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Refining Vent Emissions from Fine Droplet Aerosols

Puring S.M., Vatuzov D.N., Novopashina N.A.
Samara State Technical University, Institute of Architecture and Civil Engineering
Address: Molodogvardeyskaya St., 194, Samara, 443001, Russia

***Abstract.** Vent emissions from industrial enterprises cause air pollution to a great extent. These emissions contain solid or liquid particles. it is necessary to install cleaning units for those particles. Existing methods of cleaning as applied to fine droplet aerosols have a number of limitations, especially within liquid disperse phase. This is why it is relevant to design highly-efficient cleaning units for vent emissions refining from droplet aerosols of sub-micron sizes. The research reveals the most important parameters for designing highly-efficient cleaning units for vent emissions refining from droplet aerosols. The authors designed a pilot plant and performed a series of experiments to define the optimal geometrical characteristics and modes of operation for cleaning units. These theoretical and experimental studies mase it possible to design three types of cleaning units with precipitating elements in the form of pipes and slotted channels with L/D = 250 dimensions.*

***Keywords:** purification devices, ventilation emissions, high-dispersity aerosols.*

I. INTRODUCTION

In modern times in industrialized countries the industrial production performance should include environmental protection through technical and organizational complex of measures that directly or indirectly targeted at stopping or reduction of air pollution. The ventilation emissions of factories containing solid or liquid suspended particles or aerosols contribute significantly to air pollution and to purify the air from these emissions it is necessary to provide the installation of purification devices being a part of the ventilation system [1].

Taking into account the fact that for the modern industry, on the one hand, the increase in the use of high dispersion ability materials is typical and on the other hand, increasing adoption of technology in industrial process that involves submicron particles emissions and finally the requirements for cleanness of working places are constantly growing [2]. The creation and development of air purification devices from high-dispersity aerosol particles with the size less than 1 mkm, that are the most dangerous for human health, plays an important role.

Small size and the mass of such particles exclude or significantly limit the use of traditional purification methods. The analysis of existing methods and purification devices has shown that they have a number of significant disadvantages that limit their use as high-dispersity aerosol purifiers, especially with the availability of liquid dispersed phase [3].

As can be seen from the above, it is really important to design high efficiency ventilation emissions purification devices from submicrometer dropping aerosols with low air drag, user – friendly and assisting the return of caught raw materials back in the production.

II. THEORETICAL BACKGROUNDS OF THE CREATION OF AIR PURIFICATION DEVICES

The design basis for purification devices is the movement peculiarities of turbulent stream in the thin pipes and parallel-plate ducts. The analysis of literature sources revealed that aerosol particles settling in the pipes and parallel-plate ducts are determined by turbulent diffusion effect and turbulent migration of particles [3] - [5]. The settling unit made in the form of a pipe or parallel-plate duct is the main element of the device.

Purification efficiency η of the device with the settling unit made in the form of a pipe or parallel-plate duct can be observed as dependence of:

$$\eta = 1 - \frac{C_x}{C_n} = 1 - e^{-\frac{LV_t}{Du_m}} . \quad (1)$$

where: Cx is the final particle concentration as they leave the settling unit, g/m3, Cn – is the initial concentration of particles on entering the pipe (channel), g/m3, Vt is the particle settling velocity, m/s, L is the settling unit length, m, D - pipe diameter (De – equivalent channel diameter), m, mean flow velocity um, m/s.

As it is known, the main characteristic affecting efficiency of air purification from the fine particles is the particles settling velocity on the walls of parallel-plate ducts or small-diameter pipes [3] - [6].

It is possible to define the particles settling velocity (solid or liquid) V_t (m/s) by the semirational

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characteristic curves or experimentally. In the general case, settling velocity relation appears as follows:

$$V_t = f(Re_D, \lambda, \rho_p, d_p, \mu) \qquad (2)$$

where: Re_D - Reynolds number; λ - friction resistance coefficient; ρ_p, - particles density, g/m^3, d_p - particle size, m; μ – absolute viscosity coefficient of dispersion medium, Pa•s.

From the dependance (2) it is seen that the turbulent velocity value of particle settling V_t vary with physical characteristics of airborne particles and fluid dynamics parameter of dispersion medium.

Thus, it is possible to apply results of the unit experiment with some aerosol to calculate the V_t value of another aerosol with the same physical characteristics and in the same dispersion medium.

Analysis of (1) and (2) formulas allowed to conclude, that aerosol particle settling in pipes and parallel-plate ducts is influenced by the settling unit dimensions and motion mode of turbulent aerosol flow.

Running efficiency of the air purification device, besides air purification rate, is characterized by the device aerodynamic drag, *Δp*, Pa, when specifying which the following dependence is used:

$$\Delta p = (\lambda \frac{L}{D} + \xi) \frac{\rho}{2} u_m^2 \qquad (3)$$

where L – is the settling unit length, m, D – pipe diameter (in the case of channel D_e - is the equivalent diameter), m, u_m - average aerosol speed, m/s, ρ - dispersive medium density, kg/m^3, λ - friction resistance coefficient; ξ - restriction losses.

