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VENTILATED AIR AERODYNAMICS IN DEVICE FOR CLEANING FROM FINE-DISPERSED MOISTURE

Problem statement. The efficiency of ventilation air cleaning is defined by the time dependence of concentration of fine-dispersed moisture in environmental chamber for testing electronic products.

Results and conclusions. An aerodynamic calculation technique of the element of ventilated air cleaning assembly is proposed with consideration for specific features of determination of the concentration of fine-dispersed drop-like and solid particles arriving with atmospheric air drawn by ventilator. The calculation of constructional parameters of automatic condensate extractor is described having regard to removed mass of pollutants. This mass changes depending on environmental conditions and technology of manufacturing of finished products.

Keywords: automatic condensate extractor, aerodynamic calculation technique, concentration of fine-dispersed moisture, ventilated air cleaning.

Introduction. Aerodynamic resistance is defined not only by design and sizes of the elements of clean premise ventilation system, but also by concentration of fine-dispersed solid pollutants, including drop-like moisture. The presence of drop-like fine-dispersed moisture in atmospheric air drawn by ventilator depends on environmental conditions (for example, average long-term moisture content in Central Black Earth Area ranges from 0,98 to 8,07 g/kg of dry air) [1], as well as on technological features of finished products manufacturing. For instance, the use of spraying system for cooling ventilation air requires 5 g of drop-like moisture per cubic meter of return forced air.

The efficiency of ventilation air cleaning is defined by the time dependence of concentration of fine-dispersed moisture in environmental chamber for testing electronic products. Concentration of microparticles is calculated on the following assumptions:

1. An amount of fine-dispersed particles which forms in chamber is constant;

2. Discharge of ventilated air is constant;

3. Filtration coefficient of ventilated air cleaning assembly does not vary with time [2].

Concentration C of fine-dispersed particles (drop-like moisture of solid particles) in environmental chamber is

$$C = X / V \qquad \text{or} \qquad X = V \cdot C, \tag{1}$$

where X *is* the total amount of fine-dispersed particles; V is the effective volume of environmental chamber for electronic products testing.

$$dX = V \cdot dC, \tag{2}$$

provided that concentration of microparticles in the air varies over dC in an infinitely small period of time, dX is the change in total amount of fine-dispersed particles.

Change in the amount of microparticles dX_1 releasing in return circuit of environmental chamber in this time is equal to

$$dX_1 = M \cdot dt, \tag{3}$$

and change in amount of microparticles dX_2 because of inflow of outward ventilation air into return circuit is equal to

$$dX_2 = -(C - C_0) \cdot \Theta_0 \cdot dt, \tag{4}$$

where M is the amount of solid microparticles of rust and scale releasing in return circuit; C_0 is the concentration of microparticles coming with induced air of ventilator; Θ_0 is the total air volume, delivered into the chamber by ventilator.

Reduction in the amount of fine-dispersed particles dX_3 in the cleaning assembly of ventilation air is equal to

$$dX_3 = -(C - C_S)\, \Theta_S \cdot dt, \tag{5}$$

where C_S is the concentration of fine-dispersed particles in environmental chamber downstream of cleaning assembly; Θ_S is the volume of ventilation air downstream of cleaning assembly.

Total change in amount of fine-dispersed particles in environmental chamber is

$$dX = V \cdot dC = M \cdot dt - (C - C_0)\,\Theta_0 \cdot dt - C \cdot \eta \cdot \Theta_S \cdot dt, \qquad (6)$$

where η is the coefficient of filtration of cleaning assembly,

$$\eta = \frac{C - C_S}{C}.$$

By integrating expression (6), we obtain

$$\int_{C_{t=0}}^{C} \frac{-V \cdot dC}{C \cdot (\Theta_0 + \eta \cdot \Theta_S) - (C_0 \cdot \Theta_0) + M} = \int_0^t dt. \qquad (7)$$

Then

$$C = C_{t=0} \cdot \exp\ -\frac{\Theta_0 + \eta \cdot \Theta_S}{V} t\ + \frac{C_0 \cdot \Theta_0 + M}{\Theta_0 + \eta \cdot \Theta_S} \cdot \left[1 - \exp\ \frac{\Theta_0 + \eta \cdot \Theta_S}{V} \cdot t\ \right], \qquad (8)$$

where $C_{t=0}$ is the initial concentration of fine-dispersed particles in environmental chamber.

