14th International Symposium on Exploitation of Renewable Energy Sources and Efficiency

April 04-06, 2024, Subotica, Serbia

EXPRES 2024

Proceedings

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DESIGN OF A DUST SEPARATOR CYCLONE

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At agricultural sites, various field crops are cleaned, dried and stored. After the delivered product is covered on the hopper, it reaches the cleaner with a bucket applicator. After pre-cleaning, the feed is - if necessary - dried and then stored. The separation of dust formed during feed cleaning with a dust separation cyclone is a story. In the course of our work, we describe the operational sizing of the cyclone required to clean dusty air with a solid concentration of 107-120 mg/m^3 and a flow rate of ~8400 m^3/h. During the calculations, we determined the cyclone's boundary particle size and hydraulic pressure drop.

Keywords: *dust separator cyclone, operational sizing, boundary particle size, hydraulic pressure drop*

1. Introduction

Dust separation cyclones are the most common mechanical dust separation devices, in which centrifugal force created without moving parts causes the separation of dust particles from the gas flow [1]. Cyclones can generally be used to separate solids larger than 10 μm with good efficiency. The main parts of the cyclone with the markings in Figure 1: the gas inlet stub (1), the cylindrical part (2), the conical part (3), the dust outlet (4), the gas outlet tube/dip tube/vortex tube (5), dust outlet dust container under the opening (6), rotary valve (7).v_{in} and v_{out} are the inlet and outlet velocity of air, H is the height of the cyclone.

Due to the centrifugal force, the dust particles are separated on the wall and fall into the lower conical funnel, from where the dust can be removed. The purified gas escapes through the outlet pipe, which is placed concentrically with the cylindrical part. Cyclones are cheap and easy to manufacture, their disadvantages are their moderate degree of dust removal, high resistance and strong wear.

The tangential velocity along the wall of the cylindrical part of the cyclone is the smallest and does not differ much from the entry velocity. In the conical part, the wall velocity increases proportionally with the decreasing radius and is highest near the dust outlet. The maximum value of the tangential velocity is reached at a circle smaller than the outlet pipe, but it always decreases downwards.

When planning a cyclone or developing an existing one, it is essential to know its dust separation effectiveness. Several methods have been developed in the literature for determining the cyclone's pressure drop and dust separation efficiency, which are based on the characterization of air and particle movement inside the cyclone [2].

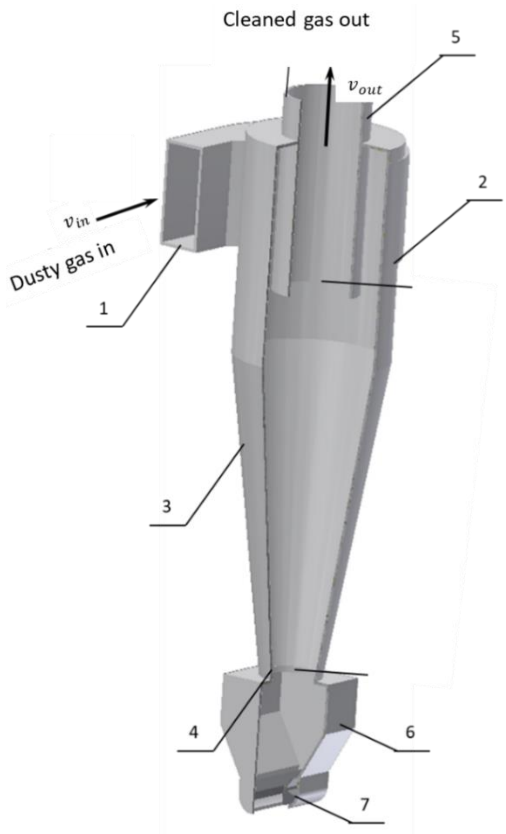

Figure 1. Parts of the dust separator cyclone
(1. Gas inlet stub, 2. Cylindrical part, 3. Conical part, 4. Dust outlet, 5. Gas outlet/vortex detector tube, 6. Dust container, 7. Rotary valve)

Although cyclones of various designs are used, hereafter we examine cyclones with a tangential gas introduction, cylindrical and conical parts, because this type is most often used for industrial dust separation. The outline of the cyclone with its main geometrical parameters is shown in Fig. 2. In this design, the particle-laden air enters the cyclone tangentially through the air intake stub, which then forms a vortex within the cyclone. The air stream moves radially inward into a lower-pressure central section located below the air outlet pipe. The air, cleaned of particles, leaves the device through an immersion tube through the outlet channel. The collected particles move along the wall of the cyclone, through the cylindrical and conical parts towards the particle guide opening. To design a cyclone, the main dimensions of the cyclone are shown in Fig. 2.

