

ISTC Project A- 1605

Development of High-Efficient Filter Systems on the Basis of a Super-Thin Basalt Fiber for Radioactive Aerosols Purification and Creation of a Work Cycle for Filters Manufacturing with the Purpose of Their Operation at the Nuclear Power Plants

Final Project Technical Report

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PROJECT OBJECTIVES

The final objective of the project is creation of a functional highly efficient filtering system on the basis of modified basalt fiber for decontamination of radioactive aerosols from nuclear power plants. To realize the objective, it was necessary to solve the following problems:

- To study - on the basis of physical models - inertial, diffusion, sedimentation effects, as well as entanglement effect and sieving effect of filters on the basis of super-thin basalt fiber.
- To study of the dependence of filtration coefficient on parameters of the filtering systems to be created.
- To determine the aerosol particle size distribution in ANPP premises and environmental emissions, as well as the aerosol radionuclide composition.
- To develop chemical methods for treatment of basalt fibers aimed at obtaining highly effective filtering materials.
- To develop an experimental device for investigation of filter systems characteristics.
- To manufacture industrial filtration units on the basis of chemically treated basalt fibers analogous to those used in NPP ventilation systems, and determine experimentally their efficiency.
- To develop and test standard units from chemically modified basalt fibers for cleaning of incoming air.

1. Characteristics of basalt rocks and fibers obtained on their basis

It is known from literature that many physical and chemical properties of all silicon containing materials (zeolites, granites, silicate glasses) and basalt are defined by ratio of oxide concentration $\text{SiO}_2/\text{Al}_2\text{O}_3$ and admixture atoms in their elementary cells [1-3].

Basalts are the basic rocks of volcanic origin and widespread practically in the whole earth crust. The basic rock-forming minerals of earth material are field spars (albites, anorthites), pyroxenes (diopside, augite), sometimes magnetite. Concentration of basic oxides in the investigated rocks is within the following ranges (in weight %): 43-58 % of SiO_2 , 1-2 % of TiO_2 , 11-20 % of Al_2O_3 , 8-16 % of $\text{FeO}+\text{Fe}_2\text{O}_3$, 4-12 % of MgO , 7-13 % of CaO , 2-4 % of $\text{Na}_2\text{O} + \text{K}_2\text{O}_3$.

It is shown in [3] that with increase of aluminium oxide concentration improvement of mechanical properties of fibers is observed. It also counts in favor of the statement that basalts not from all deposits are suitable for obtaining of continuous basalt fibers (CBF).

It is established that fibers with large content of Al_2O_3 have high thermostability [3]. Works [2,3] present interesting data on obtaining basalt fibers and their various physical and chemical properties. [3] contains comparative characteristics of various types of fibers from basalts type rocks. Properties of basalt fiber at high temperatures and parameters of optimum thermal protection from mixture of various fibers are described in [4]. Conclusions are drawn on necessity of manufacture of composite basalt fibers. From the results of investigations carried out by Dzhigiris D.D. and Makhova M. F., as single-component material basalts of Marneuli (Georgia) and Sulu-Terek (Kirghizia) deposits, basanites of Zolakar (Armenia) deposit and andezito-basalts of Podgornjansk (Ukraine) deposit were recommended for manufacturing CBFs [3]. Analysis of these data shows that the investigated rocks differ from each other in contents of silicon, aluminium, iron, calcium, magnesium, sodium and potassium oxides. Final melting temperature of all species obtained from rocks does not exceed 1400°C , which gives the opportunity to obtain homogeneous melt at 1450°C in the existing melting furnaces. One of the important assessment criterion of suitability of various rocks for manufacture of fibers is melt viscosity, especially at temperature 1300°C , i.e. close to fiber production temperature. The most viscous melts form andezito-basalts from Podgornjansk deposit possessing characterized by increased content of SiO_2 , Al_2O_3 and smaller total amount of CaO and MgO . Along with viscosity, the important criteria determining suitability of raw materials for obtaining continuous fibers, are temperature of the upper limit of crystallization and temperature interval of fiber production. The widest interval of fiber production and lower values of upper limit of crystallization are characteristic for melts of basanites from Zolakar deposit (Armenia), which is caused by smaller concentration of iron and magnesium oxides. Melts of all these rocks meet the requirements of obtaining continuous fibers (upper limit of crystallization should not exceed 1250°C ; temperature interval of fiber production should be at least 700°C). Some characteristics of CBF products are presented below:

1. Diameter of fiber: 6-25 microns.
2. Operating temperature: $\text{C}-200\dots +600$.
3. Density, kg/m^3 : 2800.
4. Elastic modulus, $\text{kg} / \text{sq. mm}$: 9100... 1100.
5. Tensile strength (after heat treatment during 1 hr), % 20 grad. C - 100%, 200 grad. C - 94%, 400 grad. C - 65% C.
6. Weight loss in % after 3 hr boiling in H_2O : 0.16 %, 2N NaOH - 5.0 %, 2NHCl - 2.1.
7. Specific volume electric resistance, $\text{Ohm}\cdot\text{m}$ $1\cdot 10^{12-13}$

8. Normal acoustic absorption coefficient 0.9... 0.99, stable.

They also have much higher acoustic absorption coefficient than fiber glasses.

One of the important characteristics of basalt is its specific resistance or specific conductivity. The knowledge of this parameter can help to find correlation with both its filtering capacity and other physical, chemical properties. So, in [4, 5] temperature dependence of basalt and granite samples from Egypt was studied within the range from room temperature (RT) to 1000 K. It was found that specific resistance for both samples decreases with increase of temperature. It is established that for both samples specific resistance has two characteristic areas. In the first area (from RT to 450 K for basalt and from RT to 400 K) for granite samples, specific resistance reveals mild reduction. In the second area (400-1000 K for basalt and 450-1000 K for granite) specific resistance shows strong reduction with increase of temperature. Energy of activation was determined for both samples within the specified temperature intervals. In the first area energy of activation was equal to 0.152 eV for basalt and 0.14 eV for granite. In the second area these values were equal to 0.93 eV and 0.761 eV, correspondingly. Specific resistance of Egyptian basalt at RT was equal to 10^{12} Ohm·m, that coincides with the bottom boundary for basalt fibers ($1 \cdot 10^{12-13}$ Ohm·m). It can be caused by the fact that basalt rock contains more admixture ions in comparison with fiber samples.

It is experimentally shown that penetration of aerosol particles into fiber medium depends on their type, form, sizes, movement velocity [6-9] and charge state [10], as well as on chemical content of the medium. In [11] process of migration of particles through micro capillaries is investigated theoretically and experimentally, and a new mathematical model is offered, which considers complex interactions between the particles themselves and carrier gas taking into account the carrier gas composition, nature of aerosol particles (sized approximately 1 μ m) and geometry of micro capillaries.


Process of filtration of aerosol particles depends on both their properties and properties of filtering material. Quality, mechanisms and various factors (size, form, density, velocity of particles, etc.) determining criteria of filtration of aerosol particles, are described in [12]. These results can form a basis for modeling of the obtained results when producing filters for radioactive aerosols from super-thin basalt fibers. However, such fibers can only be obtained for the basalt rocks satisfying special conditions. To obtain fibers with diameter of several microns and length of more than 50 mm, basalt fiber should have optimal hardness at melting temperature, because thin fibers should not break when drawing from melt [13]. It is shown in the same paper using vibrational spectroscopy and X-ray phase analysis that with increase of aluminium oxide content the increase in connectivity of silicate glass and fiber structure is reached. Fibers with the reduced concentration of aluminium oxide contain mainly structural elements with unbridged oxygen atoms (chains, isolated tetrahedrons SiO₄). It is established that the most part of structure of mineral glasses and fibers with high content of aluminium oxide consists of three-dimensional grids on the basis of silicon- and aluminium-oxygen compounds [14-16]. The Table below shows data on about interrelation between preparation conditions and some properties of basalt fibers.

Table 1.1

Physical characteristics of preparation process	Properties of primary fibers and basalt fibers
Density of monolithic basalt, $\rho_6 = 2700 \text{ kg/m}^3$	Diameter of primary fibers, $d_H = 0,12 \dots 0,3 \text{ mm}$
Viscosity of basalt melt, $\mu_6 = 5 \dots 25 \text{ Pa}\cdot\text{sec}$	Average diameter of fiber, $d_B = 0,6 \dots 3 \text{ micron}$
Temperature in oven when melting basalt, $T_{\text{пл}} = 1450 \dots 1500^\circ\text{C}$	Coefficient of variation for average diameter, K_d , not more than 5%
Contact angle of wetting platinum-rhodium	Density of product made of basalt fiber, $\rho_B =$

draw die by basalt melt, $\theta = 10...25$ grad.	18...30 kg/m ³
Surface tension of basalt melt, $\sigma_6 = 0,2...0,5$ J/m ²	Mass fraction of fiber free inclusion sized more than 0,25 mm, M_{HB} , not more than 8%
Basalt thermal conductivity, $\lambda = 1,6$ W/(m·K)	Thermal conductivity of fabric from fiber, $\lambda_B = 0,033...0,095$ W/(m·K)
Basalt thermal capacity, $c_p = 0,8$ J/(kg·K)	Operating temperature range, $t_{pa6} = -180 ... +900^\circ\text{C}$
Density of gas mixture, $\rho_{ra3a} = 0,1$ kg/m ³ at $T = 2300^\circ\text{K}$	Moisture of fabric from basalt fiber, $W = 0,5...2\%$
Viscosity of gas mixture, $\mu_{ra3a} = 0,75 \cdot 10^6$ Pa·sec	Mass fraction of chlorine ions, M_{Cl} , not more than 0,03%

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2. Study of physical and chemical regularities of behavior of wide spectrum aerosols during filtration through filtering materials

2.1 Chemical properties of basalt fiber

Decontamination and cleaning of gas emissions and aerosol mixtures by various sorbents is an important problem in many spheres, including nuclear industry and NPP operation.

Very different requirements are imposed upon the sorbent materials depending on conditions of their use, such as radiation, thermal and chemical stability, durability, regeneration and restoration for the purpose of repeated application, etc. Basalt fibers (BF) fully meet these requirements. From known publication, BFs usually obtained by extrusion technique do not have porous structure and are exposed to chemical processing before the use as sorbents. Chemical processing is carried out taking into account chemical composition and structure of initial basalt materials, first of all acid-base character of their components. For the purpose of comparative analysis, Table 1 presents chemical composition of initial basalt materials from various deposits.

Table 2.1

Chemical composition of initial basalt materials and products* on their basis

Material	Chemical composition							
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O+ K ₂ O	Admixture	Total
Selected enriched row material	51,40	16,83	11,90	7,70	3,48	1,76	2,42	95,80
Molten material and STBF product*	50,94	17,85	10,71	8,40	3,48	1,76	0,00	93,20

*- super-thin basalt fiber (STBF).

According to known publications, the most commonly encountered method is selective leaching [1] of BF or STBF, after which BF becomes a porous sorbent. The most acceptable in terms of both environmental matter practical use application is muriatic leaching. method. Branched microporous structure of BF is reached by repeated acid treatment and washing of the products of interaction with acid. In such a manner high porosity and sorption capacity of BF are provided.

Thermal behavior of porous BFs testifies to a two-stage character of weight loss curves; moreover, in temperature interval between 100 and 300 °C the samples do not reveal weight loss.

It follows from the analysis that the matrix of BF porous structure apparently has several «energy bands» ensuring sorption and keeping particles in the matrix in the absence of specific impacts on these «bands».

2.2. Chemical treatment of super-thin basalt fiber

Basalt super-thin fibers (BSTF) as basalt fibers can only be used as adsorbents of aerosol mixtures after a special preliminary chemical processing. The most often used method of chemical processing of BSTF to form adsorbents on their base is leaching. For the purpose of obtaining adsorbents of aerosol mixtures, a technique of leaching of basalt super-thin fibers

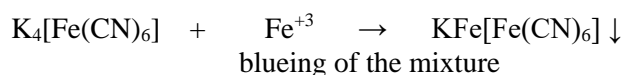
(BSTF) by means of n the basis of БСТБ for the accounting period the leaching technique of basalt super-thin fibers (БСТБ) by muriatic method was developed and applied.

It is known that muriatic method of BSTF leaching includes the following stages:

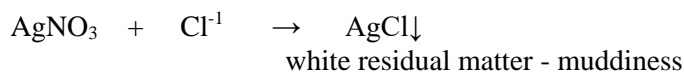
- Processing of BSTF by HCL solution with concentration 2÷5N at 92÷95°C during 30-50 min.
- Washing with distilled H₂O till absence of Fe⁺³.
- Processing of STBF by HCL solution with concentration 0.2÷3N at 92÷95°C during 4÷8 часов.
- Washing with distilled H₂O till absence of Cl⁻¹.

Three experiments on chemical processing of basalt fibers were done.

For the experiment # 1 as an initial material STBF of mass 1 g was used, and for experiments # 2 and # 3 that of mass 5 g. Leaching conditions of all experiments were practically identical. Leaching was carried out in a three-neck flask with a return condenser, thermometer and a mixer with glyceric shutter. Initial portion of BSTF was immersed in the flask, then preliminary prepared HCL solution with concentration 5N was added. The reaction mixture was heated to 92÷95°C (water bath) at constant agitation during 40 min. Then undissolved part was separated by filtration and washed out using distilled water till negative reaction for presence of Fe⁺³ ions. For this purpose, yellow blood salt was used according to the following reaction:



Residual matter is transferred back to the reaction flask, and processing is continued using preliminary prepared HCL solution with concentration 1.5N. The reaction mixture was heated to 92÷95°C (water bath) at constant agitation during approximately 4 hours. At room temperature residual matter was separated from the solution by filtration and repeatedly washed out by distilled water till negative reaction for presence of Cl⁻¹ ions. Formation of silver chloride was used by the following reaction:



After that the reaction product was dried at 110÷120°C during approximately 9 hours. At room temperature the isolated BSTF was weighted.

Weight of BSTF isolated in experiment # 1: 468.35 mg.

Weight of BSTF isolated in experiment # 2: 2.408 g.

Weight of BSTF isolated in experiment # 3: 2.545 g.

BSTF yield after leaching in experiments # 1, # 2 and # 3 was 46.8, 48 and 51%, correspondingly. According to known publications [1], concentration of silicon dioxide in BSTF fluctuates within 48÷54 %, hence taking into account inevitable losses of the product during its processing and filtration it is possible to assume that the used technique allows complete leaching of BSTF i.e. chemical modification using hydrochloric acid. Work on investigating leaching processes of BSTF will be continued.

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2.3. Study of electro-physical characteristics of Armenian super-thin basalt fiber

2.3.1 Introduction

Determination of electrophysical parameters of superthin basalt is of great importance among its other physical and chemical characteristics. Revealing correlations between these parameters and its filtering abilities will help in selecting materials for manufacturing optimum filters for aerosol particles. As electrophysical parameters of superthin basalt we have chosen electrical resistance for alternative (ac) and direct (dc) current (dc) as well as dielectric constants. It is known from publications that physical properties of superthin basalt (including the basalt rock, from which the fiber is manufactured) are highly sensitive to its impurity content [1-3]. The values of electrophysical parameters known from publication (both for basalt rock [1] and superthin fiber [2,3]) vary within a rather wide interval. Measurements of the above-stated parameters are carried out for the first time and can have some correcting value. The results obtained simultaneously by two methods will promote more precise interpretation of the observable effects and determination of the mechanisms causing electromigration processes.

2.3.2 Measurement of specific electrical resistivity for direct current

Basalt is a porous dielectric material, which pores contain various alkalis, salts, impurity atoms (ions) and water. The amount of these substances and their distribution depend on temperature, pressure and humidity of vicinity. Density, type and mobility of electrical current carriers is determined by the content of these substances in samples. With growth of temperature, water, alkaline and salt compounds leave the pores, which can result in increase of basalt electrical resistance. Measurement of electrical resistance of basalt is carried out according to the Ohm law: $\rho = R \cdot S/d$, where R is the sample resistance, S and d are the area of cross-section and thickness of the sample, correspondingly (current passes in d direction). However, both for usual dielectrics and basalt samples, polarization takes place at energization of current power supply [4]. Here, after energizing current power supply, resistance increases with time and after a time (relaxation period), which sometimes makes 10-15 minutes depending on the sizes and composition of samples, reaches its final value. Measurements were carried out using rectangular samples. Along with the sample from superthin basalt fiber (Astbaz1 sized $S=1.5 \text{ cm}^2$, $d=0.074 \text{ cm}$), two rectangular samples were prepared for comparison from different Armenian basalt rocks (Arock, $S=0.6 \text{ cm}^2$; $d=0.06 \text{ cm}$ and Arock1, $S=0.65 \text{ cm}^2$; $d=0.234 \text{ cm}$). To measure fibrous samples, a special holder was manufactured, which will be improved later. Ohmic contacts on the samples from basalt rock were obtained using standard high-resistance conductive glue (Vontactol type) with specific conductivity $\rho = 1.5 \text{ Ohm} \cdot \text{mm}$. Resistance of samples was measured by digital electrometric voltmeter V7-30 with resistance range from 10^6 to 10^{18} Ohm . Measurement error does not exceed 5-7 %.

Fig. 2.1 shows the obtained results on specific electrical resistance.

It is seen from Fig. 2.1 that in all samples specific electrical resistance ρ in two minutes after energizing current power supply (100-120 seconds), basically comes to its final value. However, ρ values for samples 2 and 3 differ by an order of magnitude, and for sample 1 by 2-3 orders of magnitude. It is supposed that such behavior is caused by various contents of the samples. It is known from publications that basalt fibers are formed from the same rock by melting at temperature above $1000 \text{ }^\circ\text{C}$ and after corresponding chemical treatment [3]. Here, redistribution of many impurity atoms takes place in the pores, and some chemical substances and water leave the material, which results in fast increase of ρ . The observed difference in ρ

values for samples 2 and 3 can be attributed to their structural contents. Measurements have shown that for the sample of Egyptian basalt rock at room temperature $\rho = 10^{12}$ Ohm·cm [1], which is more than 6 times higher than for our samples.

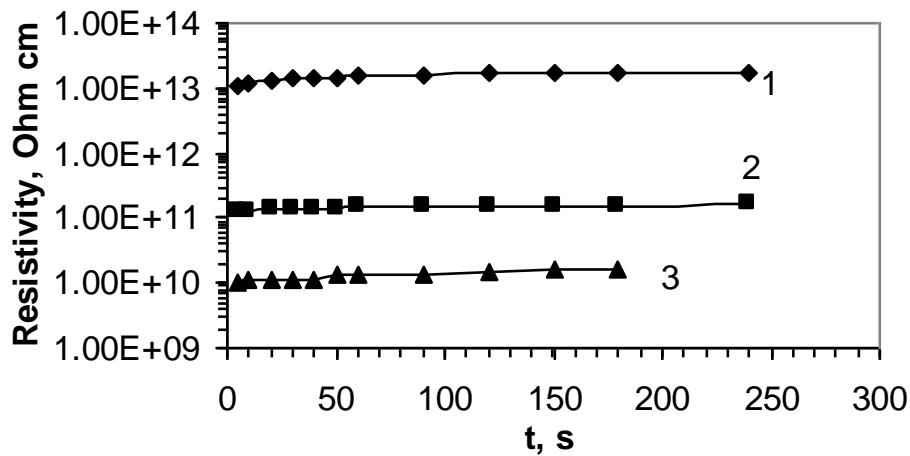


Fig. 2.1 Specific electric conductivity (ρ) depending on the period of energization of current power supply for the investigated samples (1 Astbaz1, 2 Arock, 3 Arock1) at temperature $t=22^{\circ}\text{C}$ and relative air humidity of 52 %.

2.3.3 Measurement of electrophysical parameters for alternating current

Measurement of dielectric parameters of basalt fibers was carried out using a specially developed device, block diagram of which is presented in Fig. 2.2. By means of this device it is possible to measure active and reactive components of the investigated samples accurate to $\Delta G = 10^{-9} \Omega^{-1}$ and $\Delta C=0,04$ pf, correspondingly. Calibration of the device and testing the accuracy of measured objects were carried out using known R and C components, which have been measured in advance by impedance meter BM 507 and capacity meter BM 400 G, accordingly.

