis time what is supporting the particles within the vortex system. The constant K_c is calculated by the following relationship:

$$K_c = \frac{V_s + \frac{V_{el}}{2}}{D^3}, \tag{5}$$

where V_s is the upper volume, m^3; V_{el} - volume actually heading back to the lower vortex in the cyclone, m^3. The volume values are determined by:

$$V_s = \frac{\pi D^2}{4} h, \tag{6}$$

$$V_{el} = \frac{\pi \cdot D^2}{4}(h-s) + \frac{\pi \cdot D^2}{4}\left(\frac{\ln + s - h}{3}\right)\left(1 + \frac{d}{D} + \frac{d^2}{D^2}\right) - \frac{\pi \cdot D_e^2 \cdot \ln}{4}, \tag{7}$$

where *ln* is the natural length of cyclone, in m;

$$\ln = 2.3 D_e \left(\frac{D^2}{a \cdot b}\right)^{1/3}, \tag{8}$$

$$d = D - (D - D_B)\left(\frac{s + \ln - h}{H - h}\right), \tag{9}$$

By replacing the known terms were obtained the following relations:

$$\eta = 1 - \exp\left\{ -2\left[\left(\frac{8k_c}{a \cdot b} \right) \cdot \left(\frac{\rho \cdot d_p^{\ 2} \cdot v}{18 \cdot \mu \cdot D} \right) \cdot (m+1) \right]^{\frac{1}{2 \cdot 0,5+2}} \right\} \cdot 100 , \tag{10}$$

$$\eta = 1 - \exp\left\{ -2\left[\left(\frac{8 \cdot \frac{V_S \cdot \frac{V_{ei}}{2}}{D^3}}{a \cdot b} \right) \cdot \left(\left(\frac{\rho \cdot d_p^{\ 2} \cdot v}{18 \cdot \mu \cdot D} \right) \cdot (m+1) \right) \right]^{\frac{1}{3}} \right\} \cdot 100 , \tag{11}$$

$$\eta = 1 - \exp\left\{ -2\left[\left(\frac{8 \cdot \frac{\frac{\pi \cdot D^2}{4} \cdot h \cdot \frac{\frac{\pi \cdot D^2}{4} \cdot (h-s) + \frac{\pi \cdot D^2}{4} \cdot \left(\frac{\ln + s - h}{3} \right) \cdot \left(1 + \frac{d}{D} + \frac{d^2}{D^2} \right) - \frac{\pi \cdot De^2 \cdot \ln}{4}}{2}}{D^3}}{a \cdot b} \right) \cdot \left(\left(\frac{\rho \cdot d_p^{\ 2} \cdot v}{18 \cdot \mu \cdot D} \right) \cdot 1,5 \right) \right]^{\frac{1}{3}} \right\} \cdot 100 , \tag{12}$$

Known parameters and formulas were introduced in Microsoft Office Excel 2003 (table 1) and was drawn the chart which shows the influence of inlet section in the cyclone separation efficiency (figure 2).

Table 1: Separation efficiency values

De [m]	ln [m]	Db [m]	s [m]	h [m]	H [m]	d [m]	Vei [m^3]	Vs [m^3]	Kc	C
0,122	3,53562	0,061	0,028	0,56	1,06	-0,2090	0,01310	0,02617	0,00798	40,5520
0,122	1,91229	0,061	0,028	0,56	1,06	0,0881	0,11470	0,02617	0,02038	55,9874
0,122	1,12999	0,061	0,028	0,56	1,06	0,2312	0,10251	0,02617	0,01889	30,6685
0,122	0,84271	0,061	0,028	0,56	1,06	0,2838	0,08675	0,02617	0,01697	20,5439
0,122	0,74847	0,061	0,028	0,56	1,06	0,3011	0,08019	0,02617	0,0162	17,3866