In steady state ($t \to \infty$), therefore,

$$C_{t \to \infty} = \frac{C_0 \cdot \Theta_0 + M}{\Theta_0 + \eta \cdot \Theta_S} \qquad (9)$$

Calculation of ventilation rate N is performed by the formula

$$\frac{N}{t} = \frac{\Theta_0}{V} \ \text{or} \ N = \frac{\Theta_0 \cdot t}{V}, \qquad (10)$$

where t is the time of the electronic products testing in environmental chamber.

With consideration for m-constant of stirring of recirculated air with ventilation air arriving at environmental chamber, concentration of fine-dispersed particles is equal to

$$C = C_{t=0} \exp\left(-\frac{\eta \cdot \Theta_S \cdot m}{V} t\right). \qquad (11)$$

Movement of air flow saturated with fine-dispersed moisture on return circuit of environmental chamber for electronic product testing results in the fact that boundary flow near the surface of the structure made from metal is saturated with rust and scale, and obtained mix contacts with electronic devices. As a result, from 50 % t 70 % of the finished products become defective [3], because pollutants in the form of rust, scale and fine-dispersed moisture sharply reduce electric reliability of test electronic products. Therefore, the problem of ventilated air adjusting to the standardized cleaning parameters, that is minimization of pollutants, is burning.

The special feature of condensate removal from ventilated air arriving at recycling chamber for electronic products testing is the necessity of cooling process, and moisture falls most intensively upstream of the thermal equilibrium temperature, i.e. upstream of approximate equality of temperatures of moving ventilated air with excess pressure and of environment. Therefore, intensification of condensate release corresponds to the process of cooling of the air produced by ventilator and directed to return chamber with accommodated products.

One of the solutions is to remove condensed moisture from ventilated air upstream of its supply to the return chamber.

Liquid removal from atmospheric air entering the return chamber is performed by automatic condensate extractor, whose operating efficiency and sizes are determined by the mass of released water [4].

For instance, at operating capacity on condensation product output up to 300 g/h it is proposed to use automatic condensate extractor of direct-action, whose operating member scheme is shown in Fig. at lowermost (Fig, a) and uppermost (Fig., b) positions of the float.

A condensate extractor consists of valve 1, rigidly connected with valve 3 opened on the underside by rod 2. Opening of discharge hole 4 is performed by lifting force acting on the valve and lifting it to the uppermost position. Condensate goes though the hole in guide bush 5, enters the discharge hole 4 and is released outward until valve 3 closes hole 4 by valve 1.

Basic characteristics of condensate extractor (mass, geometric sizes of the valve, and diameter of discharge hole) are determined from equilibrium equation, discharge and thermodynamic state of ventilated air under valve.

For lowermost position (Fig., a), condition of force equilibrium in the moment of opening of discharge hole, that is, in the beginning of valve lifting, is determined by the following equality:

$$G_{\text{пк}} = f_{\text{о}}(P_1 - P_{\text{ат}}) + nG_{\text{п}} = P_{\text{ат}}(f_{\text{пв}} - f_{\text{ш}}) + R_{\text{п}} - R_{\tau} - S, \qquad (12)$$

where $G_{\text{пк}}$, $G_{\text{п}}$ are weights of valve and condensation products under valve; P_1, $P_{\text{ат}}$ are pressures of ventilated air under the valve and of atmospheric air; R_n, R_τ, S are forces occurring as a result of jet response on opening the discharge hole and friction of rod against guide bush, and lifting force acting upon valve strake of height h_4 and part of rod submerged at a depth of h_2; f_o, $f_{пв}$, $f_{ш}$ are cross-section areas of interior hole, interior end surface of valve and rod; *n* is the coefficient considering reduction in weight of submerged valve.

