PURIFICATION OF THE AIR FROM THE INDUSTRIAL EMISSIONS WITH THE HELP OF CYCLONE DUST COLLECTORS

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Introduction

Prompt development of several branches of industry turns cities into the large industrial centers, which is not good for the ecological situation in the cities. That makes the defense of the air environment from the air pollution with the industrial emissions very important human task. This problem become more and more actual with the increasing of the territory concentration of the plants near the large cities, where the contain of the contaminants like gases and dust-like materials exceed the norm. The solution of this problem is gas-purification. And the city development is impossible without the development of this important trend of ecotechnical science. Air purification from the dust particles can be realized by the several kinds of dust collectors and filters. Dust collectors are used for the extraction of the technological dust and purification of the air, disposable from the ventilation systems. Choosing in each case effective enough and economic dust collector may solve the problem of dust pollution. While it's important to consider not only reasonable technology and feasibility, but also the properties of the dust particles and the effect of its dispersion at the atmosphere. The purpose of these researches is increasing the quality of air purification and providing of the effective work of dust collectors.

1. Literature review. Setting a task

1.1.Types and harm of the technological dust. Dust collection systems

The dust is hygienically harmful component of the air breathed by people, having negative influence on the organism. Its insalubrities depend on its amount, size and chemical content. The more dust is in the air, and the less it's particle medium size the more is the harmful influence to the human organism. Dust particles with the size 0,1 – 10 mkm slowly gravitate in the air and penetrate deeply to the lungs. The bigger particles on breathing stay in nasopharynx or move to the stomach system. On chemical content, breathing of the dust containing silicon dioxide has very dangerous consequences. Such dust, graduating in the breathing system can cause serious professional illnesses, connected with serious changes in lungs, heard, nervous systems.

Dust containing air can be represented as the system of gaseous bearing dispersible environment and solid dispersible phase that consists of the particles, being suspended in the bearing environment for the long time. A good example of such system is so called aerosol, an air system the size of the suspended particles is less than 1 mkm.

Industrial dust can be of organic origin (wood, peat, coal) and inorganic origin (metal, mineral). Depending on the influence on the human organism, dust is classified as toxic and non-toxic.

The control on the amount of harmful substances thrown into the air should be realized on the enterprises of any branch of the industry. This is the requirement of the law in the sphere of ecology and protection of labour, exciting in all the countries, and only dust collection system can provide sufficient quality of the air [15].

Various dust collectors may be classified by several features, like:

- Function
- Main way of work
- Effectiveness
- Constriction.

Generally accepted classification is settled by the standard. [3,6].

The work devoted to the mechanical dust collectors, in which the dust particle extraction happens due to outside forces, particularly centrifugal force. These are so called cyclone type dust collector.

The cyclone air purification has a long history since 19 century. A lot of theoretical and experimental researches were devoted to this subject; several kinds of the cyclone modification had been used, but until now the flow regime of the cyclone is still not learned completely.

In 1886 representative of the American company "Knikerboker Co" Mr. Merse handed in an application for the patient for the first cyclone dust collector. A lot of scientific researches were devoted to the work of cyclones. Very few of people know that L. Prandel who had based on his theoretical conclusions the present mechanic of the stream, also was making research of the cyclones. And in 1901 in Nuremberg Man Co applied for the patient for the cyclone dust collector, founded by Prandel.

These dust collectors are widely used for the dry cleaning of the gases, evolved in the several technological processes.

1.2. Setting a task

An importance of the researches on the field of air purification from dust is obvious. Usually the methods of the estimation of dust collection effectiveness are based on theoretical and experimental researches. The experimental researches of cyclones give more reliable results, but such researches are expensive and give the data only regarding one particular construction of cyclone. Whereas the mathematics models of hydromechanical process in the cyclone dust collectors provides general results and recommendations. Analyzing materials regarding air purification with the cyclone dust collector, the author found out some imperfections of the existing methods of calculation and estimation of the effectiveness of dust collection. At the present time the computation of the effectiveness of flow cyclone dust collector with the spiral supply of air is made mostly by formulas received by approximation of the experimental data, without consideration of the hydraulic processes. Theoretical estimation which are usually made do not include estimation of the fractional precipitation effectiveness, only total effectiveness [1,16,18]. So there is no way to consider the minimum size $d_{\min}$ of the collected particles. Consequently, the purposes of this work are:

- Creating mathematics models of the hydromechanical processes in cyclone dust collectors
- Creating methods of estimation of the dust collection effectiveness and experimental control of the method.