Continuation of tabel 1

m	v [m/s]	ρ [kg/m^3]	d_p [m]	S [m^2]	D [m]	m [m^2/s]	y	B	expB	η [%]
0,5	15	1110	0,00004	0,001575	0,244	0,00185	0,004918	-1,16851	0,000	100,000
0,5	15	1110	0,00004	0,002912	0,244	0,00185	0,004918	-1,30114	0,272	72,778
0,5	15	1110	0,00004	0,004928	0,244	0,00185	0,004918	-1,06461	0,345	65,514
0,5	15	1110	0,00004	0,006608	0,244	0,00185	0,004918	-0,93151	0,394	60,604
0,5	15	1110	0,00004	0,00744	0,244	0,00185	0,004918	-0,88111	0,414	58,568

where S is the value of the sectional areas of the cyclone inlet in cyclone, (a·b), în m^2, and B is:

$$B = \exp\left[-2(C \cdot \psi)^{\frac{1}{2 \cdot m+2}} \right], \tag{13}$$

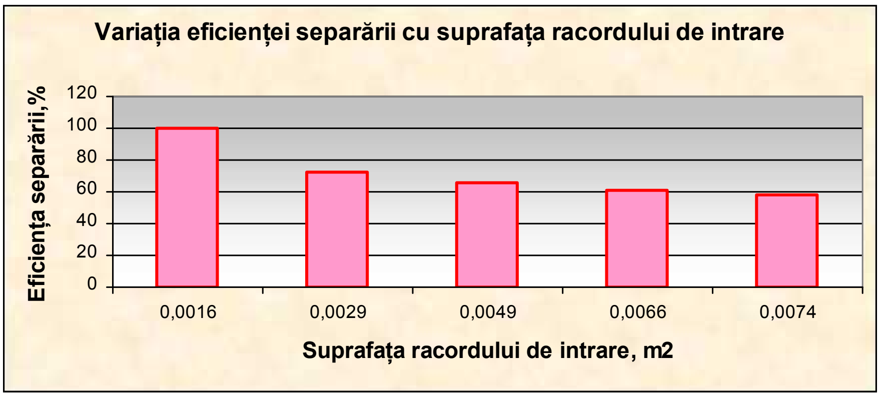


Figure 2: Variation of separation efficiency with the sectional areas of the cyclone inlet in cyclone

In the graph from figure 2 can be seen that separation efficiency decreases with increasing the sectional areas of the cyclone inlet, this significantly influence the separation process in cyclone.

For a section of 0,001575 m^2 particle separation inside the cyclone has maximum efficiency, compared with a higher inlet section (0.00744 m^2), the separation efficiency decreases to a value of only 58,568%.

3. EXPERIMENTAL RESEARCH REGARDING THE INFLUENCE OF INLET GEOMETRY IN CYCLONE OVER THE EFFICIENCY SEPARATION

For the experimental investigations it was used the installation presented in figure 3 composed of a centrifugal fan driven by an electric motor single phase and a cyclone with tangential entry. Measurement equipment used allowed to measure the airflow velocity in the fan input, output and exit gate of the central tube, the pressure loss from inside the pipe pneumatic conveying powdery material, mixture temperature and the quantities of solid material circulated. These measuring devices have consisted of a propeller anemometer equipped with temperature sensor, an electronic scales and a liquid-column manometer. For the airflow velocity and temperature measuring it was used the multifunctional device VT 300 which permits the air speed measuring with two probes: the hot wire anemometer and the propeller anemometer.

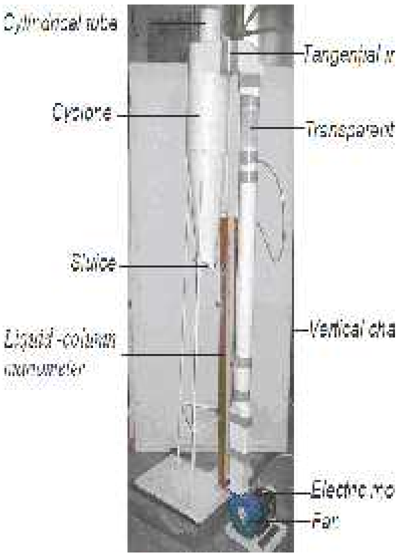


Figure 3: Pilot plant with cyclone

Propeller anemometer

Electronic scales

Figure 4: Measuring instruments

The measurements of air flow velocity were performed for three values of surfaces of the cyclone inlet section (figure 6), aiming to influence this has on the efficiency of centrifugal field separation.