A number of experiments were carried out to determine constructively technical engineering factors of the devices for high-dispersity dropping aerosol separation in pipes and parallel-plate ducts providing high efficiency purification.

III. EXPEREMENTS

Pilot unit scheme is shown on Fig. 1. For the experiments dioctyl phthalate aerosol was used, its particle distribution function is changed according to normal law and the size of 99% particles is less than 1 mcm [2], [7]. Dioctyl phthalate aerosol was formed from fluidizing agent vapour, produced by controlled heating, which was mixed with air in the upper part of the cabinet unit. The concentration of high-dispersity dioctyl phthalate aerosol was supported at the level of 100-200 mg/m^3. Pipes and slick bores D=8÷25 mm, «were blown» in the form of bank consists of 8-10 pipes assembled in a package.

All experiments were conducted for a range of $2300<Re_D<34000$, in which all investigational settling elements refer to hydraulically smooth pipes.

A great number of experiments was devoted to finding optimal value of particle precipitation efficiency based on the relation of pipe length or channel *L* to their equivalent diameter *D*.

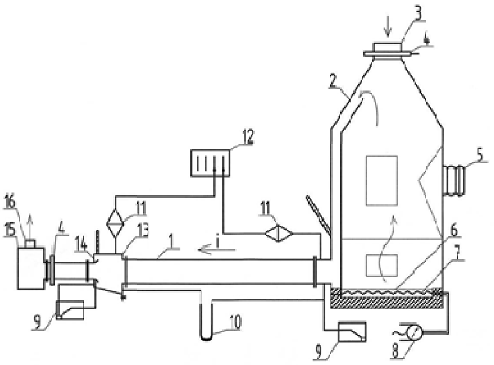

Fig. 1. Pilot unit: 1- settling element; 2- airing cupboard; 3- pipe union under ASO – 3 measurement; 4 - chimney valve flow control regulator with screw; 5 – pressurized hung sleeve; 6 – atmometer; 7 - heater; 8 - current controller; 9 – mictomanometer; 10 - U-type magnahelic gauge; 11 – allonge; 12 – portable rotary device; 13 – storage of equal static pressure; 14 – collector; 15 – blower unit; 16 –air extraction pipe to the atmosphere.

In our experiment several kinds of pipes of different diameter, length and materials were investigated. Research results on efficiency determination of dioctyl phthalate aerosol particles settling in pipes at various *L/D* dependence are shown in figure 2.

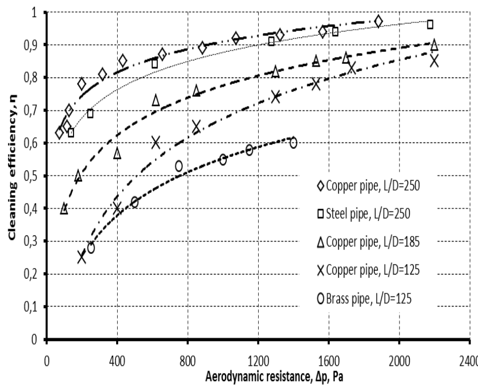

Fig. 2. The dependence of perufication level on aerodynamic drag for different

Separation efficiency η is shown in a from of full aerodynamic drag – dependence, Δp, which is the main characteristic in economic efficiency estimating (from the energetic point of view) when selecting separation method in one case or another. As can be seen in the figure, all experimental data are well approximated by logarithmic relationships.

It was founded that [8] the best separation effect is achieved by L/D = 250 proportion. By $L/D \leq$ 250 proportion, the separation effect is significantly reduced due to aerosol particles stay time in them is less than in longer pipes. Thus, further experiments were carried out for settling elements with L/D = 250 geometrics. Special attention was paid to the aerosol particle settling in the channel with dimensions of

0,5×4,0 cm, because these data were accepted as a basis for the designing of the industrial-grade device.

Figure 3 shows summarizing results of the experiments on settling efficiency determination of dioctyl phthalate aerosol particles in pipes and channels with L/D = 250 proportion. It is noted that when settling element geometrics satisfy L/D = 250 proportion, the shape of settling element and material from which it is made has no effect on purification efficiency.

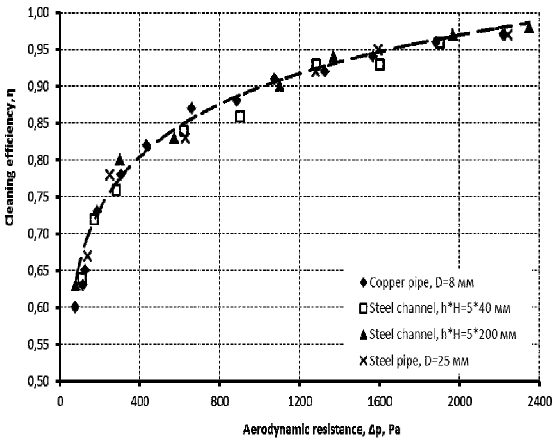

Fig. 3. The dependance of purification level on aerodynamic drag when L/D=250.