2. Theoretical researches

2.1. Features of the particles moving in a rotating stream

To solve the problem put by, it's necessary to work with the models of particles moving in the rotary stream, considering the generally accepted scheme of the movement of rotary blast and separation in the body of cyclone dust collector [1,9,11]. Powder-gas flowing with a high speed at a tangent move in the crown of cyclone is subjected to centrifuge separation. In this work a number of assumptions were accepted. It was important to consider all the physical-mechanical properties of the single particle.

The size of the radial displacement of one particle, moving in the cyclone or through the ring channel, can give an idea about an amount of collected particles.

At movement of a stream in a cyclone the mode of current of gas is turbulent. The mode of movement is characterized by Reynolds number [1,4]:

$$\mathrm{Re} = \frac{v_T D_{Ch}}{\nu}, \qquad (2.1)$$

Calculated on external parameters of a stream:

ν - kinematical viscosity of the gas environment,

v_T - tangential speed of a gas stream,

D_{Ch} - Diameter of the channel (exhaust pipe)

For the speeds of stream 3 -18 m/s (usual for cyclones) Reynolds number we got is $\mathrm{Re} \geq 10^5$, at the same time $\mathrm{Re} \geq 10^4$ means mode of the advanced turbulence [4].

First behavior of the particle under the influence of all the forces was analyzed. (fig.2.3.)

Due to the fact that the density of the particle ρ_s is more than the density of air, the particle moving on the body of cyclone with the speed of the bearing stream, aspires to move rectilinearly and uniformly (fig.2.1, trajectory 1); at this time, deviates from the axle of cyclone (fig.2.1, trajectory 2). Resisting force can be calculated with the Stokes formula:

$$F_c = 3\pi\mu\, v_R d, \qquad (2.2)$$

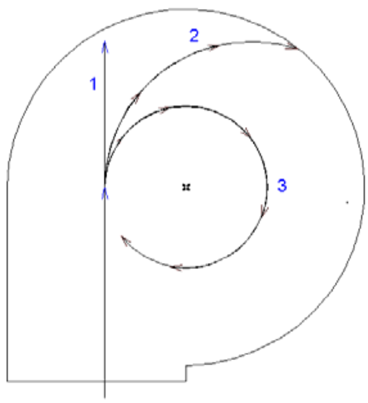

Fig. 0.1. Trajectories of the movement of dust particles

There are

μ - dynamic viscosity of the gas environment,

v_R - radial speed of the particle,

d - diameter of the particle.

As a result, the particle moves with the curved trajectory (fig.2.1, trajectory 2 and 3). It's obvious, that the less is the mass and the more viscosity of gas (so the inertia), the trajectory will be more like a circle (fig.2.1, trajectory 3).

Force of the centripetal acceleration is:

$$F_C = \frac{\pi}{6 \cdot R_p} v_T^2 \rho d^3 , \qquad (2.3)$$

There are, ρ - density of the particle,

v_T – tangential speed of the particle,

R_p - radius of curvature of the trajectory of the particle.

As the resisting force is the only source of the centripetal acceleration, we can equate force and receive the radial speed of the particle:

$$v_R = \frac{v_T^2}{18 \cdot R_{\text{ч}}} \rho_s \frac{d^2}{\mu} . \qquad (2.4)$$

For all the calculation the Stokes formula may be used, as Reynolds number for the particles:

$$\mathrm{Re}_p = \frac{v_R d}{\nu} , \qquad (2.5)$$

received for the particles of maximum size (diameter 100 mkm) is $\mathrm{Re} = 13$. So for the practical tasks the formula can be use, as the deviation is less than 20% [4]. (fig.2.2)

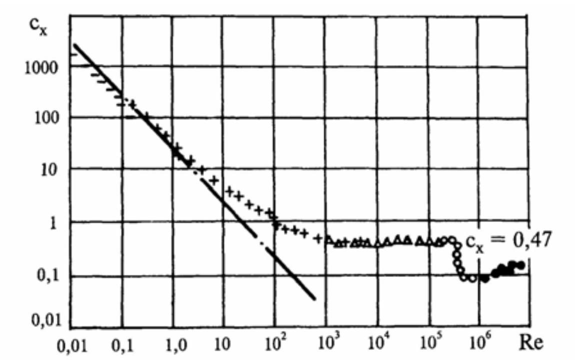

Fig. 2.2. Dependence of the coefficient of resistance of the sphere in the Reynolds number, and influence terms of the experiment into c_x near the critical Reynolds number.