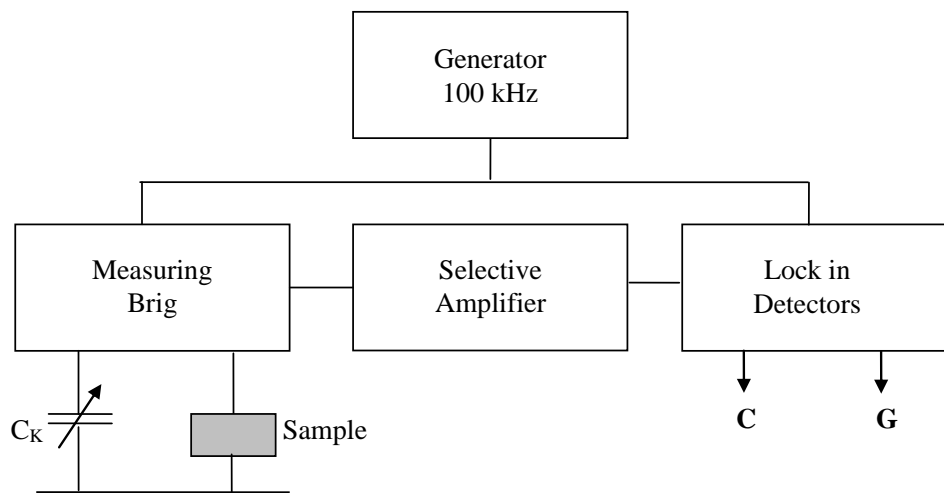


Fig. 2.2. Block diagram of the device for measurement of dielectric parameters of basalt fibers. C_k is a calibrated variable capacity used for compensation of reactive component of the amplifier output target signal.

Basalt fiber is located in a special holder, which allows creating a certain pressure without destruction of the fibrous material structure.

Table 2.2. Dielectric parameters of basalt fibers and basalt rocks measured at room temperature

Sample	ε'	ε''	$\tan\delta$	Specific electrical resistivity, ρ_{ac} [$\Omega \cdot \text{cm}$]	Electrical resistivity ρ_{dc} [$\Omega \cdot \text{cm}$]	Notes
Data from publications	2,2 [2]		0,005 [2]	-	$\approx 10^{14}$ fiber [2] 10^{12} rock [1]	Measuring frequency 1 МГц
Armenian basalt fiber Astbaz1	2.2	$1.78 \cdot 10^{-2}$	0.0081	$1 \cdot 10^9$	$1.76 \cdot 10^{13}$	Measuring frequency кГц
Armenian basalt Arock-1	6,6	$3,97 \cdot 10^{-1}$	0,136	$2 \cdot 10^7$	$1.58 \cdot 10^{10}$	Measuring frequency кГц
Armenian basalt Arock	48	4,96	0,1	$3,6 \cdot 10^6$	$1.6 \cdot 10^{11}$	Measuring frequency кГц

It is seen from the table that dielectric constant ε' for Astbaz1 coincides with value 2.2 from publications, whereas these parameters for two our rock samples make 6.6 and 48. It is also seen that dielectric losses ε'' and $\tan \delta$ for fiber samples are much less, whereas specific electrical resistance both for alternating current ρ_{ac} and direct current ρ_{dc} reveal reverse behavior, i.e much higher in fiber samples. Probable, these parameters should also depend on alternating frequency, temperature, humidity and pressure in vicinity. The presented results show that the measurement of electrophysical parameters for constant and alternating current can serve as a universal technique for description of physical properties of basalt samples. This technique is a sensitive method in view of availability of water, impurities and other structural defects, to temperature, pressure and humidity in vicinity, and can become a basis for selection and manufacture of air filters with optimum parameters on the basis of superthin basalt fibers.

Conclusion

The presented results show that the measurement of electrophysical parameters for constant and alternating current can serve as a universal technique for description of physical properties of basalt samples. This technique is a sensitive method in view of availability of water, impurities and other structural defects, to temperature, pressure and humidity in vicinity, and can become a basis for selection and manufacture of air filters with optimum parameters on the basis of superthin basalt fibers.

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2.3.4 Diffusion effect conditioned by molecular transfer of impurity in direction of lower concentrations

It is known that to assure high modern requirements to clearing gases from the suspended aerosol particles, fine-fibered filters are used which are the most effective means of catching particles in comparison with all other types of filters.

Perfection of these filters is due to the use of super-thin fibers, as the effect of "gas sliding" near the surface of the thin fibers characterized by Knudsen number $Kn = \lambda/a$ (λ is free path of air molecules, a is the fiber radius), is manifested by reduction of the fiber hydrodynamic flow resistance and increase in particle sedimentation on fibers.

Sedimentation of submicron aerosol particles from the flow on super-thin fibers at air (gas) velocity of about several cm/sec occurs as a result of Brownian displacement of particles from flow lines, and with the increase of the particle radius their filter blow-off curve goes through a maximum caused by the influence of the "own" size of particles on their sedimentation at the expense of the "engagement" effect, when the particle centre passes along the flow lines at a fixed distance from the fiber surface (which is smaller than the particle radius).

The maximum of particles blow-off at a fixed air (gas) velocity corresponds to the worst clearing conditions. From evaluation of the penetrating size r^* , the basalt fiber filter efficiency was estimated.

It is known that for modern super-thin filters the radius of the most penetrating particles is close to the fiber radius [1] which, in turn, is comparable with free-path length of air molecules, λ .

Theoretically, diffusion sedimentation for super-thin basalt fibers depending on the penetrating size of particles is studied insufficiently.

When calculating the particle radius corresponding to the blow-off maximum, it is necessary to consider the "own" size of particles.

In [1,2] the capture coefficient is calculated for a model filter taking into account the radius of non-diffusing particles and point particles at intermediate Knudsen numbers, and an option of the joint consideration diffusion and engagement of the finite size particles is presented at $Kn = 0$. It is shown that the total capture coefficient exceeds the sum of separate capture coefficients.

Diffusion sedimentation of aerosol particles on super-thin basalt fibers was studied using a model of the fiber filter presenting a system of the parallel fibers located normally to the flow direction. The flow field in the system is presented as a cell model with which packing density $\alpha = (a/b)^2$, where a is a fiber radius, b is a cell radius. Analytical solution of integral equations is a large amount of work, but as a result we obtain for the total particle flow a relationship reflecting the fact of particle engagement on fibers.

It is determined that at large Re/δ , capture factors η is equal to:

$$\eta = (Re/\delta)(1+R)/Pe^{1/2}, \quad (2.1)$$

where Re is the Peclet number ($Pe = 2a U/D$, where D is diffusion, U is gas flow velocity), R is a dimensionless particle radius, δ is the small size ($\delta = 1/Pe^{1/2}$).

Thus, pure engagement effect can be expressed as:

$$\eta = R_o (1+R), \text{ where } R_o \sim 1 \quad (2.2)$$

Fig. 2.3 (a, b) presents the results of calculations of capture factor curves for pure engagement and for total capture factor. It is seen from the figure that the curves are almost parallel, i.e. sedimentation mechanisms are additive. The effect of sliding of gas-aerosol near the surface promotes the accelerated movement of particles along the fiber surface that, in turn, leads to reduction of diffusion sedimentation of particles. But, on the other hand, with the increase of sliding velocity the increase in velocity of the particle radial transport to fiber is possible, which is equivalent to reduction of the particle diffusion sedimentation. The change in the capture factor of point particles depends on these effects ratio.

Modeling of the fine filtration process in real filters has shown that at $Kn \sim 1$, $\eta = \eta_R + \eta_D$ equality specifies a possibility of relative increase of efficiency of highly efficient basalt filters at increase in both Knudsen number and the radius of the most penetrating particles. Therefore, to increase the filter efficiency, it is necessary to strive for reduction of radius of filtering fibers.

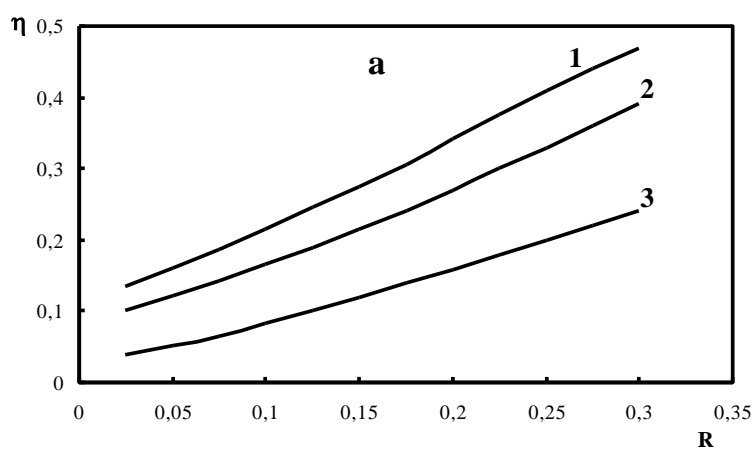


Fig 2.3. Capture factor η dependence on the engagement parameter R for a filter with $\alpha=(1/6)^2$ at different Knudsen numbers.

(a) - $\delta=0,05$ ($Pe = 400$); (b) - $\delta=0,3$ ($Pe = 12$). Curve 1 correspond to $Kn = 10$; curve 2 to $Kn = 1,0$; curve 3 to $Kn = 0,1$.

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2.3.5 Study of sedimentation deposition of aerosols on the filter fibers

The problem of super-thin cleaning of aerosol particles from gases and weighed micron-size particles is solved by means of fiber filters, fibers and pores of which sized tenth and hundredth parts of micron. At such small sizes of fibers and pores, sedimentation of particles is influenced by Van der Waals forces, and at low velocity of the aerosol flow this influence can be considerable.

As it has been shown earlier, the influence of Van der Waals forces can be commensurable with other effects of sedimentation of particles on fibers.

Owing to ascendant flow of not Brown and inertialess large particles, just the molecular attraction should compensate the influence of gravitational sedimentation of particles, which is manifested in “runaway” of particles downwards from fibers, i.e. in displacement of the centre of particles from the path line near its bottom part. Van der Waals attraction is especially pictorial in the case of filter fibers at low flow velocity, which is of a great interest for practice as at low velocity of ascending flow the particle sedimentation essentially reduces their catching efficiency. The aforesaid concerns the case when the parameter of sedimentation deposition is small, $G < 1$, i.e. when sedimentation rate is commensurable with the hindered velocity of gas or particle flow near the fiber surface.

For theoretical research of sedimentation deposition on fibers, such regime of filtration is selected when the influence of inertia, diffusion and electric effects is negligibly small. Calculations of the capture factor of uncharged spherical inertialess particles in the absence of diffusion near the fibers located normally to the gas flow are carried out.

It is considered that when particles approach to the fiber surface, Van der Waals attraction works on them, and they deposit under the influence of gravity force.

Modeling of the filtration process of as well as calculation of capture factor (sedimentation) it carried out on a model filter example representing a hexagonal system of parallel fibers oriented normally to the flow direction.

Fig. 2.4 shows calculation of the capture factors under various filtration conditions. It is seen that the calculation involved the fiber radii within a range of 1 - 6 microns at the ascending flow velocity of $U_0 = 1$ cm/sec and packing density $\alpha = 0.01$. In all calculations it was accepted that the constant of dispersion delayed interaction of condensed bodies, A_7 is 10^{19} erg cm.

It is seen from the figure that the value of the capture factor tends to zero with increase of fiber radius. At an essential influence of gravitation, the value of the capture factor (without taking into account Van der Waals interactions) is negative, which is devoid of physical sense; hence, in this case it is lawlessly to consider the influence of sedimentation on the particle deposition without Van der Waals forces. At filtration of the aerosol flow directed from the top downward, Van der Waals interaction strengthens sedimentation deposition and manifests itself in the lesser degree the higher gravitation is.

Gravitational force can essentially influence the radius of the most penetrating particles ρ_p in case of particles with high density – its role should increase with the increase in density of particles P , which is necessary to take into account when testing filters by aerosols with heavy particles at small flow velocities. Fig. 2.5 presents the examples of calculation of η depending on radius in the region of their maximum breakthrough through the filter with $\alpha = 0,01$ and average radius of fibers $a = 1$ micron at the velocity of ascending flow $U = 1$ cm/sec.

The diffusion capture curve was calculated by formula:

$$\eta_D = 2,9k_1^{-1/3} Pe^{-2/3} (1 + 0,55 \tau KnPe^{1/3} 9k_1^{-1/3}) \quad (2.3)$$

where $Pe = 2aU_0/D$ is Peclet number, D is diffusion factor; k is Boltzmann constant; T is temperature in K; $k_1 = -0,5 \ln \alpha + \alpha - 0,75 - 0,25\alpha^2 + \tau Kn$; $Kn = \lambda/a$ is Knudsen number; λ is mean free path of air molecules; $\tau = 1.15$, B is the particle mobility and taken from [1]).

A certain character of action of Van der Waals forces in aerosols and high sensitivity of the capture factor to the change of flow velocity and sedimentation rate as well as to the direction of the rate of mutual orientation of fibers and to the packing density of the fiber system is the basis for the contribution of Van der Waals forces to the research of submicron particle sedimentation of the fibers, as the less the particle size the higher the capture factor.

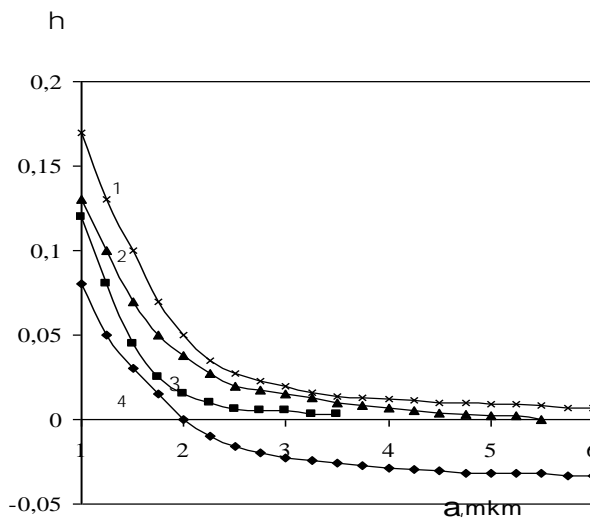


Fig. 2.4. Dependence of capture factor of the particles with radius $r_p = 0,5\text{micron}$ and density $\rho_p = 1\text{g/cm}^3$ (1,2) and 10g/cm^3 (3,4) on fiber radius. Curves 2, 4 are calculated without taking into account Van der Waals interactions.

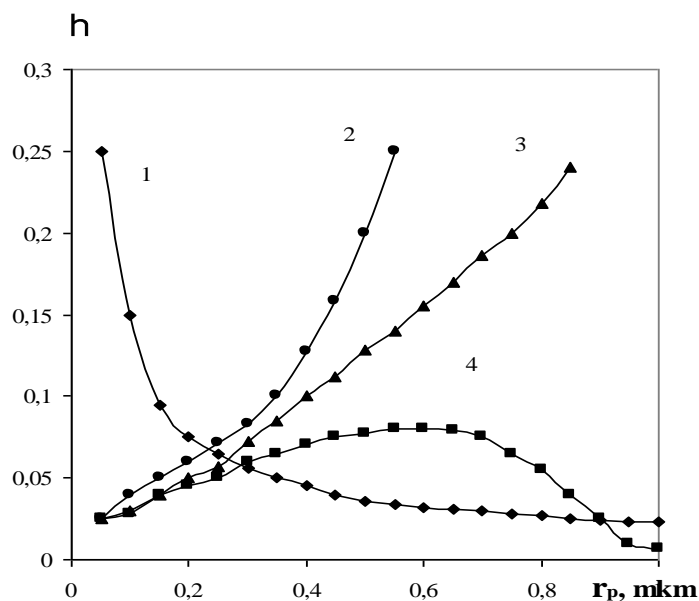


Fig. 2.5. Dependence of capture factor on radius of particles with density $\rho_p = 1\text{g/cm}^3$ (2), 10g/cm^3 (3) and 20g/cm^3 (4). Curve 1 corresponds to diffusion capture factor.

2.3.6 Study of porous characteristics of basalt fiber by BET method

Brunauer-Emmet-Teller (BET) method allows calculating of specific surface of solids, including super-thin basalt fibers, determination of sizes and volumes of pores by their effective radii as well as size distribution of pores. BET method is the most widespread method of determination of pore characteristics. Therefore the method is comprehensively developed and explained in numerous works. When estimating specific surface from adsorption data, high accuracy is practically unattainable even in favorable conditions in the case nitrogen or argon.

Deviations from the actual size of a surface by approximately 10 % are considered as normal ones.

Pore characteristics of super-thin basalt fibers (both raw and processed, i.e. chemically modified by hydrochloric acid) were determined using Accusorb2300A device manufactured by Micromeritics company (USA). Calculations were carried out according to formula:

$$V_a = V_m C P / (P_s - P) [1 + (C - 1) P / P_s] \quad (2.4),$$

Equation (1.8) can be reduced led to linear form:

$$P / V_a (P_s - P) = 1 / V_m C + [C - 1 / V_m C] \cdot P / P_s \quad (2.5)$$

where V_a is volume of gas adsorbed at pressure P ; V_m is the volume of gas adsorbed in the case when all adsorbing surface is covered by a monomolecular layer; C is a constant; P_s is gas saturation pressure.

Physical measurements of the adsorbed gas volume as a pressure function at the fixed temperature allow calculating V_m - the volume of gas necessary for formation of a monomolecular layer. The graph of dependence of $P / V_a (P_s - P)$ on P / P_s presents a straight line in the P / P_s region from 0.05 to 0.30, which crosses axis of abscisses in $1 / V_m C$ point and has a slope of $C - 1 / V_m C$. On the basis of V_m value and the size of one adsorbed molecule, the surface area of the adsorbing basalt fiber is calculated. Determination of the surface area is carried out by inlet of adsorbing gas (adsorbate) in a chamber with the sample of the material with a known weight (adsorbent) which was preliminary dried up, weighed and released from the adsorbed gases and vapors (captured from atmosphere) by heating and pumping out. Gas is released by separate portions. In practice, firstly gas is released to a system of the distributive pipeline by V_d at temperature T_d and there its pressure P_1 is measured. The amount of gas is determined by formula $P_1 V_d = n R T_d$, where R is gas constant. Then the valve connecting the pipeline system with the chamber containing the sample, is opened and gas extends in new volume, reaching its new pressure P_2 . A part of the gas part is adsorbed by the testing sample at a low temperature T_s (as a rule, temperature of liquid nitrogen). Thus, in the new state gas is located partly in the distributive pipeline at the device temperature, partly within the space, surrounding the sample at an intermediate temperature T_i , and partly in the adsorbed state. Fig.

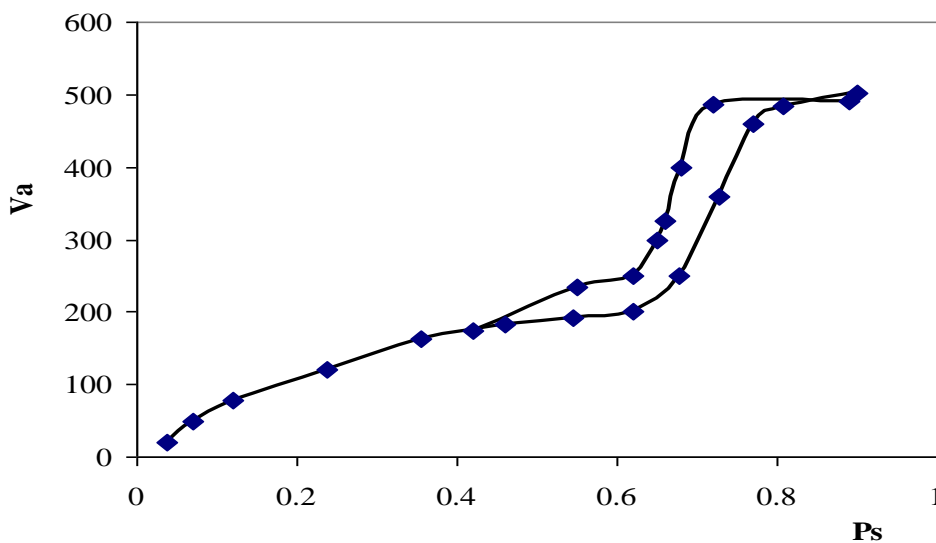


Fig. 2.6. Isotherm of adsorption depending on the volume of gas (nitrogen) adsorbed on the surface at corresponding pressures.

2.5 presents isotherms of adsorption depending on the volume of the gas (nitrogen) adsorbed at a certain pressure; the bottom curve corresponds to the raw sample and the top one to chemically modified. Continuing adsorption process stage by stage almost to the saturation pressure, we obtain a full isotherm of adsorption (Fig. 2.6). Then, reversing the process by gradual reduction of pressure over the samples (raw and chemically modified one) and registering the values of volume and equilibrium pressure, we obtain desorption isotherms.

