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PERFORMANCE CALCULATION FOR LOW-SPEED FIBROUS MIST TRAPS

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Low-speed mist traps [1] are widely used to trap submicron droplets in gas treatment, in which the gas speed v_g does not exceed 10 cm/sec, and the best performance in droplet deposition is attained with v_g = 0.5–2 cm/sec. It is difficult to devise engineering methods of calculating such filters because there are several deposition mechanisms operating simultaneously. In addition to the inertial mechanism, whose importance decreases as the filtration rate is reduced, the trapping mechanism (contact) retains its significance, and the diffusion mechanism acquires substantial effect.

Figure 1 gives calculated values for the deposition mechanism parameters [1] in relation to droplet size for various speeds.

The parameter in the inertial mechanism is

$$Stk = \frac{C d_d^2 \rho_d v_g}{18 \mu d_f}, \tag{1}$$

where C is the Cunningham–Millikan correction, d_d droplet diameter in m, ρ_d droplet density in kg/m^3, v_g the filtration speed in m/sec, μ the dynamic viscosity of the gas in Pa·sec, d_f the fiber diameter in a filter in m, while that for the contact mechanism is given by

$$R = d_d / d_f, \tag{2}$$

and the parameter for the diffusion mechanism is given by

$$D = 1/\mathrm{Pe} = D_d / (v_g d_f), \tag{3}$$

where Pe is the Peclet number and D_d is the diffusion coefficient for the droplet suspended in the gas flow, in m^2/sec.

From Stokes's law, the diffusion coefficient can be put as

$$D_d = C K_B T_g / (3 \pi d_d \mu), \tag{4}$$

where K_B is Boltzmann's constant, which is $1.38 \cdot 10^{-23}$ J/K, and T_g is the absolute temperature of the gas in K.

Calculations have been performed from (1)–(4) for air under normal conditions: temperature 0°C, pressure 101.3 kPa, droplet density taken as 1000 kg/m^3 (water), and fiber diameter 9 μm.

Figure 1 shows that for droplets of size less than 2 μm and $v_g \le 0.05$ m/sec, the diffusion mechanism begins to predominate over the inertial one.

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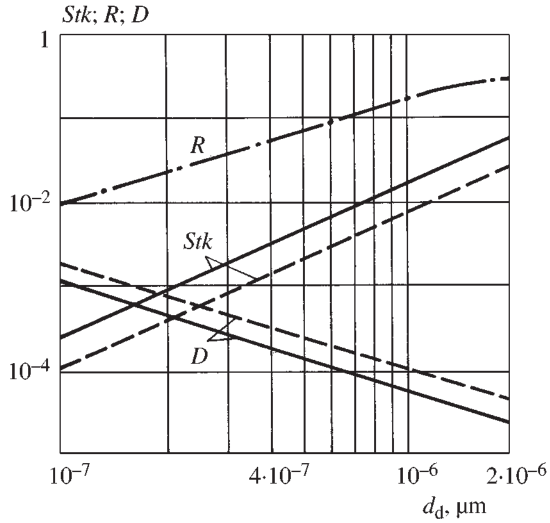

Fig. 1. Comparison of parameters in droplet deposition mechanisms for laminar gas flow (air under normal conditions, ρ_d = 1000 kg/m^3, $d_f = 9 \cdot 10^{-6}$ m): ——) v_g = 0.05 m/sec; – – –) v_g = 0.02 m/sec.

To calculate the fractional performance, one can use the following [1, 2]:

$$\eta_{fr} = 1 - \exp\left(-\frac{4\alpha H}{\pi d_f}\eta_t\right), \tag{5}$$

where $\alpha = 1 - \varepsilon$ is the backing density, ε is the porosity of the filter material in m^3/m^3, H the thickness of the filter layer in m, and η_t the trapping coefficient for a single fiber.

As the diffusion mechanism predominates at low gas speeds, we use the formula for the deposition performance characterizing the deposition of suspended droplets with viscous flow around a cylinder (fiber) [1, 3]:

$$\eta_t = 2.92(2.002 - \ln \mathrm{Re})^{-1/3}\mathrm{Pe}^{-2/3}, \tag{6}$$

where $\mathrm{Re} = v_g d_f \rho_g / \mu$ is Reynolds number and ρ_g is the density of the gas flow in kg/m^3.

As (6) includes Pe and Re, it incorporates the deposition due to the R trapping mechanism. It has been found [4] that there is satisfactory agreement between experimental results for suspended droplets on fibers and the data obtained from (6) for small Re and large Pe.

When one substitutes (6) into (5), we obtain a formula that can be used to estimate the fractional performance of a fibrous mist trap. This has been evaluated in [5] and showed satisfactory agreement between calculation and practical data. However, the mist droplets polydisperse at the inlet to the trap, so this method of estimating the deposition performance is very laborious and not adequately reliable for engineering purposes.