For each measurement it was used 100 g of powdered material weighing with electronic scales. It was used a number of 5 samples of powdered material for each of the three areas of the inlet section in the cyclone (figure 5).

After powdered material was introduced inside the installation, it was determined the quantities of the material recovered from the sluice, the quantities recovered from the cylindrical tube, and the quantities of losses from installation.

The determination of the separation efficiency was made by comparing the values of the quantities of material introduced in system and the values of the quantities of material recovered from the cylindrical tube.

Figure 5: The samples used in research

S_1=6608 mm^2 S_2=4928 mm^2 S_3=2912 mm^2

Figure 6: Sectional areas of the cyclone inlet

The results obtained from the experimental investigations for each of the three values of areas of the inlet section in the cyclone are presented in Tables 2, 3 and 4.

Table 2: Values registered for the S_1 sectional area, S_1=6608 mm^2

S_1	m_i (g)	m_e (g)	$m_{t.c}$ (g)	m_p (g)	v_i (m/s)	v_e (m/s)	v_{et} (m/s)	p_c (mm col H_2O)	T [^{0}C]	η (%)
P1	100	83,02	0,32	16,66	11,4	2,6	2,8	14	18,3	83,34
P2		89,57	0,36	10,07						89,89
P3		83,70	0,35	15,95						84,05
P4		85,48	0,27	14,25						85,75
P5		84,15	0,25	15,60						84,4

Table 3: Values registered for the S_2 sectional area, S_2=4928 mm^2

S_2	m_i (g)	m_e (g)	$m_{t.c}$ (g)	m_p (g)	v_i (m/s)	v_e (m/s)	v_{et} (m/s)	p_c (mmColH_2O)	T [^{0}C]	η (%)
P6	100	95,21	0,15	4,64	10	2,2	2,5	14	18	95,36
P7		93,02	0,19	6,79						93,21
P8		97,68	0,12	2,2						97,80
P9		94,89	0,14	4,97						95,03
P10		96,23	0,18	3,59						96,41

Table 4: Values registered for the S_3 sectional area, S_3= 2912 mm^2

S_3	m_i (g)	m_e (g)	$m_{t.c}$ (g)	m_p (g)	v_i (m/s)	v_e (m/s)	v_{et} (m/s)	p_c (mm col H_2O)	T [^{0}C]	η (%)
P11	100	84,90	0,24	14,86	9,8	2,5	2,3	14	17,5	85,14
P12		83,10	0,20	16,70						83,30
P13		85,10	0,22	14,68						85,32
P14		82,14	0,23	17,63						82,37
P15		88,15	0,28	11,57						88,43

where: S is the sectional areas of the cyclone inlet, (S_1=6608 mm^2, S_2=4928 mm^2, S_3= 2912 mm^2); m_i- mass of powdered material placed in the installation, in g; m_e- mass of material recovered from the sluice, in g; m_{tc} - mass of material ejected from the cylindrical tube, in g; m_p – losses mass of the plant, in g; v_i- input speed airflow, in m/s; v_e- speed out of sluice, in m/s; v_{et} - speed out of cylindrical tube, in m/s; p_c- airflow pressure in the pipeline, in mm col H_2O; T- Temperature, in ^{0}C.

Based on data obtained for the three values of sectional area of the inlet cyclone, it was drawn the chart of separation efficiency variation according to the sectional area inlet (figure 7).