Fig. 2.7 and 2.8 below show isotherms of adsorption 1 and desorption 2 of liquid nitrogen vapor at its evaporation temperature for chemical processed super-thin basalt fibers (various methods of processing).

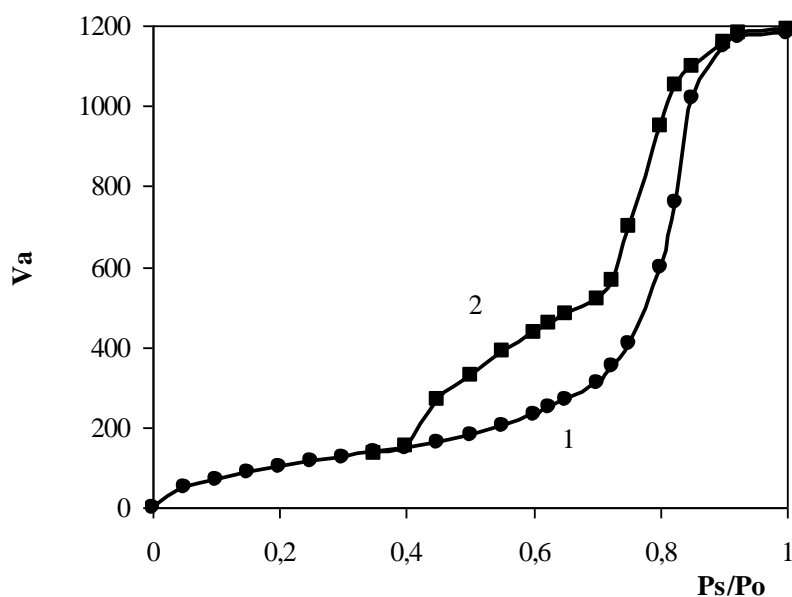


Fig. 2.7 Isotherms of adsorption 1 and desorption 2 of liquid nitrogen vapor at its evaporation temperature for chemical processed super-thin basalt fibers (two stage processing by H_2SO_4).

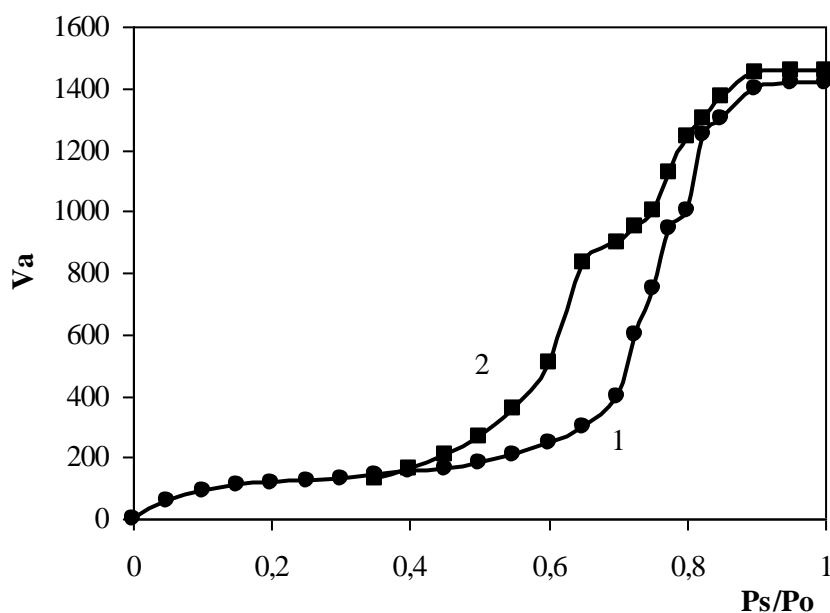


Рис 2.8. Isotherms of adsorption 1 and desorption 2 of liquid nitrogen vapor at its evaporation temperature for chemical processed super-thin basalt fibers (two stage processing by HCl).

Thus, calculations by BET method have shown that leaching allows sufficient increase of adsorption capacity: for the initial basalt fiber maximum volume of adsorbed nitrogen is 25 cm³/g and for the leached basalt after different stages of chemical processing (Fig. 2.7) 1200 cm³/g and (Fig. 2.8) 1500 cm³/g.

Pore distribution: for the initial sample total pore volume is 0.0308 cm³/g and for the samples leached by various techniques 1.7314 cm³/g (hydrochloric acid) and 1.2193 cm³/g (sulfuric acid).

Specific surface areas calculated by BET method are as follows: initially 11.5 m²/g, after one-stage leaching by sulfuric acid 348.2 m²/g, after one-stage leaching by hydrochloric acid 265.3 m²/g.

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3. Influence of external environmental factors (temperature, humidity and pressure) on specific electrical resistivity of basalt

Both the basalt rock and superthin basalt fiber (STBF) obtained on its basis using special processing technique, are porous systems. Porous systems should react on change of such external parameters as the ambient air temperature, humidity and pressure [1]. For example, it is known that electrophysical parameters of dry basalt rock are rather sensitive to the ambient air temperature and pressure [2]. It is only known that moisture (water) content in dry STBF sample varies within 0.5 - 1% mass [3-4]. Study of these factors is an important problem as filtering parameters of materials based on superthin basalt fibers also should depend to a large extent upon water content. On the other hand, because its sorption properties depend upon ionic content and charge state, study of these parameters' role becomes an important problem as there is scarcely any publications on the matter. Besides, information on the role of ambient air temperature, humidity and pressure also is important when selecting STBF materials to develop optimal filters for aerosol particles. This work is aimed at research of influence any of the three stated parameters (at fixed values of the remaining two) on electrophysical parameters of basalt rock and STBF. The research was carried out taking into account periodic changes of specific electrical resistivity for constant current (ρ_{dc}) and alternating current (ρ_{ac}) near room temperatures at different air relative humidity and pressure. Relative humidity ϕ [%], temperature and pressure p [kPa] were determined using psychrometric hygrometer VIT-2 and aneroid barometer, correspondingly. Fig. 3.1- 3.7 and Tables 3.1, 3.2 present the basic results obtained.

Basic results obtained

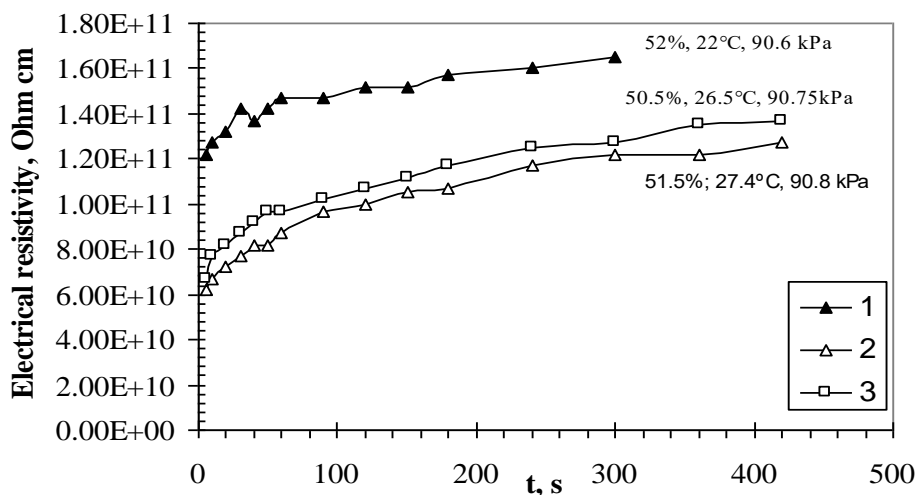


Fig. 3.1 Dependence of specific electrical resistivity of Armenian basalt rock (Arock) on ontime of constant electric field at various air relative humidity, temperature and pressure.

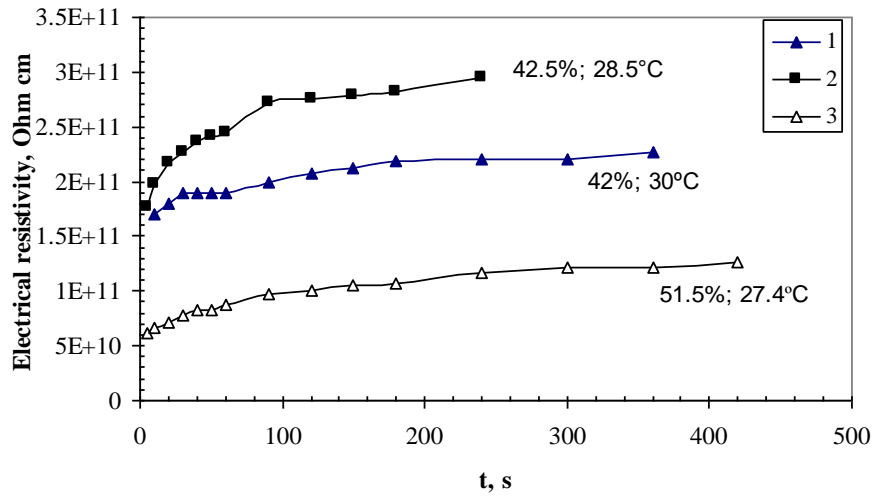


Fig 3.2. Dependence of specific electrical resistivity of Armenian basalt rock (Arock) on ontime of constant electric field at various air relative humidity, temperature and fixed pressure (90.8 KPa).

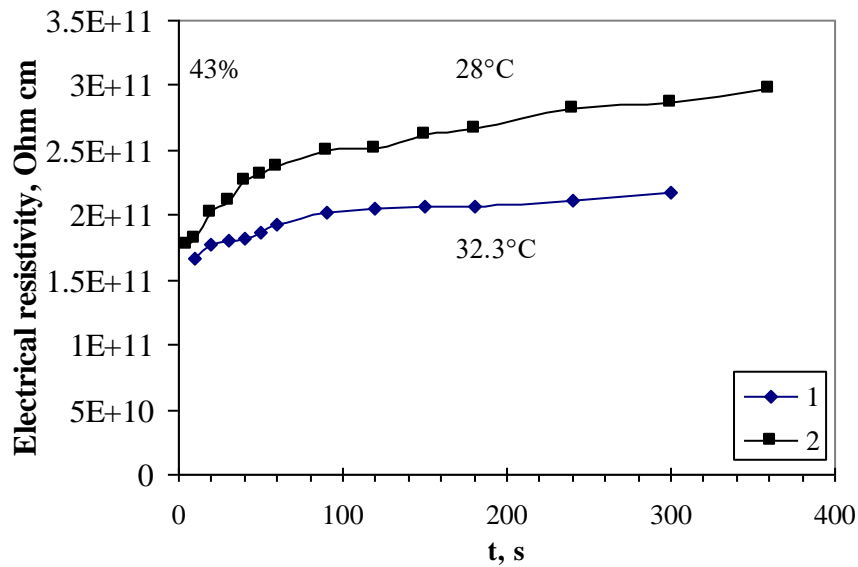


Fig. 3.3 Dependence of specific electrical resistivity of Armenian basalt rock (Arock) on ontime of constant electric field at various air temperature and fixed moisture (43%), pressure (90.75 KPa).

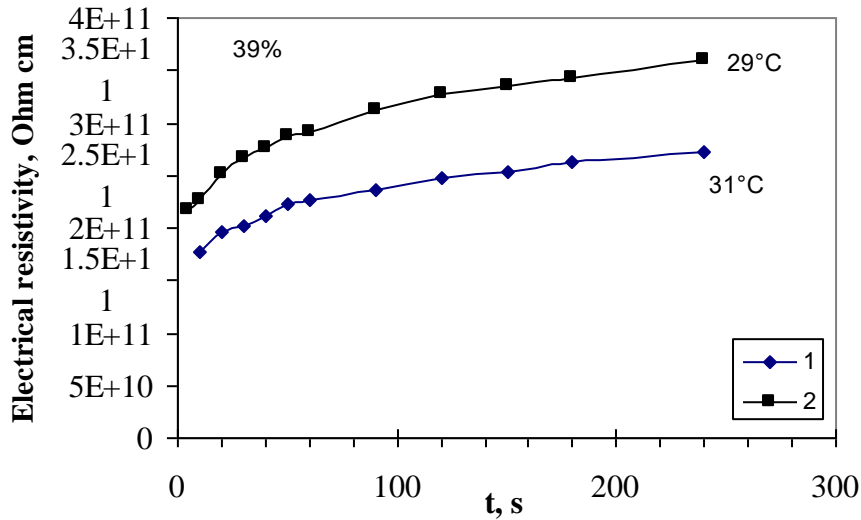


Fig. 3.4 Dependence of specific electrical resistivity of Armenian basalt rock (Arock) on ontime of constant electric field at various air temperature (curves 1 and 2) and fixed moisture (39%), pressure (90.75 KPa).

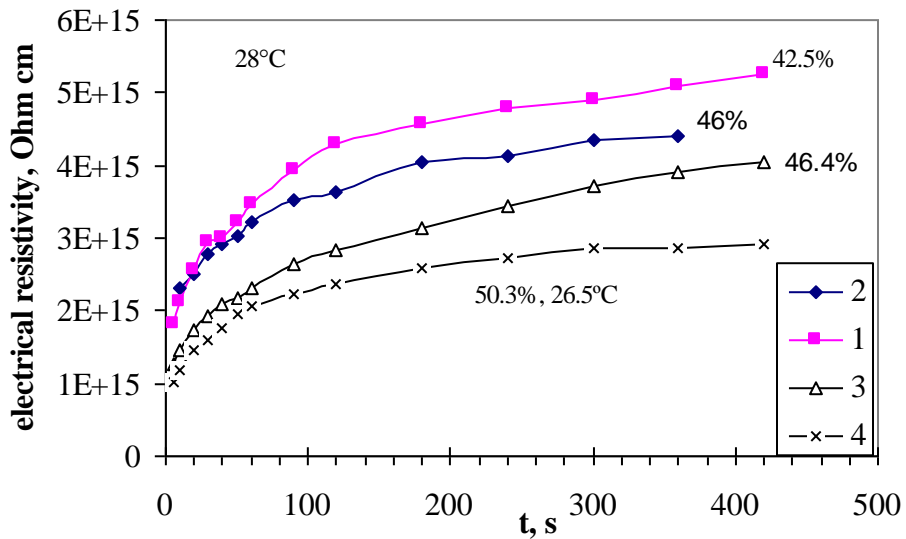


Fig. 3.5 Dependence of specific electrical resistivity of Russian basalt rock (RSTB) on ontime of constant electric field at various air moisture (curves 1, 2 and 3) and fixed temperature (28°C), as well as on temperature, relative moisture curve 4) at fixed pressure (90.75 KPa).

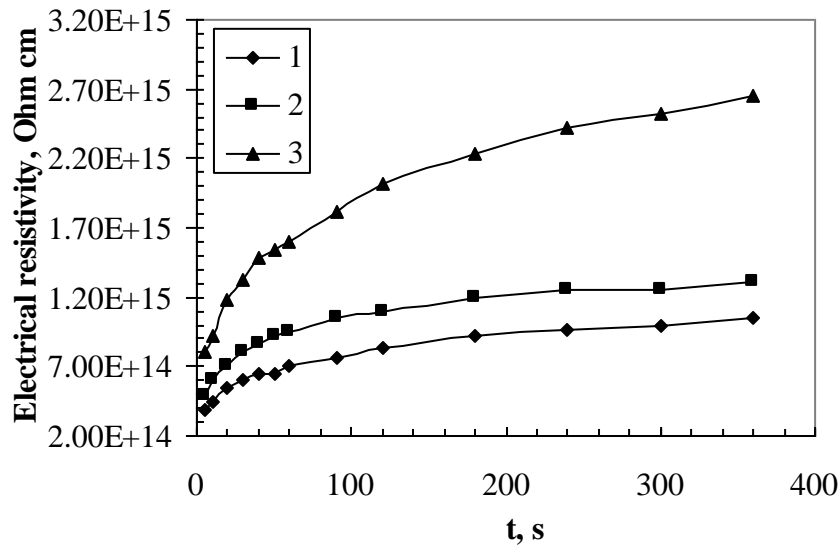


Fig. 3.6 Dependence of specific electrical resistivity of Russian basalt rock (sample RSTB-4, thickness $d=0.014\text{cm}$) on ontime of constant electric field at various conditions: **1**- air pressure $p= 91.1\text{kPa}$, relative humidity $\varphi= 43.40\%$, $T= 24.2^\circ\text{C}$; **2**- $p= 91.1\text{kPa}$, $\varphi= 41.70\%$, $T= 24.5^\circ\text{C}$; **3**- $p= 90.96\text{kPa}$, $\varphi= 39.20\%$, $T= 26^\circ\text{C}$

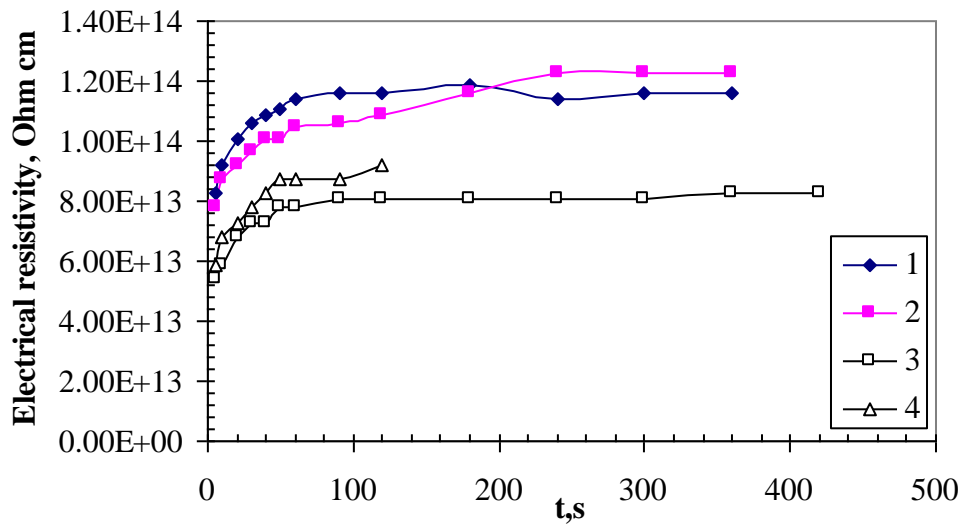


Fig. 3.7. Dependence of specific electrical resistivity of Armenian basalt rock rock (sample ASTB-1, thickness $d=0.0155\text{cm}$) on ontime of constant electric field at various conditions: **1**- 90.9kPa , 44.40% , 25.8°C ; **2**- 90.93kPa , 44.20% , 25.8°C ; **3**- 91kPa , 44.60% , 24.2°C ; **4**- 91.05kPa , 45.30% , 24.5°C

Table 3.1.

Electrophysical parameters of various basalt rocks and fibers measured at room temperature

Sample	800 Hz				1 MHz	0 Hz	d[cm]
	ϵ'	$\tan\delta$	ϵ''	$\rho_{ac} [\Omega \cdot \text{cm}]$	ϵ'	$\rho_{ac} [\Omega \cdot \text{cm}]$	
RSTB-3(1)	1.85	$1.95 \cdot 10^{-3}$	$3.65 \cdot 10^{-3}$	$6.2 \cdot 10^{11}$	2	10^{15}	0.022
RSTB-4	1.78	$2 \cdot 10^{-3}$	$3.57 \cdot 10^{-3}$	$6.28 \cdot 10^{11}$	-	$8.09 \cdot 10^{14}$	0.014
ASTB-1	1.735	$9.2 \cdot 10^{-3}$	$1.6 \cdot 10^{-2}$	$1.4 \cdot 10^{11}$	-	$3.25 \cdot 10^{13}$	0.026
Arock	6.27	$8.14 \cdot 10^{-3}$	$5.1 \cdot 10^{-2}$	$4.55 \cdot 10^{10}$	6.23	$4.5 \cdot 10^{11}$	0.06
Arock-1	13.6	$8.107 \cdot 10^{-3}$	$1.1 \cdot 10^{-1}$	$2.2 \cdot 10^{10}$	13.74	$1.8 \cdot 10^{11}$	0.22

Table 3.2

Electrophysical parameters (at 800 Hz) of Russian RSTB-4 at various external factors

ϵ'	$\tan\delta$	ϵ''	$\rho_{ac} [\Omega \cdot \text{cm}]$	T[°C]	φ [%]	p[kPa]	d[cm]
1.78	$2 \cdot 10^{-3}$	$3.57 \cdot 10^{-3}$	$6.28 \cdot 10^{11}$	25.4	44.4	91.15	0.014
1.78	$1.7 \cdot 10^{-3}$	$3.03 \cdot 10^{-3}$	$7.39 \cdot 10^{11}$	25.5	43	91	0.014
1.78	$1.6 \cdot 10^{-3}$	$2.85 \cdot 10^{-3}$	$7.84 \cdot 10^{11}$	26	41	91	0.014

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4. Effect of external factors on the properties of super-thin basalt fiber

It is known that filtering ability of STBF depends on of its packing density D (g/cm³), relative humidity H (%) and ambient air temperature T [1,2]. Research of influence of these factors on electro-physical parameters of fibers and establishment of interrelation with its filtering abilities is of great interest in the course of development of highly effective systems of cleaning.