Table 1. Cyclone dimensions [2] based on the markings in Fig. 2

Cyclone type name, design	*Ref.*	*Recommended use*	H_c/D_c	B_c/D_c	D_e/D_c	S/D_c	L_c/D_c	Z_c/D_c	J_c/D_c
Stairmand (1951) 1.5D2.5D	[4]	high separation efficiency	0.5	0.2	0.5	0.5	1.5	2.5	0.375
Swift (1969) 1.4D2.5D	[5]	high separation efficiency	0.44	0.21	0.4	0.5	1.4	2,5	0.4
Lapple (1951) 2D2D	[6]	general	0.5	0.25	0.5	0.625	2	2	0.25
Swift (1969) 1.75D2D	[5]	general	0.5	0.25	0.5	0.6	1.75	2	0.4
Stairmand (1951) 1.5D2.5D	[4]	high throughput	0.75	0.375	0.75	0.875	1.5	2.5	0.375
Swift (1969) 1.7D2D	[6]	high throughput	0.8	0.35	0.75	0.85	1.7	2	0.4

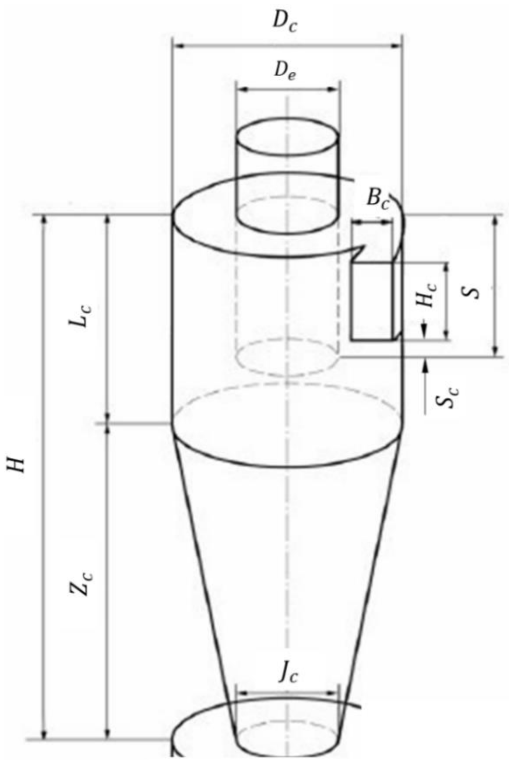

Figure 2. The main dimensions of the cyclone are according to [3].

The dimensions are usually expressed in a dimensionless form as a multiple of the diameter (D_c) of the cylindrical part of the cyclone.

The following seven dimensions are required for the operational design of a cyclone: H_c/D_c, B_c/D_c, D_e/D_c, S/D_c, L_c/D_c, Z_c/D_c, J_c/D_c.

This allows the geometrical similarity of several cyclones to be compared by taking into account their scale, without the cyclone comparison being of absolute magnitude.

2. Design of a cyclone

During the operational dimensioning of a cyclone, an important aspect is the fulfillment of the latest air pollution regulations.

Determination of geometric dimensions

Assuming a characteristic entry velocity of 15 m/s [7], the geometric dimensions shown in Table 1 are obtained based on the proposal of Stairmand (1951) [4], selecting the 1.5D2.5D type and sizing it for high separation efficiency.

The inlet cross-section area of the cyclone can be calculated as a ratio of the volume flow rate and the gas velocity:

$$A_{in} = \frac{\dot{V}_G}{v_G} = \frac{2.34}{15} = 0.1557\, m^2 . \quad (1)$$

Knowing the size of the entrance cross-section area and the dimensions proposed by [4], the dimensions of the entrance air duct can be determined.

$$A_{in} = H_c B_c = 0.5 D_c \cdot 0.2 D_c = 0.1 {D_c}^2 , \quad (2)$$

from which the diameter of the cyclone can be calculated:

$$D_c = \sqrt{A_{in}/0.1} = \sqrt{0.1557/0.1} = 1.25\, m . \quad (3)$$

Knowing the diameter of the cyclone, its main geometric dimensions can be calculated, their values are shown in Table 2.

Table 2. The main geometric sizes of the designed cyclone expressed in [mm] based on the markings in Fig. 2

D_c	H_c	B_c	D_e	S_c	S	L_c	Z_c	H	J_c
1250	625	250	625	625	1250	1875	3125	5000	469

Determination of boundary grain size

Knowing the dimensions of the cyclone to be designed, the effective circulation number of the air flow:

$$N_e = \frac{1}{H_c}\left(L_c + \frac{Z_c}{2}\right) = \frac{1}{0.62}\left(1.87 + \frac{3.12}{2}\right) = 5{,}5\,. \quad (4)$$

Based on relation (2.2), the limiting particle size, in the case of 50% separation efficiency, where μ_G is the dynamic viscosity of the gas at operational temperature, ρ_P is the density of the particles, ρ_G is the density of gas:

$$d_{50} = \sqrt{\frac{9\mu_G B_c}{2\pi N_e v_G(\rho_P - \rho_G)}} =$$

$$\sqrt{\frac{9 \cdot 1.459 \cdot 10^{-5} \cdot 0.25}{2\pi \cdot 5.5 \cdot 15 \cdot (2000 - 1.215)}} = 6.2 \cdot 10^{-6}\, m\,, \quad (5)$$

so the new cyclone separates 6.2 μm particle size with 50% efficiency.

