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Comparative Analysis of the Methods for Determining the Efficiency of Air-Purification Filters Using Dioctyl Phthalate and Turbine Oil Aerosols

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Abstract

The methods for determining the efficiency of domestic fine air-purification filters using dioctyl phthalate and turbine oil test aerosols were compared under actual working conditions. The filters used were of different types and sizes and employed different filter materials. Such filters are used in the State Research Center of Virology and Biotechnology Vector and other similar institutions of Russia for facility air purification and respiratory protective equipment for researchers and technicians involved in manufacturing diagnostic, medicinal, and prophylactic preparations and performing research of group I-IV human-pathogenic viruses. No significant differences between the permeability coefficients of these filters tested by dioctyl phthalate and turbine oil aerosols were recorded. The data demonstrate that both dioctyl phthalate and turbine oil aerosols are equally appropriate for testing air-purification filter efficiency.

Introduction

Different types of fine filters are presently used for efficient air purification in ventilation and engineering systems at medical and microbiological production enterprises and research institutions involved in studying pathogenic microorganisms. Different methods and test aerosols are used for monitoring the efficiency of these filters (Drozdov et al., 1987; White & Smith, 1967), different countries preferring different methods. In the United Kingdom, the standard method for filter testing requires methylene blue aerosol (Boyne, Dyment, & Thomason, 1971); in the USA, dioctyl phthalate (DOP) (Dorman, 1967); and in Germany, turbine oil aerosol (Dorman, 1968). As for Russia, the method for gas mask testing based on turbine oil mist is one of standard methods (Russian State Standard GOST).

The retentive efficiency of Russian filters used in ventilation systems, containment areas, and personal protective equipment (PPE) in the State Research Center of Virology and Biotechnology Vector (SRC VB Vector) while developing and manufacturing diagnostic, medicinal, and prophylactic preparations and performing research on group I-IV human-pathogenic viruses, including special pathogens (smallpox virus, Ebola, Marburg, etc.), is tested using oil mist. The efficiency of fine HEPA (high efficiency particulate air) filters, used in the United States in similar institutions for analogous purposes, is tested using DOP aerosol (Standard 49, NSF International; Standard IES-PR-CC-001-83).

The object of this study was to compare the methods for determining the efficiency of domestic air-purification filters of different types under actual working conditions at the SRC VB Vector using DOP and turbine oil aerosols.