Research of specific electric resistance for constant (ρ_{dc}) and alternating current (ρ_{ac}), as well as dielectric permeability ϵ' , dielectric losses ϵ'' and dielectric loss tangent $\tan \delta$ for the initial and acid-modified basalt fiber (AMBF) was carried out. Measurements of electro-physical parameters were carried out in alternating-current electric field at frequency of 800 Hz and 1 kHz. Dielectric parameters ϵ' , ϵ'' and specific resistance of basalt fibers for alternating current ρ_{ac} were measured by means of a precision bridge TESLA BM 400 G for measurement of capacity. This bridge allows measurements of dielectric loss tangent ($\tan \delta$) within a range from $9 \cdot 10^{-4}$ to $2 \cdot 10^{-2}$ and capacity to accuracy of ± 1 % at frequency of 800 Hz. A special installation was developed for measurement of higher $\tan \delta$: a transformer bridge circuit, which enables to measure $\tan \delta$ up to 50 in a frequency interval from 200 Hz to 1 MHz. The influence of density on the measurement results in static and alternating-current electric fields for both the initial and AMBF materials was tested on the same samples for each value of density D . Fig. 4.1-4.4 show the obtained results. It is seen from the graphs that electro-physical parameters of the initial and chemically processed samples are different depending on temperature. If ϵ' for the initial samples is the same within the whole investigated temperature interval, ϵ'' and ρ_{ac} show another behavior. Here, with increase of temperature to 300K ϵ'' increases (and ρ_{ac} decreases) and comes to saturation. However growth of ϵ'' within a range from 100 to 200K occurs at a much lower rate than in the range from 200 to 300K. It is seen from Fig. 4.1 and 4.2 that for the chemically modified samples ϵ' , ϵ'' and ρ_{ac} in the investigated interval of temperatures the following takes place: at 300K the observed minimum of ρ_{ac} is accompanied by maximum ϵ' . The obtained result is explained as follows. It was shown that in basalt fibers a dipole-relaxation polarization mechanism takes place. As dipoles molecules, water molecules operate present in fibers. With the increase of temperature, molecular forces between dipoles are weakened (according to [1]), which should strengthen dipole-relaxation polarization. However, at the same time the energy of thermal movement of molecules increases, that reducing the orienting effect of the field. With the increase of temperature, water evaporation also takes place that reduces the effect of polarization too. Due to competition of these mechanisms, a behavior presented in Fig. 4.1 and 4.2 is observed. It is determined that after acid processing the water content in basalt fibers grows from 0.4 to 18 % of its initial weight. As it is known, this fact leads to reduction of ρ_{ac} by 3 orders of magnitude and reduction of ρ_{dc} by more than on 3-4 orders (see Fig. 4.3-4.5).

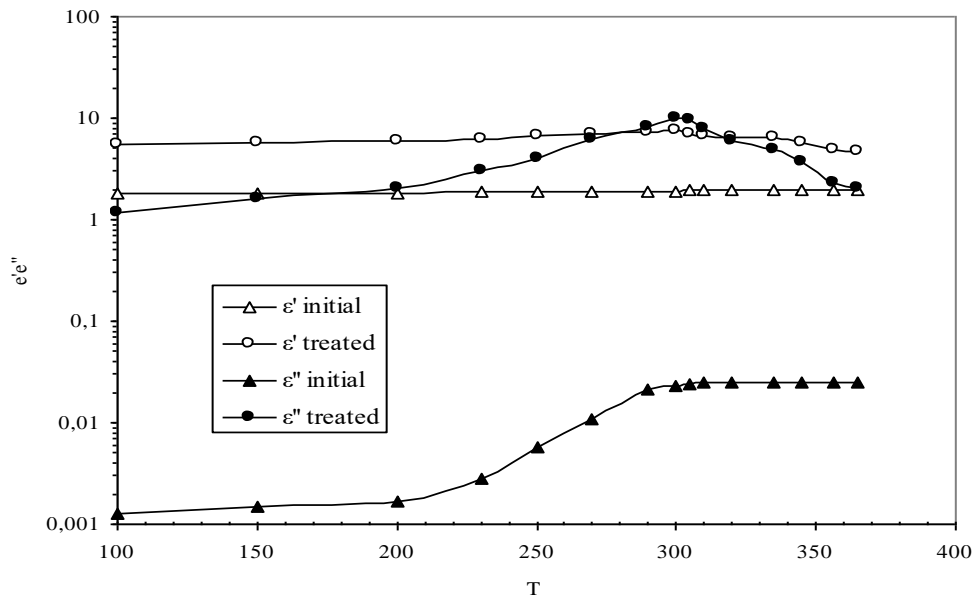


Fig. 4.1. Temperature dependence of dielectric permeability ϵ' and dielectric losses ϵ'' for initial and AMBF at the fixed density $D=0.4 \text{ g/cm}^3$ and measured at electric field frequencies of 800 Hz and 1 kHz. Relative humidity of air was 50 %.

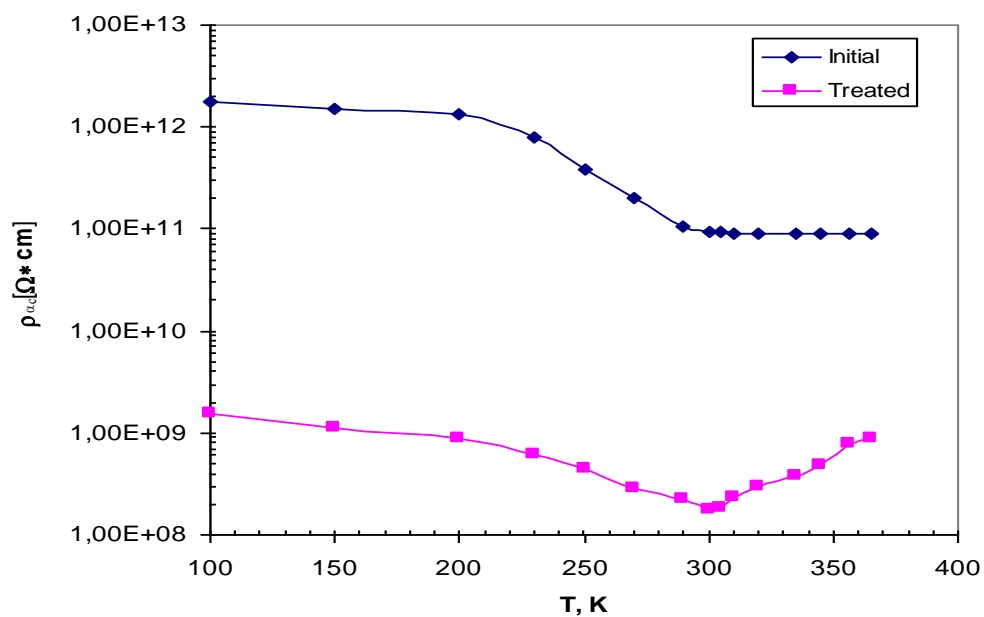


Fig. 4.2 Temperature dependence of ρ_{ac} for the initial and AMBF samples at the fixed density $D=0.4 \text{ g/cm}^3$ measured at the electric field frequencies of 800 Hz and 1 kHz. Relative humidity of air was 50 %.

Fig. 4.3-4.5 present electro-physical parameters of basalt fibers ρ_{ac} and ρ_{dc} for constant and alternating-current electric fields depending on density D and humidity. The presented parameters reveal a non-monotone character, however for the initial samples ϵ' does not react to the changes of density D . Other parameters of the initial and modified samples show another dependence on D . It is possible to conclude from the obtained results that the change of ρ_{ac} for the initial sample in the range of density up to 0.85 g/cm^3 is rather small, whereas at higher

values of density is much more significant. The change of ρ_{ac} for the modified sample in the first density region occurs much faster than in the second one. However for ρ_{dc} both samples reveal strong in the first area of D values (up to 0.85 g/cm³). For higher values of density D, these changes are weak in both samples. However, in the initial sample the maximum change of ρ_{dc} is more than 2 orders of magnitude, whereas for the second sample it is less than 1.5 orders. The reason such behavior of electro-physical parameters depending on density is probably related to the formation of some kinds of defects with various charge state in the sample, which capable to become the centers of accumulation of different amount of water molecules.

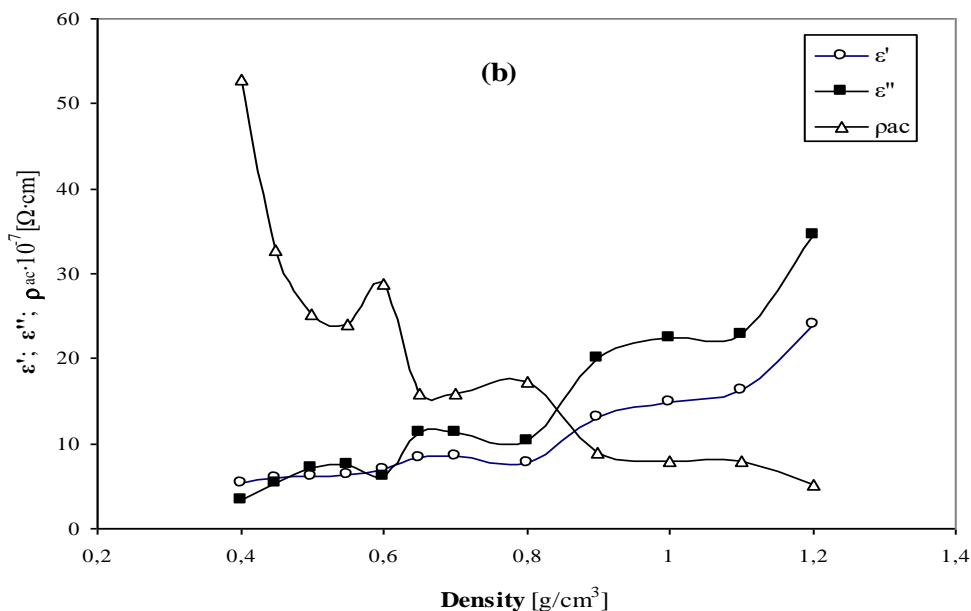
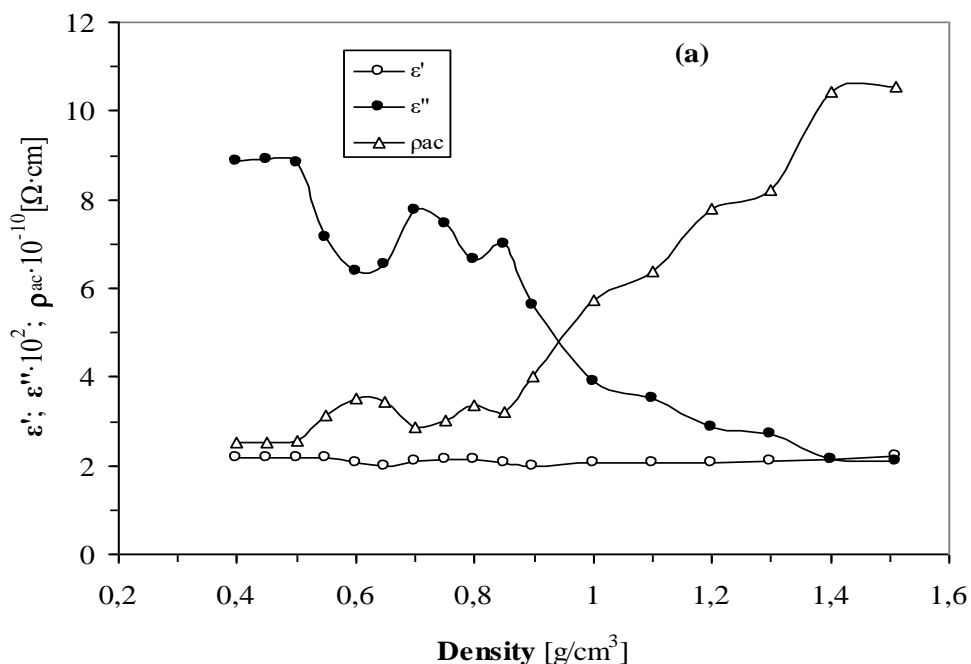


Fig. 4.3. Dependence of specific electric resistance for alternating current ρ_{ac} on packing density of initial (a) and acid-modified (b) samples.

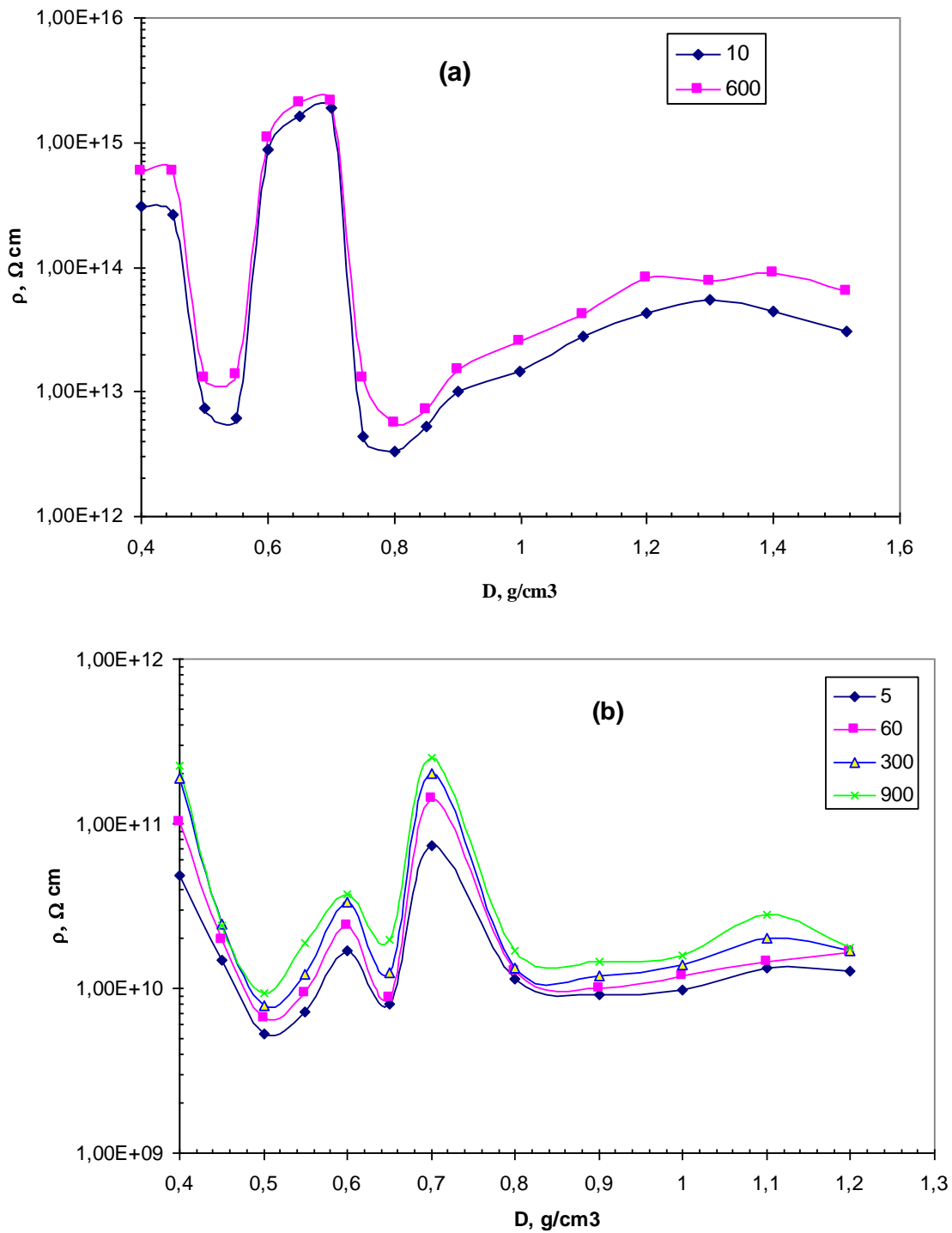


Fig. 4.4. Dependence of specific electric resistance for direct current ρ_{dc} on packing density of initial (a) and acid-modified (b) samples. Curves were obtained 5, 10, 60, 300 and 900 sec after energizing of constant electric field.

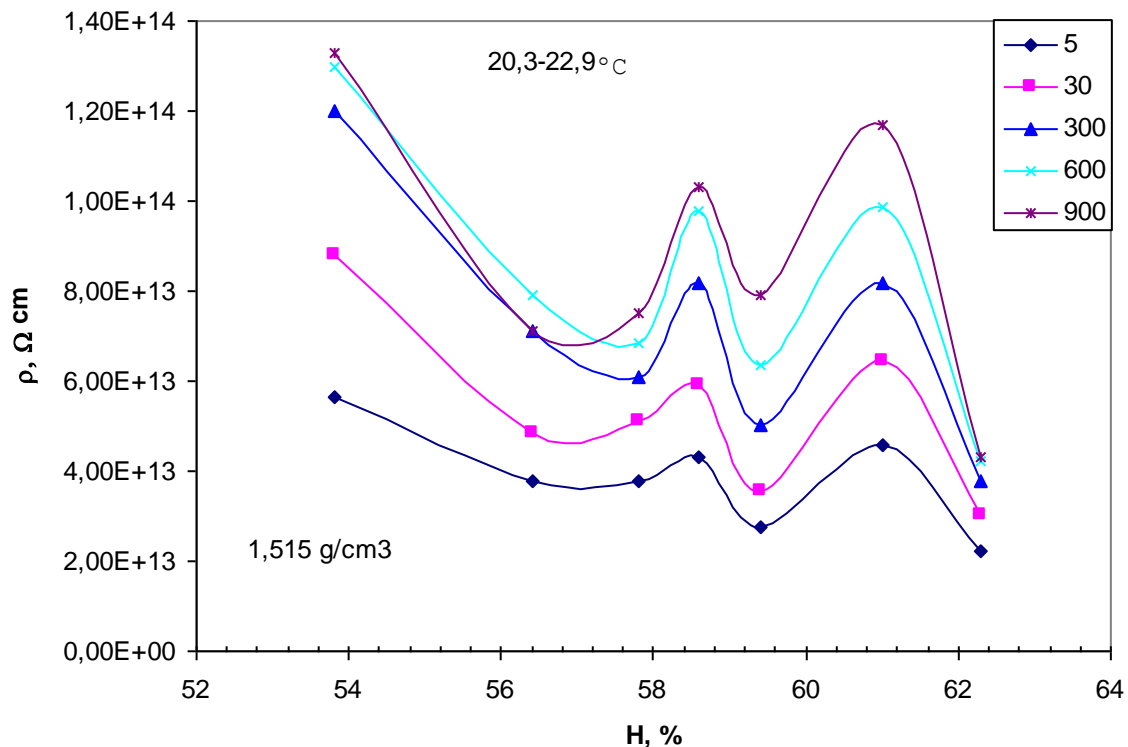


Fig. 4.5. Dependence of specific electric resistance for direct current ρ_{dc} on relative humidity of air H (%) at the fixed value of basalt fiber density.

Conclusions

The measurements have shown that some electrophysical parameters of basalt rock and STBF samples are very sensitive to temperature, pressure and humidity changes. It is revealed that for all investigated samples specific resistance for constant current ρ_{dc} is much more higher than that for alternative current ρ_{ac} , thus testifying to the hopping mechanism. It is determined that both parameters ρ_{dc} and ρ_{ac} have their maximums for the Russian STBF samples and minimums for rocks. It is shown that the Armenian STBF samples show opposite character of ρ_{dc} behavior at the change of external parameters. The reason is not clear. Besides, electrophysical parameters of Armenian STBF samples in alternative fields do not change significantly, whereas for Russian samples only dielectric permeability ϵ' does not change, and dielectric losses ϵ'' , $\tan\delta$ and ρ_{ac} are changed significantly with φ . All these facts can find correlations between filtering characteristics and electrophysical parameters to develop an optimum filter for aerosol particles.