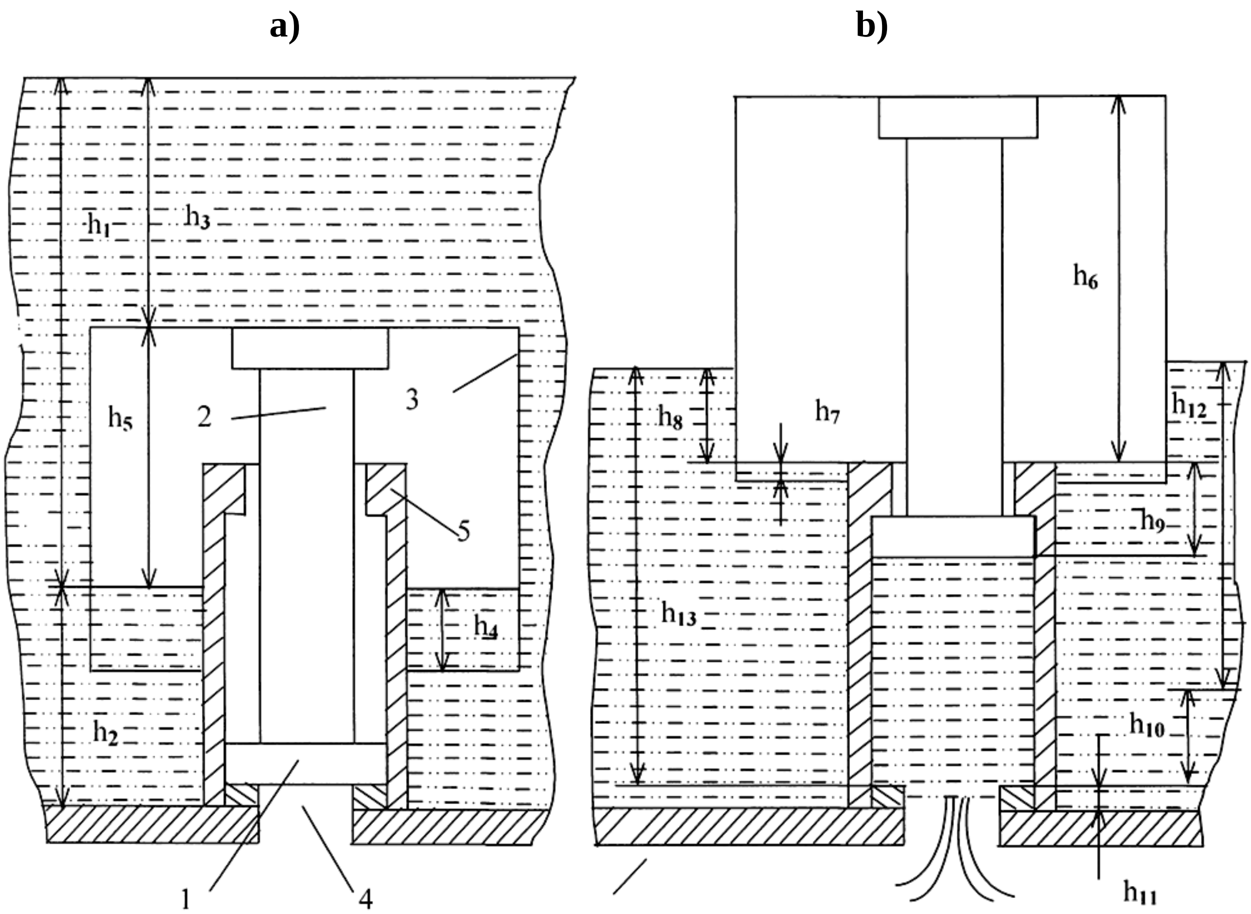

Fig. Operating member of condensate extractor:
a — lower position; b — upper position;
1 — valve; 2 — rod; 3 — float;
4 — discharge hole; 5 — bush

Increase in air pressure under float from P_1 to $P_{1ат}$ occurs at the expense of pressure of liquid column of height h_1. $P_{1ат}$ is the total pressure of ventilated air and of liquid column.

By ignoring forces *S and* R_τ because of their little values for small holes and considering that

$$P_{1ат} = P_1 + \rho_{пк} \cdot h_п$$

and

$$G_{пк} = f_{пк} \cdot h_3 \cdot \rho_{пк},$$

we obtain expression for determining the weight of the float:

$$G_{п}^{max} = [(P_1 - \rho_{пк} \cdot h_1)(f_{пв} - f_{ш}) - f_{пк} \cdot h_{п} \cdot \rho_{пк} - f_{о}(P_1 - P_{ат}) + R_{п}] \cdot n^{-1}, \quad (13)$$

where $h_{п}$ is the height of the float.

Given $G_{п}^{max}$ at $f_{пк} \approx f_{пв} = f_{п}$ corresponds to the minimum area of the float

$$f_{п}^{min} = \left[n \cdot G_{п} + f_o \cdot P_1 - P_{ат} + f_{ш} \cdot P_1 \cdot \rho_{пк} \cdot h_1 - R_{п} \right] \left[P_1 + \rho_{пк} \cdot h_1 - h_3 \right]^{-1}, \quad (14)$$

where $f_{пк}$, $f_{п}$ are the area occupied by condensate products, and average area of the float, $\rho_{пк}$ is the density of condensate products.