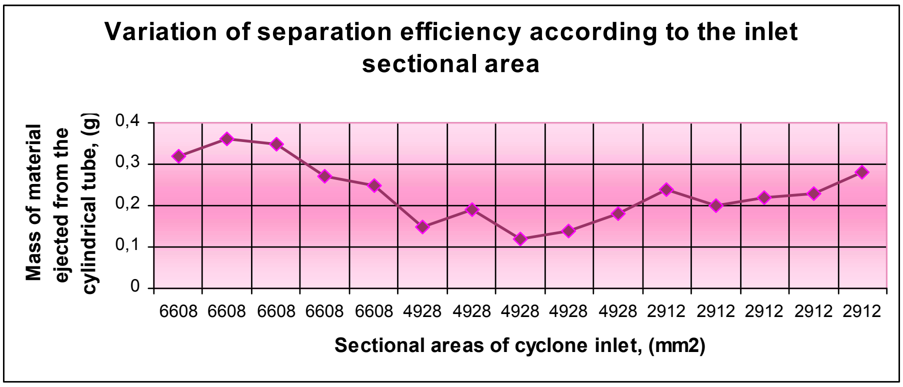


Figure 7: Variation of separation efficiency according to the inlet sectional area

It can be observed from these tables that for the S_2=4928 mm^2 of the sectional area of cyclone inlet, the mass material losses m_p due to leaks and the mass of material ejected from the cylindrical tube m_{tc}, it was obtained the minim values.

In this experiment it was demonstrated the influence of surface value in the cyclone inlet section, drawing out the fact that for the installation considered the optimal value is S_2 = 4928 mm^2. Material losses in this case are the smallest, the separation is more efficient, and the resulting work can be seen in the graph of variation of separation efficiency according to the inlet sectional area.

For the sectional area of cyclone inlet S_1= 6608 mm^2, it was obtained the highest values of the quantities of material lost at the end of the cyclone central tube, which means that separation efficiency decreases with increasing the sectional area of cyclone inlet.

4. THE COMPARISON OF THEORETICAL AND EXPERIMENTAL RESEARCH RESULTS

To make the comparison between theoretical and experimental research were considered the three surfaces of the sectional area of cyclone inlet (S_1=6608 mm^2, S_2=4928 mm^2, S_3= 2912 mm^2). In the graph from figure 8 are presented the experimental results compared to theoretical research regarding the influence of sectional area of cyclone inlet.

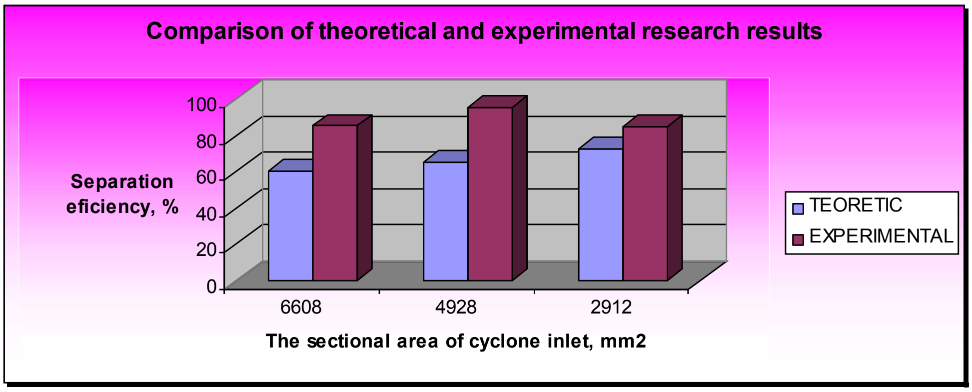


Figure 8: The comparison of theoretical and experimental research results

In experimental research, the average efficiency of separation was calculated for each of the three surfaces of the sectional area of cyclone inlet (see tables 2, 3, 4).

In theoretical research (according to the graph in figure 2), it is observed that separation efficiency increases with decreasing of the sectional area of cyclone inlet. For a section of S2 = 2912 mm^2, the separation efficiency is 72,778%, high efficiency compared with the other two sections. For the same section, at experimental research the separation efficiency was 84, 91%.

In experimental research, separation efficiency was higher for section S2 = 4928 mm^2, with a value of 95, 56%, while in the theoretical research, for the same section it was obtain an efficiency of 65, 51%.

5. CONCLUSION

The difference between theoretical and experimental research, is due to the use of relationships for calculating the separation efficiency, in the theoretical research, which is not takes into account turbulence and pressure losses occurring during the separation in centrifugal field.

The separation efficiency decreases with increasing the sectional areas of the cyclone inlet, this significantly influence the separation process in cyclone.

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