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5. Calculation of filter resources

The research of pressure difference rate in fiber basalt filters at sedimentation of particles on its surface in the form of continuous layers is of interest in connection with the development of a method of calculation of filter resource in a system of air (gas) clearing from radioactive aerosols.

It is known that pressure difference in a dusty filter with a deposit in a normal operation mode is caused, basically, by the pressure difference in the layer of settled particles. In the case when the particles settled on the filter surface form a continuous highly porous deposit layer, efficiency of their sedimentation from the flow in this layer is close to 1, and in the pressure difference calculation the model of the fibers equivalent to the settled particle chain is used [1].

It is known [1, 2] that the dependence of pressure difference on the weight of the caught particles during the deposit formation on the filter surface has linear character.

A method of definition of the pressure difference increase with time depending on the weight of particles accumulated on the filter surface is offered. This approach takes into account the change in flow field as deposit on fibers increases. Besides, the method does not require any strong determination of experimental data on initial stage of the pressure difference increase. It is accepted that the total length of fibers in a surface volume unit does not change and the pressure difference increase is caused by the deposit increase on dusty fibers.

It is considered at the pressure difference calculation that the particles have a small polydispersity. Diffusion and inertia of the particles are also not taken into account as the diffusion capture factor for small particles does not presumably exceed several percent of capture factor at the expense of engagement, and inertia for large particles is significant in the initial catching period.

With a growth of deposit on fibers, the capture factor for the fibers with a porous covering sharply increases (that is very characteristic for the modified fibers subjected to leaching using hydrochloric and sulfuric acids). Slight changes of the deposit packing density on fibers as well as consideration of incomplete sedimentation of particles in deposits, weakly influenced the calculated values of weight and pressure difference at corresponding moment (Fig. 5.1). As the growth rate is very sensitive to the particle radius change, small divergence of the obtained data is apparently related to instability at their generation.

The filtration process and pressure difference growth come into account by approximation of dusty filter fibers and calculation of weight depending on blockage time, packing density, radius of filter fibers under the specified filtration conditions.

It is common practice to describe the capture of aerosol particles in filter by the following system of equations:

$$\partial n / \partial z = - \gamma n \quad (5.1),$$

$$\partial N / \partial t = \gamma n U \quad (5.2)$$

At corresponding initial and boundary conditions

$$a(z,0) = a_0; \quad N(z,0) = 0 \quad (0,t) = n_0$$

where $\gamma = 2a \ln a$ is filtration factor, n is concentration of particles in the flow.

In equations (1.3, 1.4), the capture factor is determined as $\eta_a = \eta / \rho$, where value η is calculated by authors of [1].

To simplify calculations, the following dimensionless variables are used:

$$h = \gamma_0 z; \quad \tau = t g.$$

where $\gamma_0 = 2a_0 / \eta_0$ is a filtration factor for pure filter;

$$g = v n_0 U / \pi \beta_1 a_0;$$

where n_0 is an input concentration of particles, β_1 is packing density.

Equation (5.2) gives the dependence of fiber radius with a deposit in the surface layer $\rho(0, \tau)$ on the blockage time.

$$\tau = \int F(\rho) \rho d\rho / \eta(\rho)$$

After integration of certain intermediate expressions $\rho(0, \tau)$, relative growth of pressure difference and weight of the settled particles in dimensionless variables looks like

$$\Delta_p / \Delta_0 = 2\eta_0 / \gamma_0 H F_0 \frac{\int_{p(\gamma_0 H, \varepsilon)}^{p(0, \varepsilon)} F(\rho) \rho d\rho}{\eta(\rho)(\rho^2 - 1)} \quad (5.3)$$

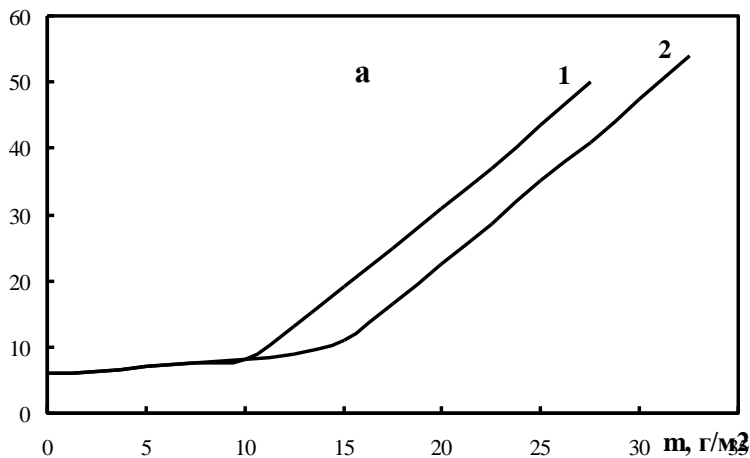
$$m = \frac{\pi \beta_1 \alpha_0 d \int_{p(\gamma_0 H, \varepsilon)}^{p(0, \varepsilon)} \rho d\rho}{\eta(\rho)} \quad (5.4)$$

From formulas (5.3, 5.4) it is possible to find the pressure difference growth and weight of particles on the filter fibers by a certain time moment.

Fig. 5.1 (a, b) shows data of calculation of pressure dependence on packing density and fiber radius. It is necessary to notice that small changes of the fiber deposit packing density as well as impossibility to consider full sedimentation of particles in deposits, weakly influenced the calculated weight and the pressure difference corresponding to a certain time moment.

The used method of calculation of the pressure difference growth can be applied to estimate the filter resource and resolve other practical question filtration questions.

$\Delta p, \text{ mm H}_2\text{O}$



$\Delta p, \text{ mm H}_2\text{O}$

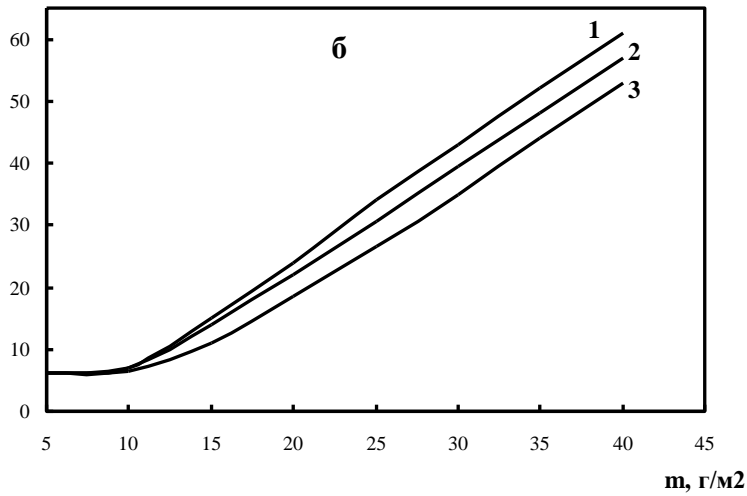


Fig. 5.1. Calculated pressure difference curves obtained for the filters with $\alpha = 0.1$ consisting of the fibers with radius $a_0 = 7.75 \mu$, by the moment of formation of a continuous layer of particles with certain packing density.

(a) $r = 0.58 \mu$, $\beta_1 = 0.005$ (1) $\beta_2 = 0.08$ (2)

(b) $r = 0.8 \mu$, 1 - $\beta_1 = 0.06$; $\beta_2 = 0.12$ 2 - $\beta_1 = 0.06$; $\beta_2 = 0.08$ 3 - $\beta_1 = 0.07$ $\beta_2 = 0.1$

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6 Manufacture of pilot series of filter materials for operation of the ANPP ventilation system

Processing of basalt super-thin fiber (STBF) in solutions of chemical acids can result in changes of its structural and, hence, many physical properties.

Study of the effect of such processing is important as it can allow modification of adsorption properties to use STBF as an adsorbent when clearing air from various aerosol particles and, hence, to find optimum parameters and manufacture efficient filters on the basis of this material.

A new technique of STBF leaching based on the use of two acids (HCl and H₂SO₄) is proposed for the same super-thin basalt fiber.

6.1 Technique of sulfuric (H₂SO₄) leaching of thin basalt fibers

The technique of leaching of thin basalt fibers (TBF) using sulfuric acid (H₂SO₄) was applied. It is known from scientific publications that leaching of TBF using sulfuric acid allows obtaining of the sorbents with regular porous structure. The technique of successive three-stage leaching of basalt fibers used in [1] (with some insignificant changes) was chosen:

Stage 1. Processing of the TBF sample by 6N H₂SO₄ solution during approximately 40 min at temperature of 92 ÷ 94°C.

Stage 2. Processing of the TBF sample by 1.5N H₂SO₄ solution during 60 min at temperature of 92 ÷ 94°C.

Stage 3. Processing of the TBF sample by 1N H₂SO₄ solution during 4 hours at temperature of 92 ÷ 94°C.

After each stage, the processed TBF sample was washed out using distilled water to the absence of the sulphate (SO₄⁻²) ions reaction. The leached TBF sample was dried after the stage 3 at 110 ÷ 120 °C during approximately 10 hours. Then the dried TBF sample was stored in an exiccator with a drying solid agent to exclude contact with the environment.

After leaching using sulfuric acid and drying, the TBF sample lost 51 % of its initial weight. The initial weight of the TBF sample made approximately 25 g. The results of chemical analysis of the treated basalt fibers are presented below:

SiO₂ - 96.27 %,

Al₂O₃ - 1.80 %,

Fe₂O₃ - 1.00 %.

(Total percentage of the components terms makes:

96.27 % + 1.80 % + 1.00 % = 99.07 %).

Comparing the obtained data of the composition of chemically processed TBF with those of the initial (not treated chemically) fibers from [1]:

SiO₂ - 48 ÷ 54 %,

Al₂O₃ - 10 ÷ 15 %,

Fe₂O₃ - 7,5 ÷ 15 %,

the following conclusion can be drawn: the losses in weight of the TBF sample are caused by essential change of their composition and correspond to the data on the losses in weight after leaching (chemical processing). The weight of the TBF sample was measured before and after the chemical processing. It has been determined that 49 % of the weight of thin basalt fibers (TBF) remains after leaching using sulfuric acid.

One of the TBF samples after leaching using sulfuric acid was investigated by thermal gravimetric analysis (TGA), see Fig.6.1 , and infrared spectroscopy (absorption and reflexion spectra). The results of the carried out TGA research conform fully to the data of [2,3], where emanation thermal analysis of basalt fiber adsorbents was carried out.

On the basis of the obtained results it is possible to conclude that the data obtained by the above listed methods of the analysis do not practically differ for the TBF samples leached by two various methods, namely using sulfuric and hydrochloric acids, i.e. identical chemical compound and close sorption characteristics, necessary for adsorbents, are provided in TBF.

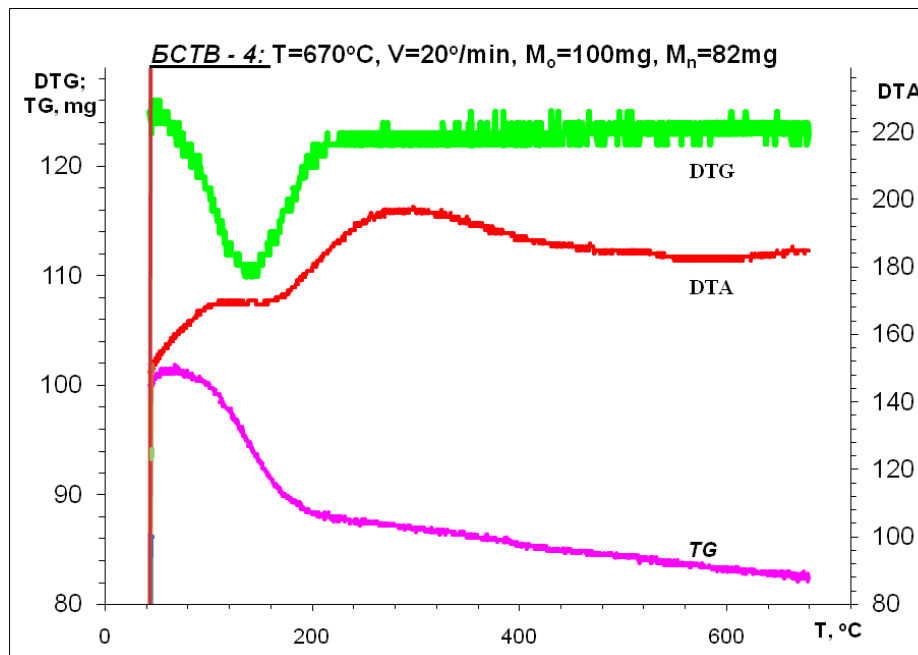


Fig. 6.1 Derivatography (TGA) of the leached (H_2SO_4) TBF sample obtained using Derivatograph Q-1500.

6.2 Hydrochloric-acid method

Basalt super-thin fibers (STBF) as well as basalt fibers can be only used as adsorbents of aerosol mixtures after special preliminary chemical processing. Most often, leaching is used as a method of chemical processing of STBF to manufacture adsorbents on their base. For the purpose of obtaining the adsorbents of aerosol mixtures on the basis of STBF, the technique of STBF leaching using hydrochloric acid was developed and applied during the period under review.

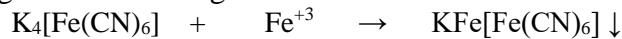
As is known, the method of leaching of STBF using hydrochloric acid includes the following stages:

- Processing STBF by HCL solution with concentration of 2÷5N at 92÷95°C during 30-50 min;
- Washing by distilled H_2O to the absence of Fe^{+3} ;
- Processing STBF by HCL solution with concentration of 0.2÷3N at 92÷95°C during 4÷8 hrs;
- Washing by distilled H_2O to the absence of Cl^{-1} .

Three experiments on chemical processing of basalt fibers were executed:

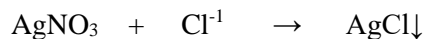
For the experiment # 1, as an initial material 2500 g of STBF was used, and for experiments # 2 and # 3 - 5000 g of STBF in each experiment. The leaching conditions were practically identical in all above experiments. Leaching was carried out in a special tank with a return condenser, thermometer and a mixer with glycerine shutter. The initial portion of STBF was placed in a bottle, then preliminary prepared HCL solution with concentration of 5N was added. The reaction mixture was heated at constant mixing to 92÷95°C (water bath) during 40

min. Then undissolved portion was separated by filtration and washed out by distilled water to negative reaction to the presence of Fe^{+3} ions. For this purpose, yellow blood salt was used according to the following reaction:



Dark blue color of the solution

The deposit was transferred again to the reaction bottle and the processing was continued using the preliminary prepared HCL solution with concentration of 1.5N. The reaction mixture was heated to $92\div 95^\circ\text{C}$ (water bath) at constant mixing during approximately 4 hours. The deposit was separated from the solution by filtration at room temperature and repeatedly washed out by distilled water to negative reaction to the presence of Cl^{-1} ions. Argentic chloride was formed according to the following reaction:



White deposit - muddiness

After that the reaction product was dried during approximately 9 hours at $110\div 120^\circ\text{C}$. At room temperature, weight of the produced STBF was determined:

Weight of STBF separated in experiment # 1 – 1468 g

Weight of STBF separated in experiment # 2 – 2408 g

Weight of STBF separated in experiment # 3 – 2545 g

For the first time, chemical method of two-stage combined treatment is used.

A new technique of STBF leaching based on the use of two acids (HCl and H_2SO_4) for the same super-thin basalt fiber is offered and carried out.

It follows from known publications (see, for example, [Beckman I.N. Diagnostics of basalt fiber adsorbents, Vestnik MGU, Chemistry, 2003, v. 44, # 5, p.p. 342-351] that H_2SO_4 leaching in comparison with HCl treatment promotes formation of STBF sample with more regular pore structure. We believe that combination of these two methods for the same STBF sample will have positive impact on its sorption characteristics (for example, sorption capacity).

The method includes the following stages:

Stage 1 – treatment of STBF samples using 5N HCl during approximately 30 minutes at $94\div 95^\circ\text{C}$. Washing of the treated samples by distilled water to absence of reaction on Fe^{+3} and Cl^{-1} ions.

Stage 2 - treatment of STBF samples using 1.5N H_2SO_4 during approximately 3 hours at $94\div 95^\circ\text{C}$. Washing of the treated samples by distilled water to absence of reaction on SO_4^{-2} ions.

Drying of the leached STBF samples (after two above described stages 1 and 2) at $110\div 120^\circ\text{C}$ during 14 hours. The yield by weight makes 57 % of the initial amount.

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7. Effect of chemical treatment on electro-physical properties of super-thin basalt fiber (STBF)

Processing of basalt superthin fiber (STBF) in chemical acid solutions can lead to changes in its structural and, hence, many physical properties.

In scientific literature, the technique used to treat our samples is known as industrial, and the process as leaching.

Research of the effect of such processing is rather important as it can change adsorption properties of STBF when using it as adsorbing agent for clearing air from various aerosol particles, to find out optimum parameters of manufacturing filters on the basis of this material.

Measurements of specific electric resistance for constant (ρ_{dc}) and alternating current (ρ_{ac}) were carried out. Also, dielectric permeability (ϵ') and dielectric losses (ϵ'') were determined. These parameters were measured at temperatures close to room temperature (from 15 to 25°C) and at relative air humidity not more than 50 %. Frequency of the applied alternative electric field varied from 200 Hz to 1 MHz.

Fig. 7.1 shows dependences ρ_{dc} on duration of constant field t for the initial and chemically processed samples. It follows from the figure that chemical processing leads to decrease of ρ_{dc} almost by 4 orders of magnitude. It is characteristic that both before and after leaching the samples, $\rho_{dc}(t)$ dependence reveals after fast initial increase of ρ_{dc} its subsequent slow growth. Besides, if in the initial sample ρ_{dc} reaches its constant value in two minutes after powering the field, for chemically processed sample it occurs in 2 hours after powering the field (in Fig. 7.1 this part of the results is not presented). It is revealed that the area of fast increase of ρ_{dc} is caused by polarization of water in large fiber pores under the effect of constant field, and rather slow growth is caused by polarization of water in smaller pores. Hence, in the case of constant electric field at first water molecules in large pores are polarized and later water molecules in small pores. Therefore after powering of constant field, fast increase of ρ_{dc} during time t is followed by the area of its slow growth. To find out the role of water in behavior of the specified areas, initial and chemically processed samples were heated up to 150°C during 1 hour and their weight recovery with time was controlled. Weighing was carried out using electrical balance accurate to 0.05 mg (absolute precision). The weight of samples varied in the range from 25 to 40 mg. The results of the weighing are presented in Fig. 7.2, where the parameter $(m-m_0) \cdot 100 \% / m_0$ determined in the course of time characterizes relative loss of the sample weight (here m_0 is weight of the sample right after its heating at 150°C during 1 hour, and m is its current weight). It follows from the results that the initial sample loses at heating less than 0.4 % of its weight, and maximum in 2 minutes after its keeping at room this sample weight comes to the stabilized value. On the other hand, the leached sample loses 15 % of its weight, and its stabilization takes only place after 2 hours. The obtained results are in keeping with the results of research of their adsorption properties obtained for various leached samples using thermogravimetric and differential thermal analysis [1]. It is known that industrial leaching of BSTF modifies size distribution of pores as follows: 9 % of macro-pores, 4 % of micro-pores and 87 % of mesopores. Besides, an increase in total amount of pores from 0.027 cm³/g to 0.1341 cm³/g takes place here. The volume of the pores formed or cleared from various impurity and saline formations is filled basically with water, which leads to reduction of ρ_{dc} and ρ_{ac} by 3-4 orders of magnitude and also to increase of ϵ' by a factor of 4.5 and dielectric losses ϵ'' by a factor of more than 500 (Table 7.1). As it was supposed, the increase of micro-pores is really one of principal reasons of occurrence of long-term relaxation processes resulting in stabilization of ρ_{dc} value after powering of constant electric field. It is also seen from Fig. 7.3 that all three parameters ρ_{ac} , ϵ' and ϵ'' decrease with growth of the electric field frequency, which according to paper [2] testifies that dipole

polarization mechanism works in the leached sample. The increase in water sorption capacity of the sample causes strong growth of ϵ' and ϵ'' (polarization phenomenon) as well as conductivity.