The dependence of the fractional performance of a fibrous trap on droplet size is log-normal no matter what the filtration speed, and as a log-normal distribution for the droplet diameters (by mass) almost always applies to the droplets at the inlet, one calculates the performance of a fibrous trap working in the low-speed (diffusional) mode by a probabilistic method as used for high-speed (inertial) mist traps [1, 6].

In that case, we need d_{50} (the droplet diameter for trapping with a performance of 0.5), which can be calculated from its dependence on the function

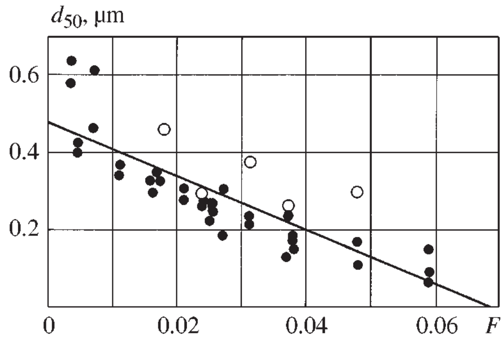

Fig. 2. Curve fitting to experimental data on d_{50} in relation to function F:
●) polypropylene; ○)Supersil.

$$F = \left[\frac{\alpha H}{\pi d_f} \left(2.002 - \ln \frac{d_f v_g \rho_g}{\mu} \right)^{-1/3} \left(\frac{C K_B T_g}{3\pi \mu d_m v_g d_f} \right)^{2/3} \right],$$

derived by substituting (6) into (5) and expanding the values of Re and Pe (here d_m is the median diameter of the droplets used in calculating the coefficient C).

This function for d_{50} incorporates the parameters of the filter material (α, H, d_f), the mode of operation (v_g, ρ_g, T_g, m), and the dispersion in the droplet composition (d_m).

The experiments were done by a standard method [1] on laboratory equipments described in [7]. The oil mist at the inlet to the trap had the following parameters: d_m = 1.3 μm; standard deviation in the logarithmic distribution of the droplet sizes $\log \sigma_d = 0.23$; $\rho_d = 885$ kg/m^3. We examined two specimens of filter material: polypropylene (d_f = 40 μm, α = 0.060) and Supersil glass fiber (d_f = 6 μm, α = 0.049).

Experimental results have been given [5] for polypropylene with gas flow speeds of 0.5, 1.0, and 2.0 cm/sec. The Supersil tests were performed with gas speeds of 1.0, 1.5, 2.0, 3.0, and 5.0 cm/sec (air at 20°C); the thickness of the filter layer was 7.5 mm.

Figure 2 shows experimental dependence of d_{50} on F.

The data give the empirical expression

$$d_{50} = 0.453 - 5.834F. \quad (7)$$

Formula (7) applies for v_g = 0.5–5.0 cm/sec and can be used to calculate the performance for low-speed fiber mist traps with a log-normal distribution of droplet diameters by mass at the input to the filter. Here the calculations were performed by analogy with those for high-speed fiber mist traps [8]. The value of $\log \sigma_\eta$ (logarithmic standard deviation in the fractional performance for droplet trapping) was taken as 1.2 from the experimental data.

The hydraulic resistance of these low-speed filters is low and usually does not exceed 200–300 Pa.

REFERENCES

1. A. Yu. Val'dberg, A. A. Moshkin, and I. G. Kamenshchikov, *Mist Formation and Droplet Trapping in Gas Cleaning Systems* [in Russian], NIIOGAZ OAO, Moscow (2003).

2. V. A. Kirsh, *Simulating Fibrous Aerosol Filters in Particle Trapping*: *Thesis for Candidate of Technical Sciences* [in Russian], Institute of Physical Chemistry, Moscow (2001).
3. G. L. Natanson, *Dokl. AN SSSR*, **112**, No. 1, 100–103 (1957).
4. A. L. Chernyakov, *Hydrodynamics of Fibrous Media with Application in Filtration Theory*: *Doctoral Thesis* [in Russian], FGUP, Karpov Physical Chemistry Research Institute, Moscow (2001).
5. A. Yu. Val'dberg, A. A. Moshkin, and I. G. Kamenshchikov, "Mist droplet trapping performance in fibrous filters at low filtration speeds," *Khim. Neftegaz. Mashinostr.*, No. 1, 40–42 (2000).
6. A. Yu. Val'dberg, N. V. Krainov, N. V. Savenkov, and N. M. Savitskaya, "Calculating the performance of fibrous filters," *TOKhT*, **28**, No. 2, 164–166 (1994).
7. A. A. Moshkin, A. Yu. Val'dberg, and I. G. Kamenshchikov, *Fibrous Mist Traps: Scientific and Technical Aspects of Environmental Protection*, No. 1 [in Russian], VINITI, Moscow (2000), pp. 25–65.
8. A. Yu. Val'dberg, A. A. Moshkin, and A. V. Ogurtsov, "A method of calculating high-speed mist traps," *Khim. Neftegaz. Mashinostr.*, No. 7, 45–46 (2002).