To receive the radial displacement of one particle, its important to certain that the relaxation time, during which the particle get the speed of the bearing stream is much less than the time, which will take particle to move to the wall of cyclone under the force of a centripetal acceleration:

$$t_{rel} << T . \qquad (2.6)$$

And such verification was made for the particle of the maximum size, so that the condition 2.6. was confirmed.

Considering all the conditions and calculations the formula for the radial displacement of one particle was received:

$$\Delta = \frac{v_T^2}{18 \cdot R_p} \rho \frac{d^2}{\mu} \frac{\pi R_p}{v_T} = \frac{\pi \rho}{18 \mu} v_T d^2 . \qquad (2.7)$$

2.2 Effectiveness of the cross-current cyclones with the tangential air supply.

Our task is to receive the effectiveness of the dust collection for the cyclone with the tangential air supply. We work with the model divided into the concentric channels. Such curvilian motion in the channel represents the general case of the rotation of stream or whirlwind. [2,5] Separation efficiency for dust collectors is percentage of the dust concentration before C_{bef} and after C_{aft} dust collector:

$$\varepsilon = \frac{C_{bef} - C_{aft}}{C_{bef}} \cdot 100\% . \qquad (2.8)$$

As it was mentioned before, particles reached the eternal wall of the cyclones are considered as collected. The particle situated at the internal wall, has to overhead the distance $R_2 – R_1$. to be collected (fig.2.3)

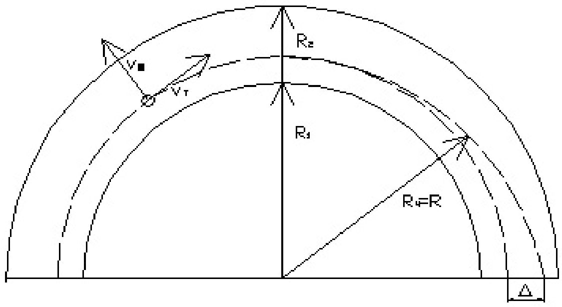

Fig.2.3. Movement on the single particle in the gas stream flowing in the concentric channel

As, according to accepted assumptions, particles are distributed uniformly over the section, percentage of the particles, which had reached the external wall of the cyclone, to the general amount of the particles is:

$$\varepsilon = \frac{\Delta}{R_2 - R_1} \cdot 100\,\% \,. \tag{2.9}$$

Taking Δ from 2.18:

$$\varepsilon = \frac{\pi \rho v_T d^2}{18\mu(R_2 - R_1)} 100\% \,. \tag{2.10}$$

This formula provides the calculation of the fraction separation efficiency. The fraction separation effectiveness for the several beginnings speed of the gas is shown on the graph (fig.2.4.)