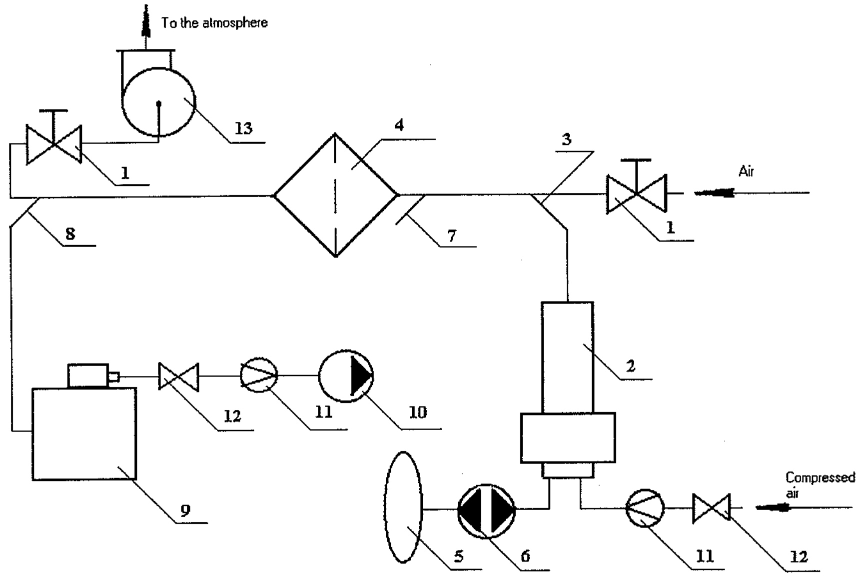
Experimental Conditions

The turbine oil grade T_{22} or T_{30}—a liquid mixture of hydrocarbons, mainly, alkylnaphthenes and alkylaromatics, with a high boiling point (T_b = 300° - 600° C)—is used in Russia as a mist-forming substance. The turbine oil is produced during oil refining and contains antioxidants, anticorrosives, antifoam additives, and demulsifiers. For comparison, DOP produced by Sigma-Aldrich (USA) was used. An oil mist consisting of a fine particulate aerosol of these substances was produced using a small-scale unified condensation aerosol generator GAK-UM (Russia). Concentrations of the aerosols produced were determined in a standard photometer FAN-A UkhL-4, 2 (Russia) with a measurement range 10^0 - 10^7 particles/m^3.

The efficiencies of individual filters and ventilation chambers housing banks of filters were evaluated according the protocol below. A schematic representation is provided in Figure 1.

Figure 1

Scheme of the unit for testing filters and ventilation chambers using turbine oil and DOP mists: (1) airtight valves; (2) generator GAK-UM; (3) supply-pipe for delivering aerosols; (4) ventilation chamber (filter); (5) tank; (6) peristaltic pump; (7, 8) sampling exhaust-pipes; (9) photometer; (10) vacuum pump; (11) rotameters; (12) couplings; and (13) ventilator.



Testing Technique

Prior to testing, airtight valves I of the air duct were closed. The agents tested (turbine oil and DOP mists) were generated for 2 - 5 min from generator 2 into the air duct through supply-pipe 3 until the initial concentration prior to the filter 4 reached 10^6 - 10^7 particles/m^3. Particle concentration was measured using photometer. To produce the mist, oil or DOP was supplied to the generator GAK-UM from tank 5 using peristaltic pump 6 (Gilson, France), with a capacity of 5 - 8 ml/min, simultaneously with compressed air under a pressure of 3 atm (the compressed air is required for both production of the aerosol and its delivery to the air duct). When the required initial concentration prior to the filter was reached, the airtight valves were opened, and the agents tested passed through the filter. The air samples collected before (exhaust pipe 7) and after the filter (exhaust-pipe 8) were transported to photometer 9 to determine the mist concentrations. Pump 10 (Sartorius, Germany) facilitated the transfer of the air samples through the test system.

Results

Filter permeability coefficient (K_p) was calculated according to the following equation:

$$K_p = I_2/I_1, \times 100\%, \qquad (1)$$

where I_1 is the light scattering corresponding to the aerosol concentration prior to the filter, µA, and I_2 , after the filter, µA.

The value of light scattering is proportional to mist concentration; therefore, we omitted the conversion to concentration value. Thus,

$$K_p = I_2/I_1, \times 100\% = C_2/C_1 \times 100\%, \qquad (2)$$

where C_1 is the mist concentration prior to the filter, particles/m^3, and C_2, particles/m^3, after the filter.

Each individual filter or cascade of ventilation chamber is considered serviceable if its K_p does not exceed 1.0×10^{-3}%.

To further validate the comparison of filter retention when challenged with turbine oil and DOP, the particle size composition of these aerosols, produced under identical conditions in the generator GAK-UM, was studied and compared during the initial stages of the research project. A four-stage Andersen cascade impactor BP-35/25-4 (Russia) was used in this part of the study. To exclude the loss of the finest particles, an AFA-BA filter was used as an additional fifth stage. At an airflow volume of 25 l/min through the impactor, the four stages of the impactor retained 50% of the particles, with mass median aerodynamic diameters (MMAD) of 12, 6, 2.1, and 0.8µm, respectively. All impactors were certified and calibrated using a monodisperse aerosol generator with vibrating orifice Berglung-LIU (TSI, USA) prior to conducting tests with turbine oil or DOP. Testing in a ROYCO (TSI, USA) multichannel photoelectric particle counter demonstrated that the aerosol produced consisted of fine particulate aerosol.

The data demonstrate that MMAD$_{50}$ for the DOP aerosol particles ranged between 0.19 - 0.36 µm; for turbine oil particles, 0.17 - 0.34 µm; ???$_g$ = 1.5 - 2.0 (geometric standard deviation, characterizing the range of particle sizes in aerosol). In both DOP and turbine oil aerosols, 97.7±2.3% and 98.6±2.3% of the particles, correspondingly, fell into this size range.