As a check, Table 3 contains the boundary grain sizes calculated for the main cyclone types already presented. In each case, the calculations were performed with known air characteristics and the inlet air velocity set at 15 m/s.

Table 3. Boundary particle sizes for the described cyclone types expressed in [μm] according to [2].

1D3D	2D2D	1D2D	Stairmand 1.5D2.5D	Swift 1.4D2.5D	Swift 1.75D2D	Stairmand 1.5D2.5D	Swift 1.7D2D
6.9	6.3	7.7	6.2	6.2	6.5	8.0	8.1

From the calculation results presented in Table 3, it can be seen that among the described cyclone designs, the smallest boundary particle diameter can be achieved with the Stairmand-type device ratio.

Determination of pressure drop

The value of the constant in the equation (4) for determining the value of H_v was set to $K = 18$, for the sake of safer investment and operation.

Thus the value of H_v:

$$H_v = K\frac{B_C H_C}{{D_e}^2} = 18\frac{0.25 \cdot 0.62}{0.62^2} = 7.2\,. \quad (6)$$

Knowing this, the pressure drop of the new Stairmand-type cyclone can be determined based on relation (2.3):

$$\Delta p = \frac{1}{2}\rho_G {v_G}^2 H_v = \frac{1}{2} \cdot 1.215 \cdot 15^2 \cdot 7.2 = 985\, Pa\,. \quad (7)$$

Table 4. Pressure values for the described cyclone types expressed in [Pa] according to [2]

1D3D	2D2D	1D2D	Stairmand 1.5D2.5D	Swift 1.4D2.5D	Swift 1.75D2D	Stairmand 1.5D2.5D	Swift 1.7D2D
1230	1230	790	985	1420	1230	1230	1225

As a check, Table 4 shows the pressure values calculated for the main cyclone types already presented, for K=18. In each case, the calculations were performed with the air characteristics listed in the test report and the inlet air velocity set at 15 m/s. From the calculation results presented in Table 4, it can be seen that the smallest pressure drop can be achieved with the 1D2D-type device ratio among the cyclone designs described, but based on Table 3, the larger boundary particle diameter was obtained. This type is followed by the proposed Stairmand type.

Determination of pressure efficiency

Based on Lapple, the fraction separation efficiency, where d_x is an arbitrary particle size [6]:

$$\eta_{fr} = \frac{1}{1 + \left(\frac{d_{50}}{d_x}\right)^2}\,. \quad (8)$$

Table 5 shows the fraction separate efficiencies for a given particle size from 1 to 100, it is visualized in Figure 3.

Table 5. Fraction separation efficiencies for a given particle size

d_x [μm]	1	3	5	8	10	15	25	35	50	75	100
η_{fr} [1]	0.03	0.19	0.40	0.63	0.72	0.85	0.94	0.97	0.99	0.99	0.99

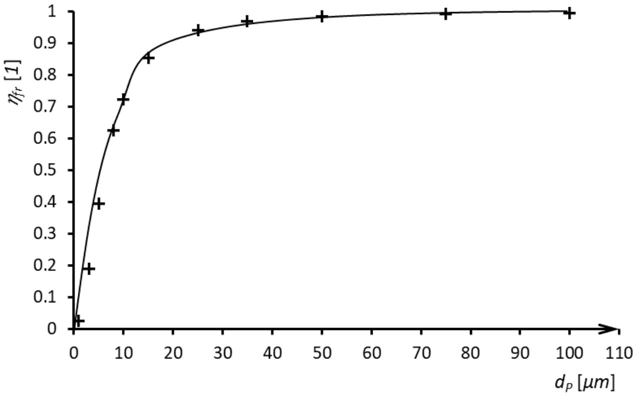

Figure 3. Fraction separation efficiency for a given particle size

3. Summary

The designed cyclone ensures the separation of particles with a grain boundary diameter of $d_{50} = 6{,}2\ \mu m$ at a given air volume flow of *~8400 m^3/h* at $\Delta p = 985\ Pa$. During the installation of the cyclone in the technology, due to its flow resistance, it is necessary to expect the displacement of the working point of the fan and thus the presence of a smaller air volume flow. The design of the gas outlet pipe is diffuser, thereby reducing the flow loss of the exiting gas [8]. The Fig. 4. shows the cyclone manufactured based on the design parameters.

Fig 4. The produced dust separator cyclone

When designing the construction of the cyclone, it must be taken into account that the erosive and abrasive effect of the dust is strongest at one third of the conical part of the cyclone. The small container placed under the dust outlet of the cyclone serves for the temporary storage of particles buffered as hold-up. As a result, the dust removal of the particles from the conical part is continuous, the flow of the air cannot drag the material towards the air outlet pipe. This is necessary in cases where the rotary cell feeder cannot for some reason deliver the material immediately (in the case of a more intense dust load) and at the same time it also reduces the gap loss of the feeder.

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