IV. RESULTS AND DISCUSSION

In order to evaluate device purification efficiency with the settling element and L/D=250 geometrics over a range of Reynolds numbers from 2300 to 3400 ($2300 \leq Re_D \leq 34000$) the dependence $\eta = f(\Delta p)$ is given:

$$\eta = 0,107 \times \ln(\Delta p) + 0,153 . \quad (4)$$

The dependence $\eta = f(\Delta p)$ can be transformed into $\eta = f(u_m)$.

$$\eta = 0,189 \times \ln(u_m) + 0,412 \quad (5)$$

Experimental data has a good repeatability with proposed dependences, which is characterized by determination coefficient R^2=0,9835 and 0,9815 respectively. As can be seen from Figure 3, when aerodynamic resistance value Δp varies from [1200 Pa; 1600 Pa] and appropriate speed u_m varies from [14m/s; 17m/s], the expected separation efficiency varies from [92%; 95%].

Obviously, when designing purification device it is necessary to follow this prerequisites and to use this characteristics as reference. In case of special need (high toxic level or importance of recovered products) it is possible to achieve higher value of purification efficiency by increasing the aerosol flow rate. However, it is necessary to weigh practicability η increasing taking into consideration growth of energy losses.

It is known that for the high-performance aerosol particles settling, the gas flow should be evolved turbulent, i.e. the Reynolds number in pipes is $Re_D \geq$ 4000 and in flat channels it is $Re_{De} \geq 2000$. Consequently, using the flat channels, it is possible to reduce the length of settling element and overall size of purification device.

Also an important factor impacting aerosol separation efficiency is channel curves, which are estimated by ratio of the curvature radius R_b to equivalent diameter D_e . A number of aerosol settling in curve channels experiments (D_e = 8 mm) were carried out to reduce the working length L of the prototype device. The experiments showed that when $R_b > 8D_e$ the influence of curves on the interlayer formation is insignificant and when straight and curve channels having the same length, particle settling efficiency η is almost the same. However, the picture is changed as the R_b/D_e is reduced. Comparison of two equal channels with channels initial length (L_1=L_2, D_{e1} = D_{e2}), one of them is having curves at $R_b/D_e \leq 1,5$, showed, that with the same pressure losses Δp, channel with curves has a high degree of particle settling. For example, when R_b/D_e= 0,75 purification efficiency coefficient is η > 0,99, while in the straight channel in pari causa η value does not exceed 0,95.

As a result of the made experiments, a number of devices for air purification from high-dispersity dropped aerosol have been designed. In all constructed devices the length ratio of the settling elements (of thick pipe or parallel-plate duct) to their diameter is L/D_e=250. In Fig. 4 the configuration of aerosol tilted-plate separator is shown [9].

Vertically positioned thin metal plates arranged in plane-parallel package with rimose splits h= 4 mm between the plates are used as the settling elements. h size is adopted on the basis of turbulence scale, where submicrometer dimension particles are captured most effectively.

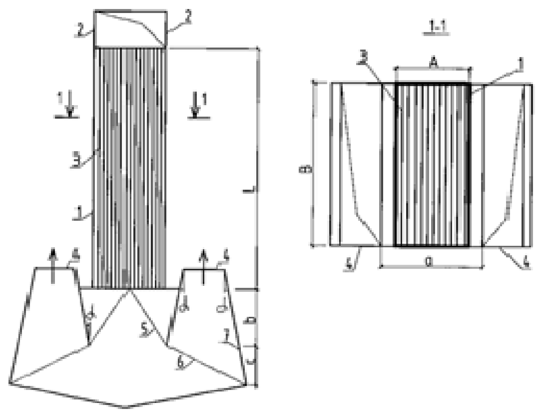

Fig. 4. Aerosol tilted-plate separator.

Working principle of aerosol tilted-plate separator is as follows. Purified gas enters separator-housing 1, through equal distribution air flue 2, travels into parallel-plate ducts between the settling plates 3. On the plate walls there is coagulant which flows down through the drop coagulant net 5 into the hopper 7, and purified gas through the net 6 and stabilizing converging pipes 4 is removed from the separator.

V. CONCLUSION

Thus, the performed experiments allowed determining the he most significant geometric characteristics of air purification devices from dropping aerosols, identifying specific analytic dependences and defining devices optimal operation.

The results of theoretical and experimental research allowed to develop three types of air purification devices with adhesional-settling elements in the form of thick pipes or parallel-plate ducts with the dimensions L/D=250, ensuring the most optimal working mode when trapping high-dispersity dropping aerosol [9] -[11].

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