Thus, the experimental data obtained have demonstrated that the DOP and turbine oil aerosols produced through nebulizing in the generator GAK-UM display essentially the same particle size composition ($P<0.05$). We proceeded with the second stage of the work.

Discussion

Standard, domestically produced, highly efficient filters of different types (Table 1) (Gaponov, 1981) were selected for comparative testing. Filters FETO-750, FTO-1000, FTO-500, and FTO-60 are routinely installed in microbiological laboratories and production facilities in the systems for ventilation and air purification. Filters of another type, FTO-S-500K, are used in the systems supplying compressed air and autoclave vacuum of the entrance through autoclaves. These filters are capable of filtering moisture air and retain their filtration capacity after steam sterilization. Gas mask filters EO-16 and filters V-0.4 are designed for use in PPE, such as individual protection suits (suits "L-1," "Korund," and pneumatic suits). Note also that the EO-16 filter contains another filtering material—activated charcoal—and, therefore, this was another reason to include these filters into our study.

Our main attention was focused on testing the filters installed with the systems purifying the facility air that was exhausted from both level II (BSL-3) rooms (Drozdov et al., 1987) within single cascade ventilation chambers and level III (BSL-4) within dual in-line filter ventilation chambers. The efficiency of each single cascade was tested individually; for dual in-line cascade chambers, the data were pooled. The airflow capacity for each individual ventilation chamber or filter was determined under actual working conditions within the corresponding engineering systems installed in different buildings of the State Research Center of

Table 1

Types and Main Characteristics of the Filters for High Efficient Air Purification

Type of filter or filtration unit	Material	Characteristics
FTO-750 (filtration unit for fine air purification with a capacity of 750 m^3/h), V-0.4	FPP-15-1.5; FPP-15-4.5 (Petryanov's polyvinyl chloride filter with a fiber diameter of 1.5 and 4.5 μm, respectively)	Polyvinyl chloride fibers on a gauze base; thermostable at 60-70°C, hydrophobic
FTO-60, FTO-500, and FTO-1000 (fine filters with a capacity of 60, 500, and 1000 m^3/h, respectively)	FPAN-10-3.0 (Petryanov's acryl nitrile filter with a fiber diameter of 3.0 μm)	Polyacryl nitrile fibers on a gauze base; thermostable at 180°C
FTO-S-500 (sterilizable fine filter)	Basalt paper and board	Superthin basalt fiber with addition of cellulose
EO-16 (gas mask filter)	Activated charcoal	—

Virology and Biotechnology Vector. The results of the testing are shown in Table 2 (single cascade ventilation devices and individual filters) and Table 3 (dual in-line cascade ventilation chambers).

The K_p values of domestic filters, installed in various engineering systems, were virtually equal when results were compared following challenge with DOP and turbine oil (Tables 2 and 3). Analysis of the data obtained has demonstrated the correlation between the permeability coefficients of the test aerosols used (Batova & Motina, 1977; Lakin, 1980). The correlation coefficients calculated demonstrate a strong and reliable correlation between the indices compared.

We have demonstrated that both DOP and turbine oil have virtually equal particle size composition and are equally suitable for producing test aerosols for determining the efficiency of various domestic filters used for air purification.

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Table 2

Efficiency of Single Cascade Filtration Devices Tested with Turbine Oil and DOP Aerosols