So, the results of investigations of electrophysical parametres in case of both constant and alternative fields, as well as those of thermogravimetric calculations have revealed that BSTF processing in hydrochloric acid leads to increase in their water vapor sorption capacity. To obtain more detailed results on sorption properties of BSTF, it is necessary to carry out measurements in a wider interval of temperatures [3] for the samples heated at higher temperatures during the processing.

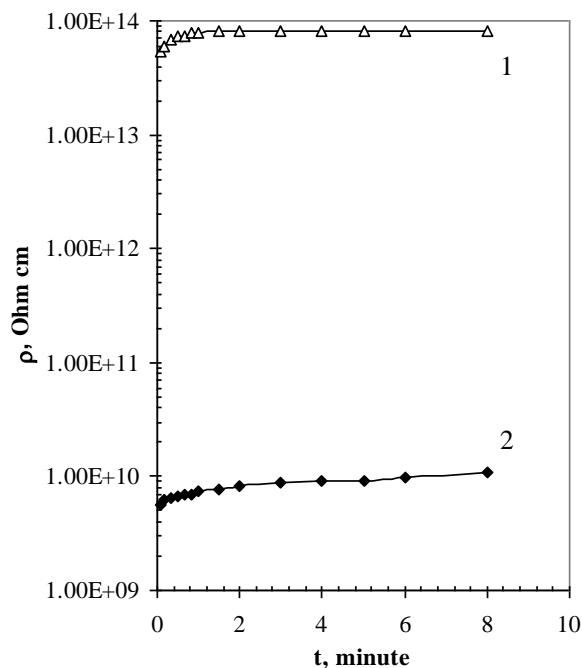


Fig. 7.1. Dependence of specific electric resistance on the constant field ontime for the initial (curve 1) and leached (curve 2) BSTF. Curves 1 and 2 are registered at the following air temperature and relative humidity: 24.2°C, 44,60 % and 20.4°C, 49.9 %, correspondingly.

Table 7.1

Electrophysical parameters for initial and chemically treated BSTF measured at 15°C with applied alternative field (frequency of 800 Hz)

Sample	800 Hz		
	ϵ'	ϵ''	$\rho_{ac} [\Omega \cdot cm]$
Initial	1.735	$1.6 \cdot 10^{-2}$	$1.4 \cdot 10^{11}$
Chemically treated	7.8	9	$2.2 \cdot 10^8$

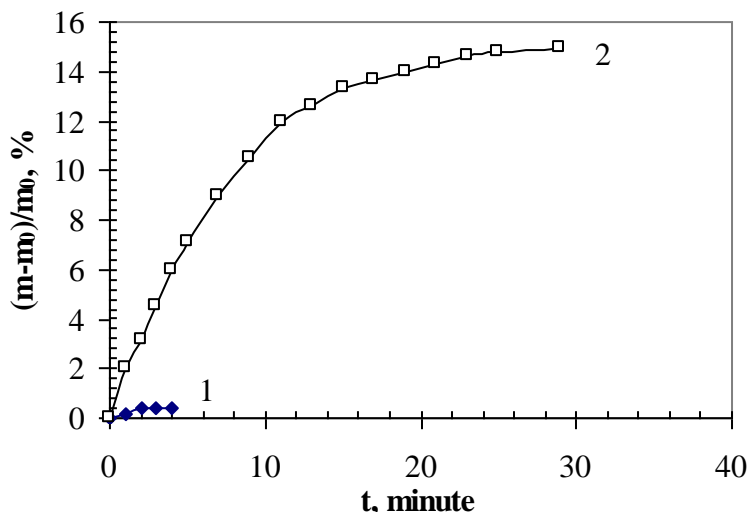


Fig. 7.2. Recovery of weight for the initial (curve 1) and chemically treated (curve 2) samples of superthin basalt fiber after heating at 150°C within 1 hour. Weighing was carried out in air at 18°C.

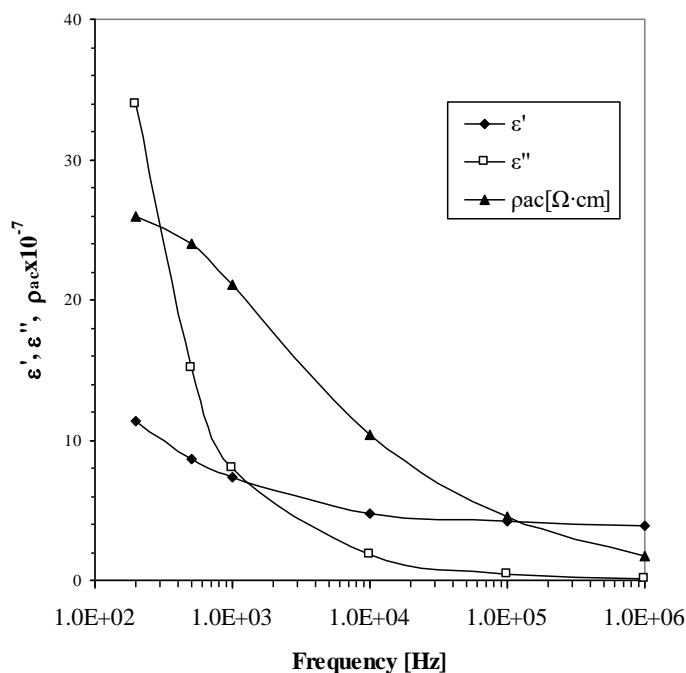


Fig. 7.3. Frequency dependence of dielectric constant (ϵ'), factor of electric losses (ϵ'') and specific electric conductivity for alternating current (ρ_{ac}) at $T = 15^\circ C$ for the BSTF sample after chemical treatment.

Conclusions

Thus, the results of measurements of electrophysical parameters in constant and alternative fields as well as thermogravimetric investigations have shown that BSTF chemical treatment in hydrochloric acid results in increase in water vapor sorption ability. However, the measurements of electrophysical parameters were carried out at near room temperatures, and sorption ability was determined after heating of samples only at one fixed temperature (150 °C) during fixed time period (1 hour). To obtain more detailed conclusions on sorption properties of BSTF, it is necessary

to carry out measurements within a wider temperature interval [3] on the samples heated at higher temperatures. Besides, it is necessary to compare these properties for both sorption and desorption regimes [1]. Also, it is necessary to treat samples in sulphuric acid [1]. All these treatments and measurements important for obtaining highly active filters on BSTF basis are currently in progress.

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8. Study of physical regularities of behavior of a wide spectrum of aerosols when filtering using various filter materials.

Review of publications describing the mechanisms influencing degree of aerosol filtration was carried out. It is known from the general theory of aerosol filtration that one of the main effects influencing sedimentation of dispersed phase is diffusion. It can be stated after detailed analysis of capture mechanisms of aerosol particles that at filtration of aerosols through macroporous dispersion, the aerosol phase is deposited on macro-grains at the expense of diffusion and inertial effects. Calculation of filtration (cleaning) factor of aerosols by macro-granular filters was made without taking into account mutual influence of the above mentioned effects.

For the filtration factor the following formula was obtained:

$$K_{\phi} = t^{(\lambda_{\text{д}} + \lambda_{\text{ин}})h} \quad (8.1)$$

$\lambda_{\text{д}}$ is coefficient of diffusion sedimentation of aerosols;

$\lambda_{\text{ин}}$ is coefficient of inertial sedimentation;

h is thickness of filter layer.

Calculation of coefficients of sedimentation $\lambda_{\text{д}}$ and $\lambda_{\text{ин}}$ was carried out using "capillary" model on the assumption that diameter of pore channels is defined by the following expression:

$$d_{\text{коп}} = 2 \frac{K}{t}. \quad (8.2)$$

Accepting Prandtl-Taylor hypothesis, according to which mass transfer of substances in the turbulent flow core up to the laminar interlayer is carried out at the expense of turbulent diffusion, and the laminar interlayer near to the walls of pore channel at the expense of the molecular diffusion, the following formula was obtained for the coefficient of diffusion sedimentation of aerosols on macro-granular filters:

$$\lambda_{\text{д}} = \frac{\sigma \sqrt{m t}}{K \sqrt{\nu U_{\phi}}} \quad (8.3)$$

where σ is coefficient of molecular diffusion of particles;

ν is kinematic viscosity of gas;

β is proportionality factor.

When investigating the diffusion effect, an important factor is nuclide composition of the investigated aerosol fractions.

To determine radionuclide composition of aerosols presenting in air of premises and emissions, an historical database characterizing sizes and radionuclide composition of aerosols in air emissions and ventilation systems (see Tables 6.1 and 6.2) was created at the Armenian NPP.

Table 8.1
Nuclide composition and size of emissions during ANPP operation period (10^7 Bq/year)

Year of oper.	Basic radionuclides								
	LLN*	^{131}I	^{137}Cs	^{134}Cs	^{60}Co	^{110m}Ag	^{90}Sr	^{54}Mn	^{51}Cr
1978	16,9	276	0,10	--	7,80	6,40	0,03	5,60	20,0
1979	633	579	17,2	5,10	31,0	--	1,40	19,1	313

1980	428	777	48,6	46,7	18,1	--	0,30	13,6	70,0
1981	214	735	22,4	15,5	26,9	--	0,60	10,7	11,6
1982	341	230	9,5	10,0	62,8	48,5	0,37	22,3	11,5
1983	884	70	5,0	1,70	20,6	4,80	0,06	5,80	0,70
1984	1785	228	66,3	51,0	28,2	37,0	0,04	4,90	4,60
1985	754	151	60,6	33,1	17,2	71,6	0,11	4,0	16,2
1986	794	44	25,0	12,8	21,7	73,4	0,25	8,40	--
1987	259	103	13,4	5,60	34,7	122,0	0,08	7,20	17,2
1988	338	602	14,9	24,0	128	142,0	0,06	26,8	10,2
1989	181	108	10,1	--	29,4	56,60	--	--	--
1990	113	--	8,8	--	12,3	16,10	0,09	--	--
1991	46,0	--	6,2	4,0	8,9	11,80	0	1,30	--
1994	82,0	--	--	--	60,1	--	--	--	--
1995	193,0	9,70	23,3	--	83,7	--	0,15	--	--
1996	121,0	23,5	15,4	0,80	22,4	25,80	0,12	0,80	11,6
1997	278,0	36,7	11,6	1,27	9,0	7,24	0,36	0,33	0
1998	238,4	28,8	9,35	1,32	18,4	7,72	0,29	1,89	21,6
1999	44,43	25,8	10,2	0,89	11,94	10,8	0,44	1,22	--
2000	30,7	26,0	4,20	5,97	17,7	22,60	0,38	8,78	--
2001	31,1	18,8	16,5	5,36	23,5	18,70	0,49	3,42	2,24
2002	9,9	59,6	7,90	2,28	6,6	2,50	0,2	0,16	--
2003	29,3	38,1	26,7	5,0	22,1	25,0	0,23	3,23	--
2004	28,5	97,1	5,59	0,38	14,6	11,3	0,04	1,35	2,53
2005	20,9	3,04**	7,0	0,83	5,10	1,35	0,03	--	--
2006	18,3	3,65	5,12	0,54	9,45	1,77	0,03	--	--
2007	46,0	1,90	4,88	1,60	7,15	1,17	0,05	0,10	--
2008	7,0	0,47	3,82	1,20	23,7	8,0	0,04	1,45	--
% composition without regard to ¹³¹ I and LLN			20,59	1,4	35,08	32,89	0,28	6,83	2,9
% composition without regard to LLN	59,7	6,40	3,30	10,9	10,25	0,087	2,14	7,16	

*LLN are radionuclides with half-life period more than 24 hours

** starting from 2005, new and more sensitive equipment and technique of measurement of ¹³¹I emission were introduced at ANPP.

It is seen from the Table that the greatest percentage contribution to aerosols activity is made by the radionuclides of corrosion origin (⁶⁰Co and ^{110m}Ag) as well as uranium fission product ¹³⁷Cs.

Table 8.2

Concentration of radionuclides in ventilation systems . 10⁻⁷ Bq/l (data for 2007-2008)

Ventilation systems	Max					Min				
	Cs-137	Co-60	Ag-110m	Mn-54	Cs-134	Cs-137	Co-60	Ag-110m	Mn-54	Cs-134
2007										
B1C	215,3	26,1	--	--	--	6,7	--	--	--	--
2B2	85000	8000	182	--	90000	28,2	27,3	37,0	--	73,8

B3	12,9	98,0	111,0	--	--	7,4	55,9	74,4	--	--
2B4	31005	1260	--	--	72005	185	--	--	--	111
2008										
B1C	127,1	109,4	--	--	--	52,7	54	--	--	--
2B2	117,8	236,9	70,9	--	--	95,7	--	--	--	--
B3	60,6	380,5	--	--	--	--	--	--	--	--
2B4	81,9	1619	475,6	209,5		41,5	110	--	--	--

In 2009 the measured concentration of Co-58 in 2B4 was Max=193.

When analyzing the contents of radioactive aerosols, it is necessary to consider the diffusion effect caused by impurity transport in direction of smaller concentrations. When taking samples from flow, it is necessary to observe a series of conditions. The sampling tube axis should be parallel to flow lines in air duct (the coaxiality condition). Otherwise when observing correct sampling speed, concentration of aerosol in sample C_i will be lower than in investigated aerosol Q , and the aspiration coefficient $a' = C_i/C_e$ will be below 1. The average flow velocity in nozzle U_i should be equal to low velocity U_e in corresponding flow line (which passes the tube axis) in the gas duct (the isokinetic condition, Fig. 8.1).

At $\omega = U_i/U_e < 1$, flow lines diverge prior to the tube input; the particles displace from the flow line to the tube axis under the influence of inertia, and as a result the concentration in sample becomes higher than the real one ($a' > 1$).

At $\omega > 1$ the situation is vice versa and $a' < 1$.

At last, to the two above conditions it is necessary to add the third one: the sampling tube walls (nozzle) should be infinitely thin.

Errors due to non-coaxiality of sampling of particles with diameter d at small angles ν between the flow direction in air duct ($\omega = 1$) can be taken into account by formula 8.3.

$$a' \approx 1 - 4 \sin \nu S_i / \pi, \quad (8.4)$$

where $S_i = U_e \tau / D_{tr}$ is Stokes number; $\tau = p_c d^2 / 18 \mu$ is the particle relaxation time; p_c is the particle density; μ is dynamic viscosity of air; D_{tr} is internal diameter of the sampling tube.

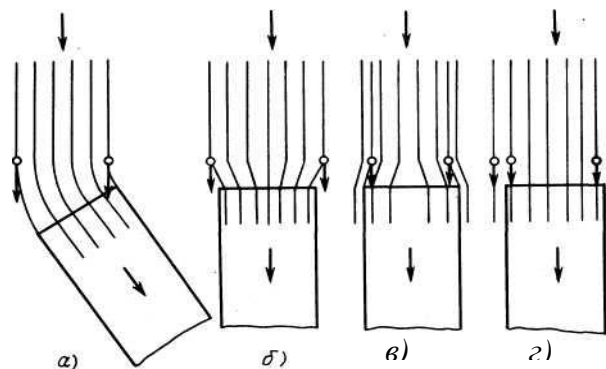


Fig. 8.1. Aspiration of aerosol. a – violation of coaxiality (at correct sampling velocity); b – increased sampling velocity; c - decreased sampling velocity; d - correct sampling velocity.

The errors due to violation of isokinetic conditions of sampling can be estimated using empirical Beljaev-Levin formula:

$$a = 1 + \frac{(\omega^{-1} - 1)(2 + 0.62\omega)St}{1 + (2 + 0.62\omega)St} \quad (8.5)$$

where $-0,2 < \omega^{-1} < 5$

In practice to observe isokinetic conditions, a nozzle with internal diameter D_H (mm) determined by expression

$$D_H = 4,6 * \sqrt{\frac{Q}{U_e}} \quad (8.6)$$

where Q – is the tapped air rate in dm^3/min ; U_e is air speed in the sampling point, m/s ,

is put on the end of sampling tube.

9. Development of mathematical models of filtration processes

Catching (capture) of radioactive aerosols can be carried out by means of fibrous filters, which are macroporous media with very complex geometrical characteristics. The majority of known results on determination of filter operation effectiveness were obtained experimentally and are theoretically poorly known. It is known that process of filtration of particles depends on a lot of parameters, and it is practically impossible to consider all of them when carrying out experimental work. In this connection, very important and actual is mathematical modeling of filtration process to estimate efficiency of filtration at simultaneous variation of a lot of parameters in a wide interval of their variation. Basic equations necessary for mathematical modeling of filtration processes depend on both the sizes of radioactive particles and structural features of the filter. When generating of equations, it is necessary to consider a series of physical phenomena participating in process of filtration. One of examples is effect of engagement, including sieving effect, when aerosol particles are retained in pores and channels with cross-section less than the sizes of particles. Another example is inertial force - when changing direction of movement of radioactive flow, particle deviate from this direction and sediment. Brown movement to a considerable extent determines movement of finely dispersed submicron particles. Under the action of electrostatic forces aerosol particles and filter material can obtain electric charges or polarize. If the sizes of aerosol particles are large in comparison with gas molecules, laws of movement of particles are of aerodynamic nature. However, if the sizes of particles are small, laws of movement of particles are of molecular-kinetic nature. In this case the particles are considered as large molecules moving among small ones, and their capture by filter fibers is considered within the framework of adsorption. As an adsorption model, Henry and Langmuir isotherms will be used.

When developing mathematical modeling of filtration processes, it is necessary to remember that radioactive aerosol particles have spherical form and that all particles contacted with fibers adhere to their surface and are kept on it either by Van der Waals' forces or by electrostatic forces. In this case filter fibers are represented in the form of cylinder or microporous cylinder. Finally, the primary objective of mathematical modeling is calculation of capture coefficient of particles by fiber, which, generally, depends on many parameters: radius and density of captured particles, velocity viscosity, temperature T and pressure of air, presence of external forces, as well as filter parameters - thickness, packing density, average diameter of fibers and their dispersion characterizing inner structure of filters. For non-stationary process of filtration, when deposit accumulates on fibers, the capture coefficient also depends on the amount of deposited particles. It follows from the analysis of filtration process that there are various mechanisms of sedimentation of aerosol particles, and it is expedient to express the capture coefficient through the filter parameters and dimensionless parameters characterizing conditions of filtration. As dimensionless parameters it is necessary to take Knudsen number and Peclet's diffusion parameter.

Research of influence of Van der Waals forces on sedimentation of aerosol particles on super-thin fibers.

Sedimentation of aerosol particles takes place from a thin gas layer adjoining to the super-thin fiber. Therefore to model the particle catching process, an exact knowledge of aerosol flow and Van der Waals forces immediately near the fiber surface is necessary.

It is known that one of the important problems of gas filtration theory is calculation of radius of the most penetrating r_p^* particles, because the filter efficiency is estimated just for these particles.

It is known from theory [1,2] that two mechanisms of sedimentation: Brownian diffusion and engagement of particles are usually considered. However, appreciable influence on sedimentation of submicron particles on fibers is exerted by molecular Van der Waals forces. It is accepted to distinguish short-range Van der Waals forces, which operate at distances less than 0.01 micron, and long-range (so-called late) forces. The late forces manifest themselves considerably at distances of approximately 0.1 micron by attracting to fiber the flowing particles. The preliminary analysis has shown that capture of particles from the stream is just determined by the late forces, and their contribution to total efficiency of sedimentation can be considerable.

It was specified that the process of sedimentation of radioactive aerosols on a fiber is characterized by a factor of capture, which depends on the filter parameters, conditions of gas flow and the size of particles.

Until recently in the theory of submicron aerosols filtration, at calculation of radius of the most penetrating particles the influence of late Van der Waals forces was not considered, because the estimation of the role of these forces was only done for non-late forces and therefore the value of sedimentation efficiency was too high.

Study of particle sedimentation was carried out using a model filter with a known flow field. As the model filter, a system of parallel fibers of hexagonal packing located perpendicularly to Stokes flow direction was accepted. For the system of ultra-thin fibers with a diameter comparable with average free path of gas molecules, the field of velocities and resistant force of fibers depend on Knudsen number

After calculating the concentration field in the model cell of the filter, we find capture γ of fiber and efficiency of the whole filter, E:

$$E = 1 - \exp \{-2\alpha l H \eta\}. \quad (9.1)$$

where $l = \alpha / \pi a^2$ is the length of fibers in a unit volume of the filter, H is the filter thickness.