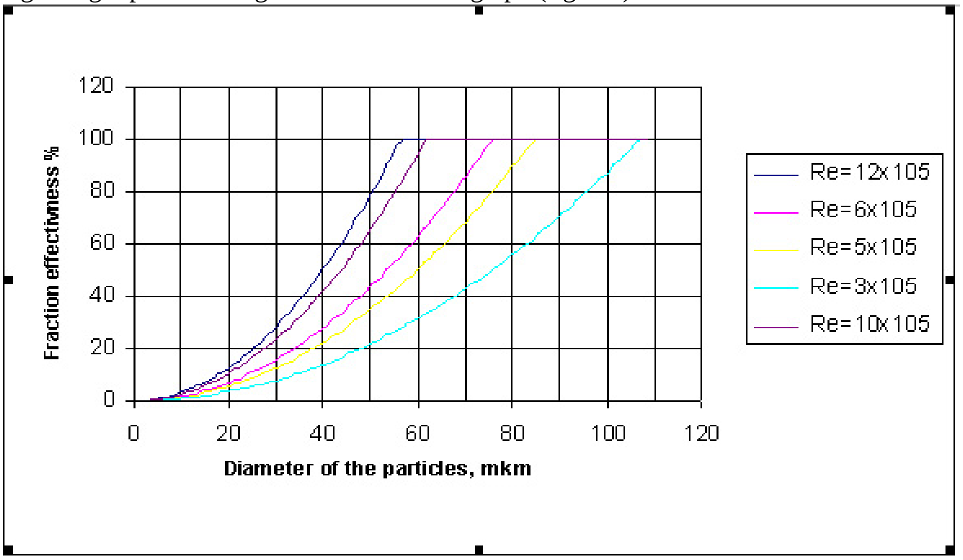

Fig. 2.4. Fraction effectiveness of the dust-collections in the curvilinear channel depending on the Reynolds number for the gas stream. (The calculations were made for the channel of unit width; density of the particles $\rho = 2000 kg / m^3$; - kinematics viscosity of the gas environment $\mu = 22{,}2 \cdot 10^{-6} Nw \cdot \sec^2 / m^2$.)

Using formula 2.10, we can estimate fraction effectiveness of cyclone, depending on the parameters of gas environment. Or this method of the effectiveness estimation can be used consideration the technical parameters of the cyclones. As an example was taken the particular cyclone type dust collector, inertial filter-separator [13,14]. (This construction is the invention of the professor of SPbGPU Tananaev A.V.). The profile of it is shown on the figure 2.5.

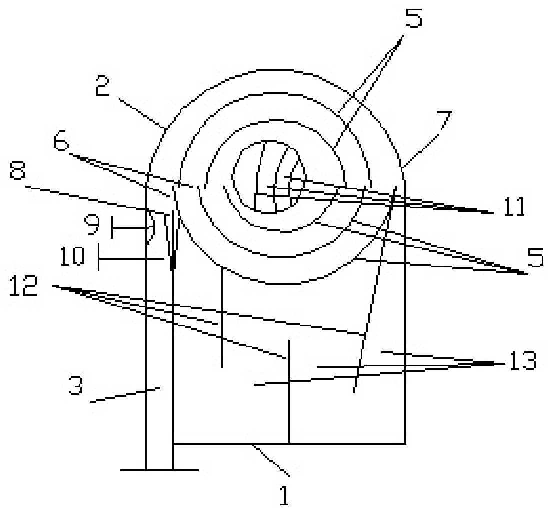

Fig.2.5. The Scheme of the repeated separation.

The fraction separation effectiveness was estimated depending on the size of the dust extraction slits, which the separator is equipped with. (fig 2.6.)

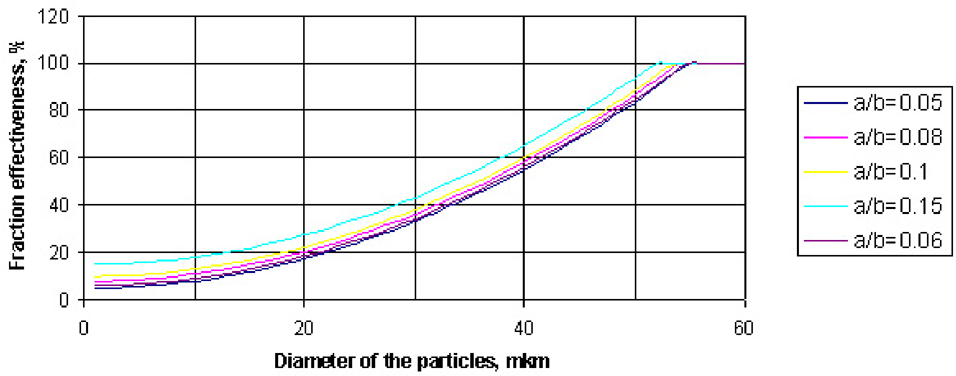

Fig. 2.6. Fraction effectiveness of the dust-collections in the curvilinear channel depending on the size of the dust extraction slits. (The calculations were made for the channel of unit width)

The note: calculation was made for the channel of individual width; density of the particles $\rho = 2000 kg/m^3$; - kinematics viscosity of the gas environment $\mu = 22{,}2 \cdot 10^{-6} Nw \cdot \sec^2 / m^2$.

2.3. Effectiveness of the direct-flow cyclones with the spiral supply of air.

After the subsequent calculation method of estimation of the fraction separation effectiveness for the for direct-flow cyclone dust collector with the spiral supply of air. The mathematic model, used for our calculation is showed on the figure 2.7.