System and type of installed filter	Number of filters in the system unit under testing	Capacity of system, m^3/h	Permeability coefficient with respect to turbine oil mist, $(X \pm J_{95}) \times 10^{-3}$, %	Permeability coefficient with respect to DOP mist, $(X \pm J_{95}) \times 10^{-3}$, %	Correlation coefficient
1	2	3	4	5	6
Flow general exchange ventilation of II* zone, FETO-750	20	4300	0.020±0.006	0.020±0.006	1.0
	12	8150	0.070±0.021	0.065±0.019	
	20	9300	0.008±0.002	0.007±0.001	
	12	6500	0.002±0.001	0.002±0.001	
	12	4600	0.003±0.001	0.002±0.001	
	20	9750	0.070±0.035	0.113±0.034	
	20	8600	0.003±0.001	0.004±0.001	
	12	6750	0.060±0.018	0.062±0.017	
Exhaust ventilation of II* zone, FETO-750	12	5300	0.047±0.028	0.033±0.021	1.0
	16	4350	0.057±0.011	0.055±0.009	
	12	9700	0.117±0.011	0.130±0.018	
	16	5050	0.017±0.011	0.017±0.011	
	12	8800	0.005±0.002	0.008±0.003	
	16	5150	0.006±0.001	0.005±0.001	
	12	7900	0.005±0.001	0.005±0.001	
	16	6400	0.033±0.011	0.033±0.011	
	12	8400	0.013±0.007	0.013±0.007	
	16	5000	0.023±0.011	0.023±0.011	
	8	4350	0.057±0.011	0.057±0.011	
	8	3350	0.053±0.011	0.053±0.011	

Exhaust ventilation of III class virological cabinets, FTO-60	1	60	0.023±0.005	0.022±0.005	1.0
	1	60	0.032±0.005	0.033±0.005	
	1	60	0.032±0.005	0.031±0.005	
	1	60	0.093±0.005	0.082±0.005	
Exhaust ventilation of II class virological-biochemical cabinets, FTO-1000	1	900	0.110±0.002	0.012±0.002	1.0
	1	900	0.127±0.011	0.125±0.011	
	1	800	0.022±0.005	0.023±0.005	
	1	800	0.217±0.053	0.173±0.046	
Autoclave vacuum, FTO-500, FTO-S-500K	1	360	0.002±0.001	0.002±0.001	1.0
	1	360	0.002±0.001	0.002±0.001	
	1	72	0.012±0.005	0.011±0.005	
Exhaust air filtration of sewage-collectin	1	0 - 16	0.037±0.021	0.050±0.026	1.0
	1	0 - 16	0.012±0.005	0.011±0.005	
collecting tanks, FTO-60	1	0 - 16	0.004±0.001	0.004±0.001	
Exhaust filtration of specialized plumbing (internal sewage system), FTO-60	1	0 – 60	0.230±0.084	0.163±0.023	0.8
	1	0 – 60	0.165±0.106	0.120±0.060	
	1	0 – 60	0.122±0.063	0.088±0.019	
	1	0 - 60	0.147±0.087	0.154±0.108	
Individual PPE filtration systems in protection suit, V-0.4	1	1,2	0.033±0.024	0.030±0.015	0.9
	1	1,2	0.450±0.032	0.495±0.034	
	1	1,2	0.326±0.106	0.253±0.095	
	1	1,2	0.707±0.386	0.873±0.224	
Individual PPE filtration system in gas mask, EO-16	1	1,2	0.099±0.049	0.109±0.086	0.9
	1	1,2	0.198±0.054	0.194±0.046	
	1	1,2	0.081±0.017	0.088±0.013	
	1	1,2	0.065±0.030	0.031±0.012	
	1	1,2	0.124±0.021	0.094±0.009	

Note: Five measurements were made for each filter or ventilation chamber in lines 1-7; six, in lines 8-9.

* II zone according to the Russian classification corresponds to BSL-3.

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Table 3

Efficiency of Dual In-line Cascade Ventilation Chambers of Exhaustive Ventilation Tested with Turbine Oil and DOP

Number of filters in dual in-line cascade ventilation chamber	Capacity of system, m^3/h	Permeability coefficient with respect to turbine oil mist, $(X \pm J_{95}) \times 10^{-3}$, %	Permeability coefficient with respect to DOP mist, $(X \pm J_{95}) \times 10^{-3}$, %	Correlation coefficient
8 (2 cascades with 4 filters in each)	3000	0.212±0.021	0.205±0.021	1.0
24 (2 cascades with 12 filters in each)	8300	0.120±0.011	0.125±0.031	
16 (2 cascades with 8 filters in each)	3000	0.130±0.021	0.133±0.021	
16 (2 cascades with 8 filters in each)	5000	0.573±0.110	0.538±0.113	

Note: Five measurements were made for each ventilation chamber.