The capture factor is determined by integration of a component (normal to the fiber surface) of the whole flow along the circle over the angle.

$$\eta_{DRW} = r_h \int_0^\pi \left(\frac{2dn}{P_e} dr - V_r n \right) dQ \quad r = r_b. \quad (9.2)$$

The lower estimate for δ is found from the equation determining the point of intersection of extreme trajectory by a non-diffusing particle (as though behind fiber at $\theta = \pi$):

$$V_r(1 + \delta + R, \pi) = 0$$

The influence of Van der Waals forces is shown in the graph of capture factor as a function of particle sizes and, that is especially important, near minimum of these curves, i.e. for the most penetrating particles.

The figure presents the curves (ηr_p) calculated using formula (9.2) for two values of A_7 , constants of van der Waals interaction, differing from each other by an order of magnitude. Taking into account Van der Waals forces leads to appreciable increase in the capture factor, and in case of high A_7 values to displacement of minimum towards smaller r_p^* .

At small speed, characteristic for testing and operation of super-thin filters with average diameter of fibers 0.3-0.5 microns and packing factor close to $\alpha = 1/16$, to estimate radius of the most penetrating particles with $U = 1-20 \text{ cm s}^{-1}$ the following formulas can be recommend for development of filters:

$$r_p^* = 0,105 A/U^{1/4} \quad (9.3)$$

$$r_p^* = 0,088 A/U^{1/4}, \quad (9.4)$$

where $A = 1 \text{ micron (cm/s)}^{1/4}$.

Thus, the idealized filter model, a system of parallel fibers, is applicable to determine radius of the most penetrating particles and will be useful at estimation of characteristics of filters based on super-thin basalt fiber.

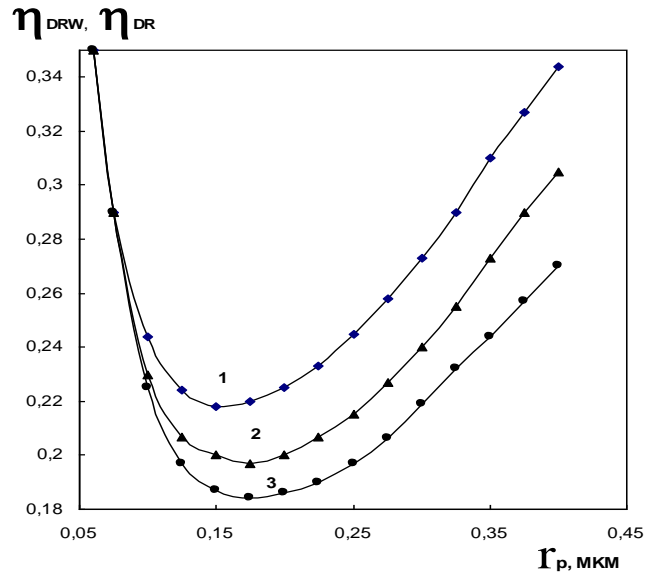


Fig. 9.1. Dependence of capture factor η_{DRW} (1,2) and η_{DR} (3) on radius of particles at various values of interaction constants
 1 - $A_7 = 10^{-18} \text{ erg.cm}$, 2 - $A_7 = 10^{-19} \text{ erg.cm}$, $a = 1 \text{ micron}$, $U = 1 \text{ cm.s}^{-1}$, $\alpha = 1/16$.

References

- A.A.Kirsh, Kolloid Journal, 2004, v. 66/4, p.p. 497-503
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10. Aerosol particle size distribution

Intake of radioactive aerosols in organism and their distribution in there depend on the aerosol particle size. Therefore, to estimate the level of radiological hazard of aerosols, is necessary to determine - except for their volumetric activity - size distribution of these particles.

To obtain information on the particle sizes, it seems promising to use the filter package method [1, 2]. This method approximates the real spectrum of particles by logarithmically normal distribution, which is recommended by MKR as basic one for the aerosols of anthropogenic origin; here from activity fraction of the nuclides caught by each of three filters with known filtering characteristics, the following parameters of logarithmically normal distribution are calculated: r_{50} (median radius of particles) and σ (standard geometrical deviation). The calculation technique is as follows:

Let's denote efficiency of the i -th filter as $\varepsilon_i(r)$, then the amount of the particles settled on the i -th filter is:

$$N_i = \int_0^{\infty} \varepsilon_i(r) f(r) dr \tag{10.1}$$

where

$$\varepsilon(r) = \exp \frac{[(\ln(r) - \ln(r_{50}))]^2}{2}$$

$$f(r) = \frac{2 \ln \sigma}{\sqrt{2\pi \ln \sigma_r}} \tag{10.2}$$

is density of logarithmically normal distribution, and r is radius of particles.

By substituting (10.2) in (10.1) and calculating integrals for various parameters of distributions r_{50} and σ , it is possible to construct nomographs connecting r_{50} , σ and the number of radioactive nuclides settled on the i -th filter, expressed in percentage. The intersection of curves $\sum_{i=1}^3 N_i = 1$ gives the required values r_{50} and σ . In practice, intersection of three curves satisfying to this condition gives an area (shaded in Fig. 10.1) formed due to experimental error of definition of activity fraction in the i -th filter and calculation errors.

The filter package method allows analyzing the particles with radius from 0.05 to 1 micron. It has a number of advantages in comparison with other methods of determination of dispersity. For example, let us note its simplicity and opportunity to analyze great air volumes, as the samples are taken at high linear velocities of filtration exceeding 1 km/s.

To measure dispersity of aerosol by the filter package method, it is necessary to know as accurate as possible the form of $\varepsilon_i(r)$ function, as the error of its determination characterizes the error of determination of the parameters of logarithmically normal distribution. Efficiency of aerosol catching depending on the particles size and filtration rate was investigated by means of polystyrene latexes with high degree of monodispersity. The used latexes had the following particle diameters d and their roof-mean-square deviations:

d, microns . . .	0,099	0,16	0,31	0,46	0,72	1,05	1,54	2,00
σ_i.....	0,15	0,02	0,01	0,01	0,01	0,04	0,14	

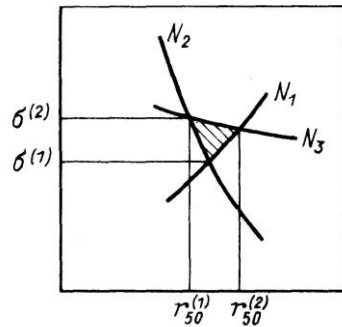


Fig. 10.1. To the solution of equation (1) (intersection of the lines corresponding to experimental results [shaded area] determines the values of distribution parameters r_{50C} [$r_{50\phi}$, $r_{50\psi}$], а£ [$a^{(1)}$, $a^{(2)}$]).

The used aerosol was obtained from a latex suspension in distilled water by means of a special spraying device. It was mixed with cleared and warmed air and directed to the investigated filter. Filtration rate was determined from the pressure difference on the filter. Aerosol breakthrough K was determined from the particle concentration ratio after and before the filter. The filter efficiency is connected with the breakthrough as follows: $\varepsilon = 1 - K$.

The following filtering materials were investigated: FPA-70-0,1 and FPA-70-0,4, which are used as the first and second layers in the filter package for analysis of aerosols dispersity. Dependences of the efficiency of catching particles sized from 0.5 to 10 microns in radius within the velocity range of 0.8 – 2.5 km/s were obtained. Fig.10.2 gives the catching efficiency for velocity of 1.5 km/s, which is optimum for the filter package method. The error of $\varepsilon(r)$ determination did not exceed 5 %.

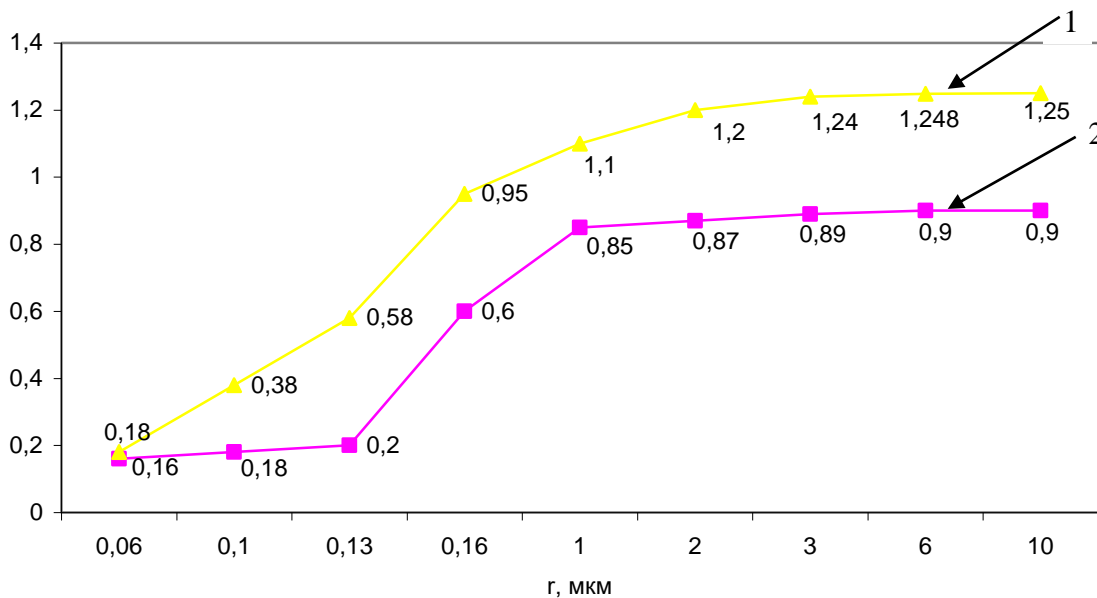


Fig. 10.2 Dependence of the efficiency of catching aerosols on the particle radius: 1 - filter FPA-70-0,1; 2 - filter FPA-70-0,4

The obtained results were processed by means of a special program.

By means of this technique, the air aerosols particle size distribution was investigated for the premises of ANPP supervised area. Preliminary, the basic radionuclide composition: ^{60}Co , ^{137}Cs , ^{54}Mn , $^{110\text{m}}\text{Ag}$... was determined. Fig. 10.3 below presents the values characterizing size distribution of aerosols in air of the premises of ANPP supervised area.

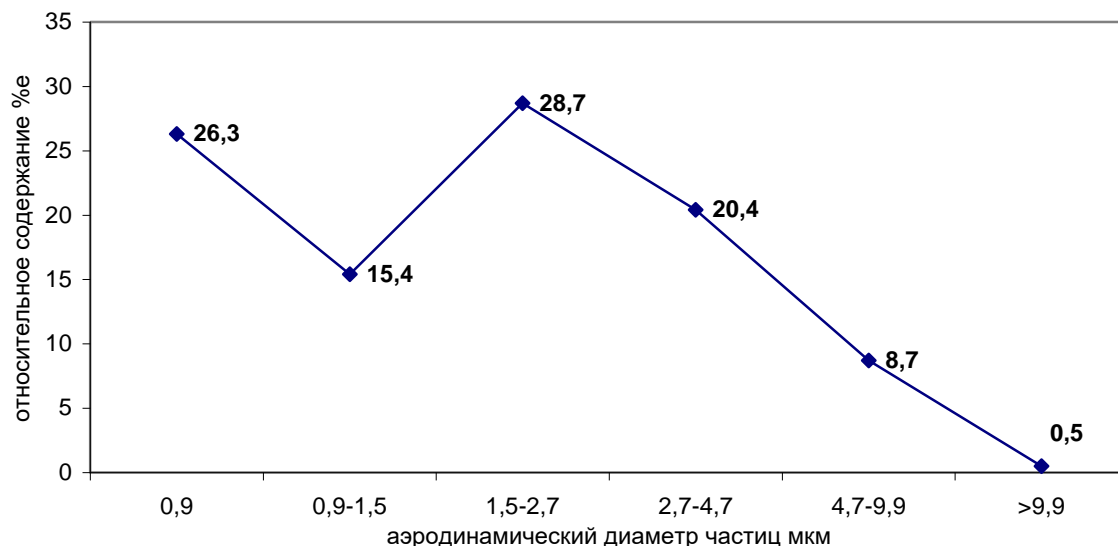


Fig. 10.3 Size distribution of aerosols in air of the premises of ANPP supervised area.

Analysis of the data presented in the figure shows that diameter of the basic percent of particles (90,8 %) varies from 0.9 to 4.7 microns; the particles with diameter from 4.7 to 9.9 microns make 8,7 %, and the particles with diameter more than 9.9 microns - 0,5 %.

References

1. Lockhart L.B., Patterson R.L., Sanndeis A.W. The size distribution of radioactive atmospheric aerosols. - J. Geoph. Res., 1965 V. 7, №24, p. 76.
2. A method for investigating size distribution of radioactive aerosols in ground atmospheric layer/N.V. Bogolapov, N.N.Kaschenko, I.E.Konstantinov et al. In "Problems of dosimetry and radiation protection". # 14. Moscow, Atomizdat, 1975, p. 86.

11. Experimental device for investigation of efficiency of the tested filter materials

The basic equipment in the systems of clearing air from radionuclides are the filters of various type and design used for different operating modes, filtering materials, etc.

It is known that the service life of any filter is influenced by the following factors: 1) increase in the filter resistance as a result of dust sedimentation in the filtering material; 2) increase in dose rate of the filter radioactive radiation as a result of accumulation of radionuclides in it; 3) destruction of the filtering material under the influence of the aggressive substances containing in air.

The filtering material practice shows that the principal factor defining the service life of filters is increase of their resistance which results in their failure and inapplicability for its intended purpose. To increase service life of radionuclide filters, it is necessary to carry out rough clearing and then thin clearing of air.

The filter design should meet the following requirements: 1) maximum surface of the filtering material at minimum dimensions; 2) minimum resistance of the filter; 3) possibility of fast and convenient change of filters; 4) reliable sealing at the filter group assembling.

The simplest proposed filter will consist of a case divided by a porous partition wall into various parts one of which is supplied with the gases to be cleared. In the divided parts of the filter, the needed pressure difference is created sufficient for passage of a specified amount of gas.

In connection with variety of the requirements to be met in real conditions of operation to clear various aerosols, many different designs of filtering devices with porous partition walls (flexible, semiflexible and rigid) are used.

When selecting porous partition walls, chemical composition, temperature, pressure and humidity of the gas flow as well as the size and concentration of the particles to be caught are taken into account.

The filter operation is characterized by the following factors: clearing efficiency, filter porosity, filtration rate, dust holding capacity, hydraulic resistance, as well as technical and economic data.

To carry out preliminary research of filtration properties of various modifications of filtering materials, a pilot device was designed and manufactured. It included rotameters for definition of air consumption, special valves for variation of air consumption, filter holders, tools for determination of aerosols activity upstream and downstream the filters.

Fig 11.1 presents a part of the experimental installation for determination of effectiveness of air cleaning from radioactive aerosols using basalt fiber filters.

The filters fixed in holders present a single-layered gauze base of circular form, on which various modifications of basalt fiber are put (similar filters with Petryanov fabric are used in a regular mode to determine aerosol activity in air of premises and various ventilation systems of NPP. Fig. 11.2 shows structure of such filters.

Besides, below a picture of the experimental installation positioned in the controlled access zone, is presented (Fig. 11.3).

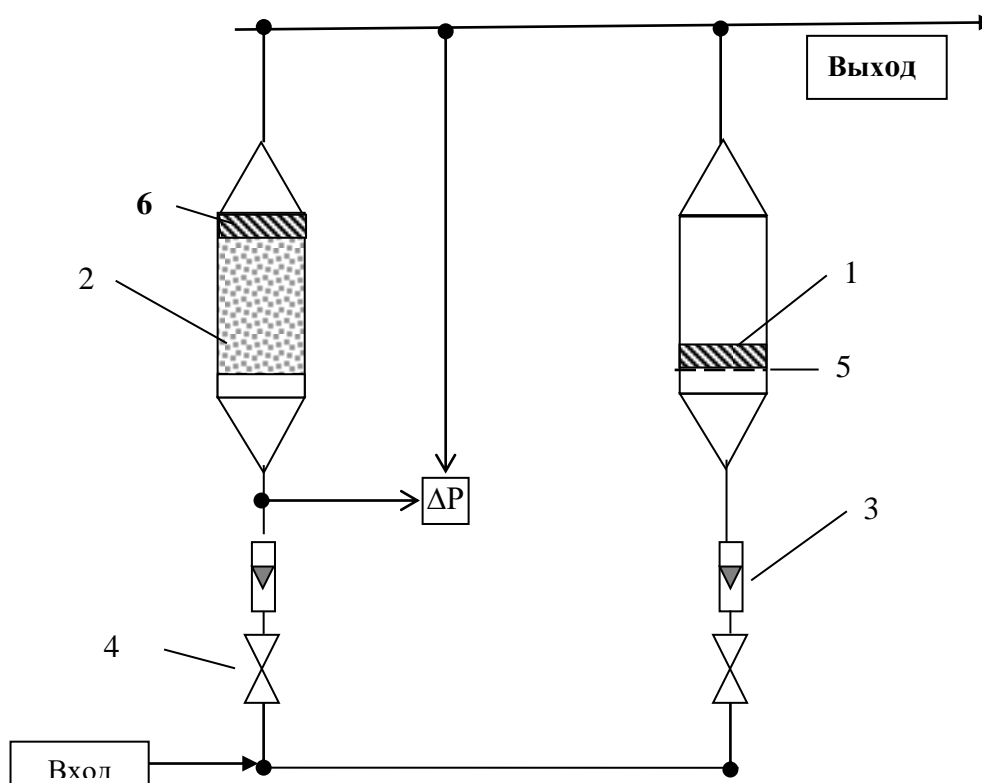


Fig., 11.1 1 and 6: Petryanov filters; 2: filter under testing;
3: rotameter; 4: check valve; 5: grid; ΔP : manometer.

Using the pilot device, research of filtering characteristics of the basalt fiber based filters depending on various physical and chemical parameters was carried out. Efficiency of the investigated filters was measured at various air rates through the filters: from 1.6×10^4 l/hour (design rate) to 3.2×10^4 l/hour. Output activity of aerosols (after passing filters) was measured by two independent measuring devices DBG2 and AERM. Activity of the aerosols deposited on the investigated filters was measured on a low-background spectrometric installation with Ge detector and GENIE software. Measurements using filtering materials with various parameters at various air rates were carried out.

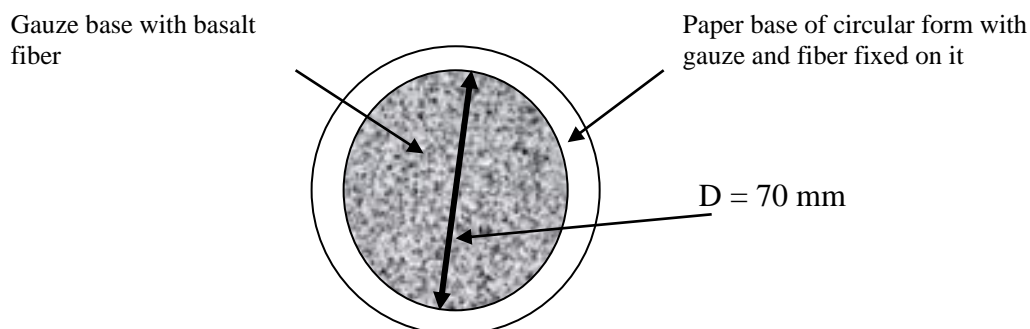


Fig. 11.2 Structure of filters fixed in holders of the experimental installation



Fig. 11.3. Pilot device installed in the controlled access zone.

Research of filtering characteristics of the filters on the basis of a basalt fiber depending on various physical and chemical parameters of pilot models was carried out.

In particular, research of filtering fibers of two types (leaching using sulfuric and hydrochloric acids) was carried out. Efficiency of the investigated filters was measured at various air consumptions: from 1.6×10^4 l/hr (design value) to 3.2×10^4 l/hr. Output aerosol activity (after passing of the filters) was measured by two independent measuring devices DBG2 and AERM. Activity of the aerosols deposited on the investigated filter was measured using a low-background gamma spectrometer with a germanium detector and GENIE software. The filters operated within 1 week.

The table below presents the results of estimation of efficiency for the filters on the basis of non-modified basalt fiber and various modified basalt fibers.