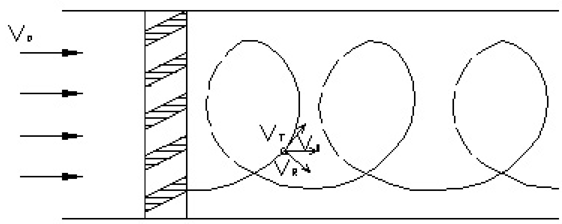

Fig.2.7. The scheme of the movement of the single particle in the direct-flow cyclone.

After the transformation mathematical model into the rated model (fig.2.8.), the formula for estimation of the fraction effectiveness was received:

$$\varepsilon = \frac{\pi(r_1^2 - r_2^2)}{\pi R^2} \cdot 100\,\% = \frac{r_1^2 - r_2^2}{R^2} \cdot 100\,\%\,, \qquad (2.11)$$

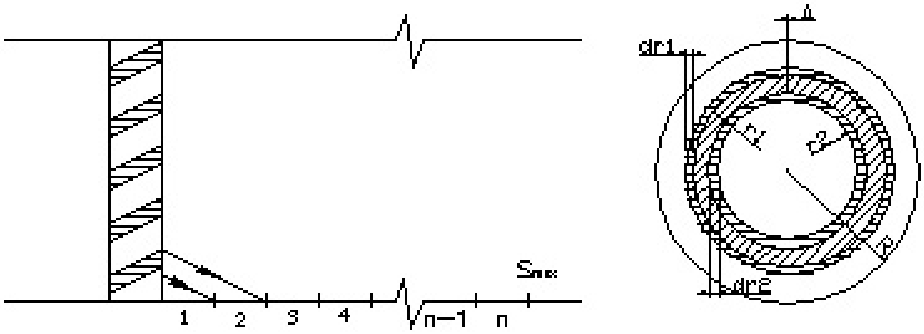

Fig. 2.8. Rated model

Using it a number of graphs showing the fraction effectiveness of the direct-flow cyclone, depending on the parameters of gas environment and technical characteristic of cyclone (appendix 1) The advantage of such method is possibility to change characteristics of dust collector at the design stage, depending on the required parameters of the air-purification, and application conditions.

3. Experimental researches

Reliability of received method was confirmed by the experiment. As an experimental sample was used direct-flow cyclone dust collector with the spiral supply of air. The scheme and the picture of the test bench is shown on the figure (appendix 2). The measurements of hydraulic resistance, entry and final concentrations were made at the test bench.

For the determination of fraction separation effectiveness samples of the dust received after the experiment were taking for the laboratory research.

At the laboratory of Politechnical University measurements of the granulometric composition of the dust particles were made. Granulometric composition was determined using areometric method in accordance with the standard (GOST 12536-79) [8]. Using formula 2.8. fraction and general effectiveness were calculated. Effectiveness received by the experiment was compared with the effectiveness received by using created theoretical method. Maximum deviation do not exceed 20 %, which confirms the fact of relevancy of the created method. (fig.3.1.)

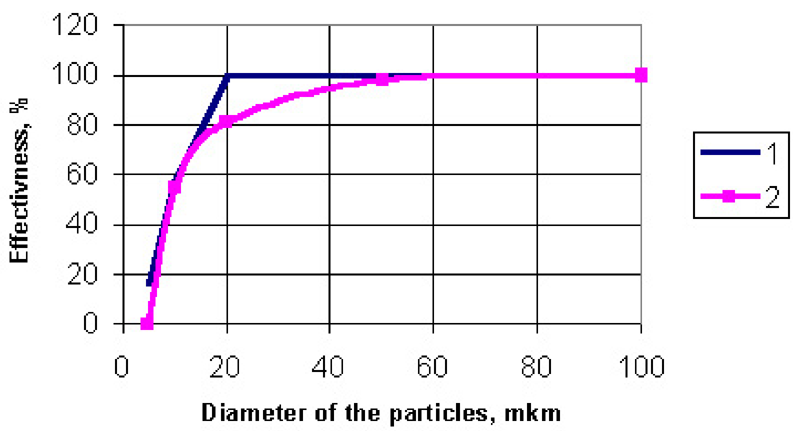

Fig. 3.1. Comparison of the effectiveness of separation received theoretically – 1, and experimentally – 2

The general effectiveness of the experimental sample is 90,4%, while the general effectiveness of the cyclones required by the standard [7] is 80%. So this construction and technological development provides the requirements at the standard and may be applied in industry.