Minimum diameter of the float can be determined from the formula (14):

$$d_{п}^{min} = \sqrt{4 \cdot f_{п}^{min} / \pi + d_{ш}^{min}},$$

where $d_{ш}$ is the rod diameter,

$$d_{ш} = \sqrt{4 \cdot f_{ш} / \pi}.$$

The height of the float without regard for the thickness of the upper end wall

$$h_{п} = h_6 + h_7,$$

can be taken to be $1{,}05 \cdot h_6$.

Equation of equilibrium of forces for upper position of the float (Fig., b) is

$$P_{1ат} \cdot f_{пк} + R_{п} = P_1 \cdot f_{пн} + G_{п} + G_{пк}. \quad (15)$$

Since $P_{1ат} = P_1 + \rho_{пк} \cdot h_8$, the process of ventilated air compression under the float can be presented isothermally, then for both positions equality (16) is true

$$(P_1 + \rho_{пк} \cdot h_8) f_{пв} \cdot h_6 = (P_1 + \rho_{пк} \cdot h_1) f_{пв} \cdot h_5 = G_{в} \cdot R_{см} \cdot T_2. \quad (16)$$

Whence the height of the float is

$$h_{п} = \frac{(1.05 \cdot G_{в} \cdot R_{см} \cdot T_2)}{(P_2 \cdot f_{п} + G_{пв} + G_{пк} - R_{п})} = \frac{(P_2 - \rho_{пк} \cdot h) \cdot h_5}{\rho_{в} \cdot R_{см} \cdot T_1}, \quad (17)$$

where $R_{см}$ is the gas constant of ventilated air; $G_{в}$ is ventilated air discharge; T_1 and T_2 are temperatures of atmospheric and ventilated air; P_2 is the pressure of ventilated air downstream of condensate extractor; $\rho_{в}$ is the density of ventilated air.

The area of discharge hole can be determined from Bernoulli equation for the liquid plane at a height of h_{13} and outer side of the bottom of condensate extractor, where discharge hole is made:

$$G_{пк} = f_о \cdot \rho_{пк} \cdot \mu \cdot \left[2 \cdot g \cdot (P_2 - P_{ат})\right]^{1/2}, \tag{18}$$

where μ is the coefficient of condensate discharge.

Expressing the discharge of condensation products as the difference in moisture content of ventilated air upstream from the condensate extractor and downstream from it

$$G_{пк} = 622 \cdot G_в \cdot (P_{н_1} - P_{н_2}) \cdot P_1^{-1},$$

we obtain

$$f_0 = 622 \cdot G_в \cdot (P_{н_1} - P_{н_2}) \cdot \left[P_1 \cdot \rho_{пк} \cdot \mu \cdot \left[2 \cdot g \cdot \left(P_1 - P_{ат}\right)\right]^{1/2} \right]^{-1}, \tag{19}$$

where $P_{н_1}, P_{н_2}$ are pressures of water vapor saturation upstream of and downstream of condensate extractor.

Time of single emission of condensate is determined from material balance equation which can be presented in the form (20) for the case of excess pressure of ventilated air under its surface equal to atmospheric pressure:

$$\tau = f_к \cdot \int_{h_{10}}^{h_{13}} h^{\frac{1}{2}} \cdot dh \left(\mu \cdot f_0 \cdot (2 \cdot g)^{\frac{1}{2}}\right)^{-1} = \left(2 \cdot f_к \cdot \left(h_{13}^{\frac{1}{2}} - h_{10}^{\frac{1}{2}}\right)\right)\left(\mu \cdot f_0 \cdot \left(2 \cdot g^{\frac{1}{2}}\right)\right)^{-1}. \tag{20}$$

Considering that the part of condensate bounded by heights h_{10} and h_{11}, is always in condensate extractor, lower limit of integration can be taken to be equal to 0, and upper limit can be taken to be equal to h_{12}, then, with consideration for increase in velocity at the expense of excess pressure above the liquid level, we obtain

$$\tau = 2 \cdot f_К \cdot h_{12} \cdot \left[\mu \cdot f_0 \cdot \left[P_2 - P_1\left(P_{ат} - h_{12}\right)\right]\right]^{-1}, \tag{21}$$

where $f_к$ is the cross-section area of condensate extractor frame, where operating member is placed.

Obtained formulae provide a way for calculating all basic elements of condensate extractor of direct action.

Conclusions. We developed the algorithm of parametric optimization of automatic condensate extractor of the ventilated air cleaning system for environmental chamber where electronic products are tested at varying concentration of fine-dispersed moisture in atmospheric air inhausted by ventilator.

The technique for aerodynamic calculation of the element of ventilated air cleaning unit is proposed to be used in design of device for cleaning from fine-dispersed moisture.

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