1. Fiber obtained by leaching of thin basalt fibers using sulfuric acid – $TBF_{H_2SO_4}$
2. Fiber obtained by leaching of thin basalt fibers using sulfuric acid – $TBF_{H_2SO_4}$

Table 11.1 contains average data from a series of 8 measurements. Efficiency was determined by the following formula:

$$\text{Эффективность} = \frac{A(\text{до} / \phi) - A(\text{после} / \phi)}{A(\text{до} / \phi)} \times 100\%$$

Table 11.1

Results of estimation of efficiency of filters from modified samples of basalt fiber

Filter type	Isotope	Activity upstream of the filter 10^{-4} Bq/m ³	Activity downstream of the filter 10^{-4} Bq/m ³	Cleaning Efficiency (%)
Non-modified basalt fiber	¹³⁷ Cs	119,2	10,7	91.02
	¹³⁴ Cs	61,6	5,54	91.0
	⁶⁰ Co	275,6	22,05	92.0
	^{110m} Ag	97,9	7,80	92.0
Average over isotopes				91.5
(ТБВ _{H2SO4})	¹³⁷ Cs	119,2	0.60	99.50
	¹³⁴ Cs	61,6	0.36	99.41
	⁶⁰ Co	275,6	1.1	99.60
	^{110m} Ag	97,9	0.29	99.70
Average over isotopes				99.55
(ТБВ _{HCL})	¹³⁷ Cs	119,2	1.31	98.90
	¹³⁴ Cs	61,6	0.7	98.86
	⁶⁰ Co	275,6	2.48	99.1
	^{110m} Ag	97,9	0.98	99.0
Average over isotopes				98.96

Analysis of the Table 11.1 data shows that efficiency of the filters on the basis of modified basalt fibers is considerably higher in comparison with the filters on the basis of non-modified basalt fiber.

Efficiency of filters on the basis of modified basalt fibers (ТБВ_{H2SO4} and ТБВ_{HCL}) manufactured by various methods is at first glance rather approximately identical. However actually even basis points of efficiency of clearing of radioactive aerosols play here essential role, because very stringent requirements are imposed to air cleaning systems at nuclear power plants.

12. Manufacture and testing of industrial filtration units used at NPP

In ventilation systems of nuclear power plants standard filter blocks are used consisting of bearing corrugated sheets located along the air stream with both sides covered by filtering fabric. The area of filtering material is 23 m². The block case is made of nonflammable plywood or other material; the sizes are specified in Fig. 12.1.

We have prepared filtering material from the leached basalt fiber (processed by the above-stated way) on the gauze basis. The processed basalt fiber was applied to on the gauze basis sized approximately 22.5 m²; the weight of the applied fiber was 910 g.

As bearing planes, corrugated sheets from fiber glass were used. In such a manner two blocks were manufactured.

When designing filtering units, the following basic requirements were particularly taken into account:

1. Whenever possible, filters should mounted in the case so that the air flow with radioactive particles press them to seals.
2. At horizontal arrangement of filters it is necessary to direct air flow from top to down to keep the dust deposit inside the installation – is should not move at servicing.
3. The case should have as few "pockets" (where dust could accumulate) as possible.
4. Free assess to the filter case should be provided from all sides.
5. Dust holding capacity of filters should be high enough to continuous operation of the installation without special supervision during a reasonable period of time.

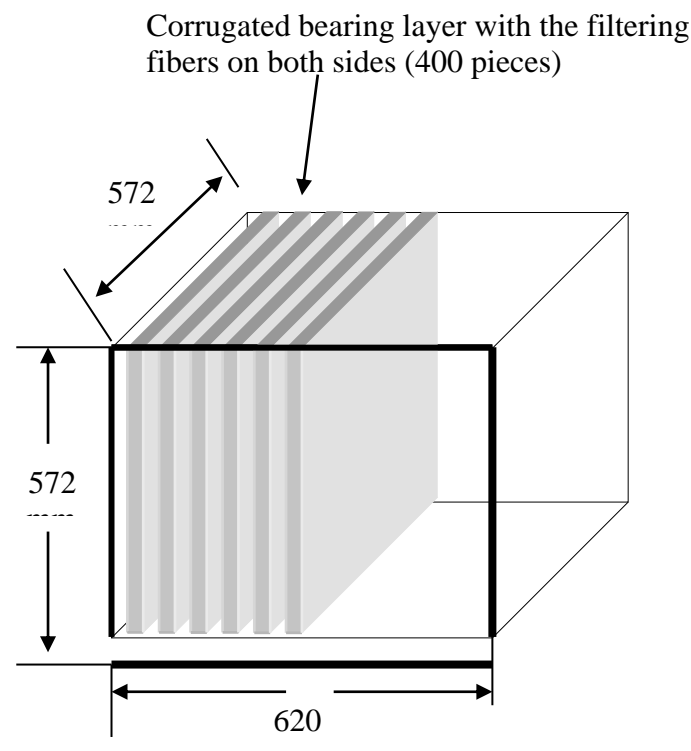


Fig. 12.1 Size of the standard filtering block used for cleaning of air from radioactive aerosols in ventilation systems of NPP.

Research of cleaning efficiency of the filtration blocks made in form of industrial samples using the filtering material obtained by leaching using sulfuric and hydrochloric acids

was continued. The filtration blocks located in the ANPP ventilation system V2 were filled with filtering material of two types: $TBF_{H_2SO_4}$ and TBF_{HCL} .

The gauze based filtering material (super-thin basalt fiber) was folded in zigzag fashion, and the goffered base layer from more rigid material were inserted into the folds. This method allowed increasing the filtering surface to 200-300 m² in 1m³ of the case. As far as stringent requirements are placed upon the filters intended for cleaning of the NPP ventilation air (radioactive aerosols), the folded lateral edges of the filtration material and lateral edges of the goffered plates were rigidly attached to two internal case surfaces. External surfaces (gauze edges of the first and last folds) were also attached to two other internal surfaces of the filter case.

The dirty air flow enters the filter through the channels (cavities of the goffered input separating elements) and - after passing the filtering material - leaves the filter through the cavities of goffered output separating elements. In this manner hermetization of filtering material in the case of blocks is provided.

Both blocks were mounted in V2 ventilation system. Air consumption in this system was 12260 m³/hr.

For the purpose of determination of cleaning efficiency, measurements of aerosols activity in air before and after filtering blocks were begun. Because of low activity of aerosols at the moment, the obtained results were not very representative. The cleaning factor was approximately 0.92-0.94. At the Armenian NPP it is supposed to carry out planned preventative maintenance in October and November. Usually during this period the aerosols activity sharply increases, therefore obtaining of rather correct results is expected.

From October 2010 and till the project end, at the Armenian NPP measurements and calculations of cleaning efficiency were carried out for standard filtering units on the basis of modified basalts. Below, data for these units over the whole operation period are presented.

"Data on cleaning efficiency of radioactive aerosols filtering units (on the basis of modified basalt fibers) installed in B2 ventilation system of Armenian NPP"

Measurement date	Fiber obtained by sulfuric (H ₂ SO ₄) leaching of thin basalt fibers (TBF _{H₂SO₄})	Fiber obtained by hydrochloride leaching of thin basalt fibers (TBF _{HCL})
	Efficiency in %	Efficiency in %
15.10.10	98,6	99,7
01.11.10	98,1	99,6
15.11.10	98,9	99,4
01.12.10	98,2	99,6
18.12.10	98,6	99,3
18.01.11	98,8	99,5
01.02.11	98,8	99,5
15.02.11	98,4	99,7
01.03.11	98,9	99,7
15.03.11	98,2	99,5
01.04.11	98,4	99,7
15.04.11	98,6	99,8
02.05.11	98,2	99,4
18.05.11	98,7	99,8
01.06.11	98,5	99,6
15.06.11	98,7	99,8
Average	98.4	99.6

The data analysis has shown that cleaning efficiency of the investigated units meets the requirements of “Radiation safety regulations of Armenian NPP”. The obtained data reveal that the investigated filtering units operate stable; the cleaning efficiency makes from 98.4 to 99.6% that is comparable to the standard filtering units on the basis of Petrjanov fabric. Moreover, fiber obtained by sulfuric leaching is more efficient.

13. Development of technological cycle of production of BSTF based filters. Obtaining the license for operation of BSTF based filters. Acquisition of patent.

Detailed inspection and study of technological process of manufacturing of basalt fiber at the enterprise was carried out.

Information on the equipment (characteristics, drawings, temperature modes, etc.), used in the course of the whole process was collected. Analysis of works regulations for all process components was carried out.

Possibilities and methods of introduction of the developed ways of chemical modification (by leaching using sulfuric and hydrochloric acids) in the enterprise work cycle were discussed.

Characteristics of the initial raw materials used for manufacture of basalt fibers were specified. Information on resources of these raw materials in Armenia was obtained. It was revealed that natural resources of basalt in Armenia are sufficient for producing large amounts of target material.

Analysis of the information necessary for development of corresponding documents specified in the list of the State Committee on Regulation of Nuclear Safety of PA, was carried out to obtain the license for operation of the super-thin basalt fiber based filters at the Armenian NPP. Complete list of the documentation and the materials necessary for obtaining of the license for operation of the super-thin basalt fiber based filters at the NPP was prepared and completed after consultations with leading experts of State Committee on Radiation and Nuclear Safety.

Description, features, operating principle, advantages of filters from super-thin basalt fiber

A new method for leaching of super-thin basalt fiber (STBF) is offered. All standard procedures on obtaining the patent titled "Method for obtaining of a sorbent for cleaning gases and radioactive aerosols" were fulfilled. The patent N° AM 20110016 is validated by the Armenian Intellectual Property Administration.

The offered method allows doubling the sorption characteristics of filtering material in comparison with the known methods of leaching, which promotes an increase of the capture in factor of radiation aerosol particles.

The filtering material manufactured from the leached basalt fiber according to the proposed method was used in standard filtering blocks of the ANPP ventilating system. This filtering material was installed in the filter block where earlier offered structure modifications were carried out, namely, increase in packing frequency with reduction of goffer amplitude.

The manufactured blocks of new filters were fixed in ventilating system V2 of the Armenian nuclear power plant. They replaced serial filters D-23.

As a result of the substitution, cleaning efficiency has improved and reached the values, which corresponds to IAEA requirements.

The filter operation is based on capture and entrapping of highly active aerosol particles that move in air low under high pressure. Thanks to increase in specific working surface of the offered filters (having the same sizes as Petrjanov filters) due to structure modifications, increase of the particle capture factor is provided.

Other advantages of the developed filters include increased mechanical durability, stability to chemical influences (absence of formation of harmful flammable gases that takes place in Petrjanov filters used in nuclear power plants), thermal stability (to 750°C in usual mode and even more temperatures at short-term exposure), durability, moisture resistance. At the end of a certain performance period Petrjanov filters break down completely due to

degradation of plastic loading material and can not be recovered, whereas our filters on the basis of super-thin basalt fibers - according to preliminary results – are subject to regeneration. The offered filters, which manufacture is based on local raw materials are cost-effective, their manufacture is much more lower in cost than others, used now in NPPs.

To optimize such important indicator of working efficiency as flow resistance, it is necessary to add fibers of different thickness to usual filters, whereas our STBF proposed as working material contain - owing to their manufacture peculiarities – fibers of different thickness: 80% from 1 to 3 micron and 20% less than 20 micron.

3. RESULTS

During the Project implementation, the following results were obtained:

1. Physical and chemical regularities of behavior of wide spectrum aerosols during filtration through filtering materials were studied.
2. Pilot series of filter materials for operation in the ANPP ventilation system were manufactured.
3. Effect of chemical treatment on electro-physical properties of super-thin basalt fiber (was investigated).
4. Mathematical models of the filtration process were developed.
5. Real size distribution of aerosols in the ANPP atmosphere was determined.
6. Experimental device for investigation of efficiency of the tested filtration materials was developed.
7. Industrial filtration units used in NPP were manufacture and tested using filtering materials from chemically modified basalt fibers.
8. Technological cycle of production of STBF based filters was developed. Patent was granted.

4. CONCLUSION

The cleaning efficiency of the manufactured industrial filtration units meets the requirements of "Radiation safety regulations of Armenian NPP". The obtained data reveal that the investigated filtering units operate stable; their cleaning efficiency makes from 98.4 is comparable to that of the standard filtering units on the basis of Petrjanov fabric.

5. COMMENTS

It is intended to use (starting from the next 2012 year, after obtaining permissions from the Armenian Nuclear Regulating Authority) the developed modified super-thin fiber basalts for air cleaning from radioactive isotopes in normal operation regime of Armenian NPP.

Attachment

- 1: **"Study of physical regularities in behavior of a wide spectrum of aerosols when filtering using filtration materials"**
R. M. Avagyan, G. H. Haroutyunyan, V. V. Harutyunyan, V. S. Bagdasaryan, E. M. Boyakhchyan, V. A. Atoyanyan, K. I. Pyuskyulyan, M. Gerchikov
PROCEEDING of the Yerevan State University, Physical and Mathematical Sciences, N 3, 51-56 2010.

The behavior of aerosol particles was studied at filtration through super-thin basalt fibers. Diffusion and inertial effects were investigated at the particle sedimentation using theoretical models for fiber filters taking into account the aerosol gas capture factor. Composition of radioactive aerosols was analyzed over the period of Armenian NPP operation

Armenian Journal of Physics, 2010, vol. 3, issue 3, pp. 187-194

**ELECTRO-PHYSICAL PROPERTIES OF SUPER-THIN BASALT FIBERS
ON THE BASIS OF ARMENIAN BASALT ROCKS
BEFORE AND AFTER CHLORHYDRIC ACID TREATMENT**

S. K. Nikoghosyan¹, A. A. Sahakyan¹, V. B. Gavalyan¹, V. V. Harutyunyan¹, A. S. Hovhannisyanyan¹, V. A. Atoyanyan², K. I. Puskulyan², and M. Gerchikov³

For the first time, electro-physical parameters of super-thin basalt fibers (STBF) on the basis of Armenian basalt rocks are measured before and after chlorhydric acid treatment. It is shown that specific resistance and dielectric parameters of super-thin basalt fibers change essentially after chlorhydric acid treatment. It is revealed from thermogravimetric and other investigations that the probable cause of the change is the increase in total amount of pores and modification of the share of pores of various sizes in STBF followed by the increase of absorption of water molecules from the ambient medium. It is shown, in particular, that the obtained results (in both alternating and constant fields) can be interpreted within the framework of dipole-relaxation mechanism of polarization of water molecules in STBF pores.

S. K. Nikoghosyan, A. A.Sahakyan, V. B. Gavalyan, V. V. Harutyunyan, A. S. Hovanisyan, V. A. Atoyan, K. I. Puskulyan, M. Gerchikov, N. Hakobyan

The influence of hydrochloric acid treatment and temperature on the electro-physical properties of super-thin basalt fibers, Central European Journal of Physics, pp.1482-1487, 2011. **Cent. Eur. J. Phys. V.9, N6 (2011) pp. 1482-1487.**

□ Electro-physical parameters of super-thin basalt fiber (STBF) from Armenian basalt rocks are measured before and after hydrochloric acid treatment. It is shown that specific resistance and dielectric parameters of super-thin basalt fiber change essentially after hydrochloric acid treatment. The temperature dependence of these parameters was studied too. The probable cause of the change is an increase in the total amount of pores and modification of the share of pores of various sizes in STBF, followed by an increase of absorption of water molecules from the ambient medium. The results (in both alternating and direct electric fields) are interpreted within the framework of the dipole-relaxation mechanism of the polarization of water molecules in STBF pores.

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Electro-physical properties of super-thin basalt fiber chemically modified by sulfuric acid

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The influence of sulfuric acid treatment on the electro-physical properties of super-thin basalt fiber (STBF) on the basis of Armenian basalt rocks was studied. Specific electric resistance for direct ρ_{dc} and alternating ρ_{ac} currents, dielectric parameters of ε' and ε'' were measured. It is shown that specific resistance and dielectric parameters of super-thin basalt fiber change essentially after sulfuric acid treatment. The temperature dependences of these parameters were studied too and their non-monotonic behavior was observed. The probable variation of mentioned STBF parameters is explained by different water absorption capacity of pores in result of acid treatment.

Attachment

2:

ELECTROPHYSICAL PROPERTIES OF THE MODIFIED SUPERTHIN BASALT FIBER

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The superthin basalt fiber (STBF) is characterized by high thermal-insulating and electrical-insulating properties and serves as a good adsorbent in highly effective filters for cleaning of air from various gases and aerosols. However physical properties of STBF are poorly known, which is the basic obstacle to their wider use. This paper presents for the first time the results of measurements of electrophysical parameters of initial (sample 1) and chemically modified Armenian STBF (sample 2) with fiber diameter $d < 10$ micron in air at room temperature. Also, specific electric resistance for constant (ρ_{dc}) and alternating (ρ_{ac}) current as well as dielectric permeability coefficient (ϵ') and dielectric losses (ϵ'') within the frequency range from 200 Hz to 1 MHz are determined. It is revealed that special treatment of the sample in the hydrochloric acid solution results in reduction of ρ_{dc} and ρ_{ac} by 3-4 order of magnitude and increase of ϵ' 4.5 times and ϵ'' more than 500 times. It is also revealed that after switching on of constant electric field, ρ_{dc} shows relaxation character: at first it increases quickly and then comes to saturation slowly. It is determined that ρ_{dc} relaxation time grows from two minutes for sample 1 to several hours for sample 2. It is found that increase of ρ_{dc} before stabilization is no more 60 % of the initial value for sample 1 and much more higher for sample 2. Gravimetric research of initial and chemically treated samples in the sorption regime has shown that the obtained results are basically caused by presence of water molecules [1] in them. Samples 1 and 2 contain 0.4 and 15 weight % of water accordingly, and it is located in pores of the various sizes. After modification, increase of both total volume of sorption pores and percentage of macro and micro pores [1] more than 4 times takes place due to reduction of mesopores share. Decrease in electrophysical parameters (ρ_{ac} , ϵ' , ϵ'') with a rise in frequency of alternative field specifies that in STBF dipole polarization mechanism works. Significant growth of water content after chemical treatment of STBF gives rise to rely on improvement of its sorption properties relative to aerosol particles, and the measurements of electrophysical parameters could become an appropriate indirect method of determination of adsorption properties.

The work is performed within the framework of ISTC-A1605 Project.

11th Europhysical Conference of Defects on Insulating Materials- PECS, Euroidium 2010, Hungary 12-16 July, p. B110

HIGHLY EFFECTIVE FILTERS ON THE BASIS OF SUPER-THIN BASALT FIBERS FOR CLEANING OF RADIOACTIVE AEROSOLS

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From the viewpoint of environmental pollution by NPPs operating in normal mode, of a prime interest are sorbent-filters on the basis of modified (chemically processed by acid solutions) super-thin basalt fibers, which promote increase of sorption capacity in respect of active gases and radionuclides and are used in the systems of gas-aerosol cleaning of NPP nuclear reactors as well in chemical industry for cleaning technological gases and radioactive aerosols. To provide radiation safety of Armenian NPP, capture of air-suspended radioactive aerosols was carried out. The used super-thin basalt fibers are macro-porous medium with very complex geometrical characteristics. In this connection very actual and critical is the filtration process modeling that depends on both the sizes of radioactive particles and from structural properties of the filters. Estimations have shown that the presence of electric charge on super-thin fibers results in polarization of weighed particles moving in flow and their attraction to the fiber surface.

Calculation of electrostatic effects is carried out in the model system, because in real filters the super-thin fibers can have the noncircular cross-section and higher uncertainty of charge distribution through the filter thickness. The results of research have shown that the process radioactive aerosol deposition on fibers is characterized by high capture factor, which depends on the filter parameters, gas flow conditions and particle sizes.

The work is performed within the framework of ISTC-A1605 Project.

8th International Conference, Nuclear and Radiation Physics , September 20-23,2011,Almaty, Kazarhstan,p.270.

Attachment 3: Information on patents and copy rights

A new method for leaching of super-thin basalt fiber is offered. All standard procedures on obtaining the patent titled “Method for obtaining of a sorbent for cleaning gases and radioactive aerosols” were fulfilled.

The invention is aimed at increasing sorption capacity of the sorbent by means of chemical treatment, leaching of basalt fiber using chlorhydric and sulphuric acid solutions; it can be used in gas-aerosol cleaning systems.

The patent N^o **AM 20110016** is validated by the Armenian Intellectual Property Administration. The offered method allows doubling the sorption characteristics of filtering material in comparison with the known methods of leaching, which promotes an increase of the capture factor of radiation aerosol particles by 99. 95%. The filtering material manufactured from the leached basalt fiber according to the proposed method was used in standard filtering blocks of the ANPP ventilating system. The manufactured blocks of new filters were fixed in ventilating system V2 of the Armenian nuclear power plant. They replaced serial filters D-23. As a result of the substitution, cleaning efficiency has improved and reached the values, which corresponds to **IAEA** requirements.