Conclusions

On the subject of city-development air-purification has very important health, ecological and economical meaning.

Pollutant emissions to the atmosphere can cause negative consequences for the industrial cities and vicinities. Effective air-purification can also solve ecological and economical problem, as the closed air cycle and recycling in plants. Which will help to improve health and ecological situation and provide considerable saving of the energetic resources.

Requirements to the quality of environment and clean air are constantly increasing. That's why the introducing of new technologies and development of perfected equipment of dust collector is the question of great importance.

The result of this researches are aim at the increasing of effectives and improvement of the qualities of dust collection equipment.

Methods of the effectiveness estimation, which were developed in this work, can be used for the assessment of advisability of the applying cyclone in industry, and also for the showing up the technological field of its best application. The programs of fraction effectiveness calculation let us increasing of precision of estimate, so it's possible to increase the effectiveness of the dust particles separation in practice.

Literature review made by author showed the actuality and urgency of hydraulic researches on the field of air-purification and necessity of creating method of estimation of the dust collection effectiveness.

The research was made using suggested by the author mathematic model of the particle moving on the rotary stream.

Methods of the estimation of fraction effectiveness of dust separation for several models of cyclone were proposed. And experimental confirmation was made.

Created method was used to development of the model of direct-flow cyclone dust –collector, its construction. The model was tested and supply in industry.

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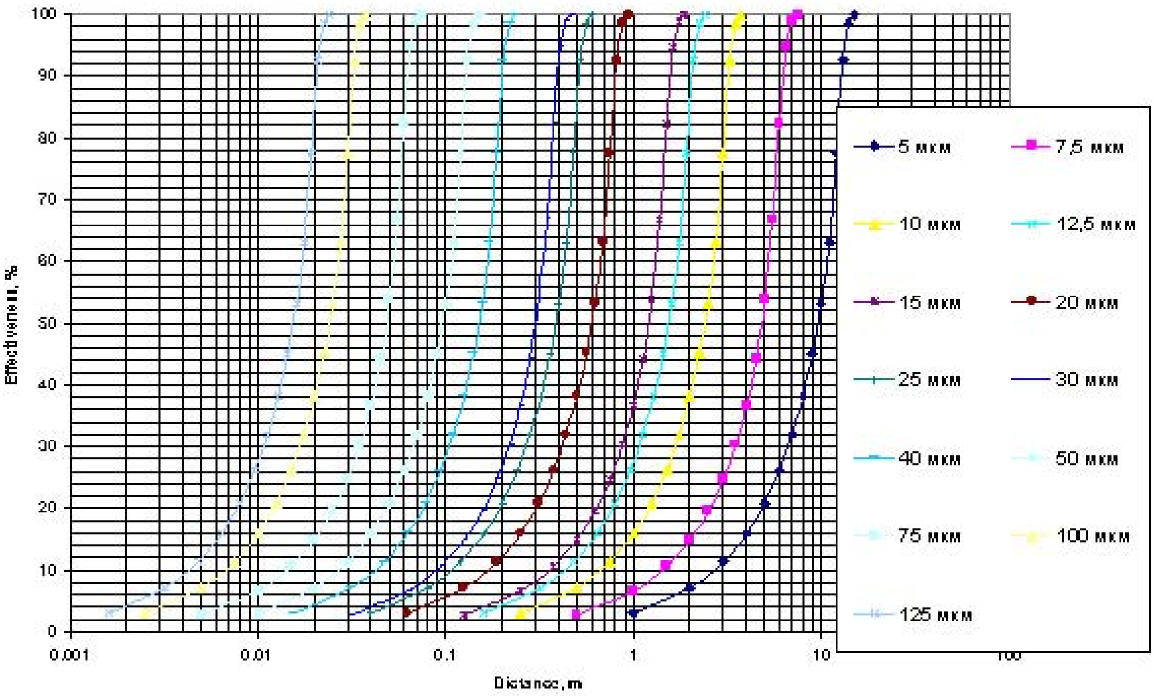
Appendix 1
Fraction effectiveness of the direct-flow cyclone depending on its length



Appendix 2
Test bench

Sceme of the test bench. Direct-flow cyclone dust collector