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# ANALYSIS OF THE TEMPERATURE REGIME OF OPERATION OF A FILTERING UNIT

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*The temperature regime of a filtering unit being cooled after an accident at a nuclear power plant is considered. A mathematical model is developed; the model is based on three-dimensional equations of thermohydrodynamics and takes into account heat-transfer mechanisms (convection, heat conduction, and radiation). For the unit variants considered, the maximum value of temperature in the sorbing module is less than* 300°C, *and the temperature reserve is* 20–50°C.

**Key words:** *filtering unit, NPP safety, natural heat convection, thermal conductivity, heat transfer.*

**Introduction.** A passive system of filtration of intershell space, which is one of the regular safety systems for nuclear power plants (NPPs) of new generation, is designed for purification and disposal of the gas–vapor medium from the intershell space of the NPP containment prior to outflow of this medium into the atmosphere in the case of accidents with failure of all sources of a.c. power supply [1, 2].

There are three basic regimes of the passive filtration system during NPP operation: 1) standby mode; 2) operation mode; 3) post-accident mode. In the standby mode, the passive filtration system is switched off; the system input and output are closed, and radioactive substances are not accumulated on the filtering modules. In the operation mode, the input and output of the system are open, and a gas–vapor medium containing radioactive species enters the filtering unit from the intershell space. When the gas–vapor medium passes through the filtering modules, radioactive substances are absorbed on filtering materials and are accumulated there. The heat released by radionuclides during their decomposition results in heating of these materials. In the post-accident mode, the passive filtration system is in a closed state. The gas–vapor mixture from the intershell space does not enter any longer, but the heat released by absorbed radionuclides continues to heat the filtering materials.

The sorption capacity of the filtering materials depends on their temperature; therefore, it is necessary to organize heat removal from the filtering modules in the operation and post-accident modes; this heat removal should be sufficient for the temperature of the sorbing agents to stay below a prescribed value. The thermal aspects of the post-accident mode of cooling of one promising variant of the filtering unit (FU) are considered in the present paper.

**Filtering Unit.** The filtering unit, in which radionuclides are accumulated and from which the heat released during radionuclide decomposition is removed, consists of 12 sections acting in parallel. Each FU section is a vertical metallic housing with an aerosol filter and a sorbing module aligned in the direction of air motion (Fig. 1).

The aerosol filter consists of Carbopon layers between two coaxial cylinders. (Carbopon is a filtering material made of carbon-based fabric.) The layers are aligned in the vertical direction and are stowed helically. The aerosol filter is fixed on the base, which completely blocks the flow through the section housing outside the filter. The bottom of the internal cylinder is also closed.

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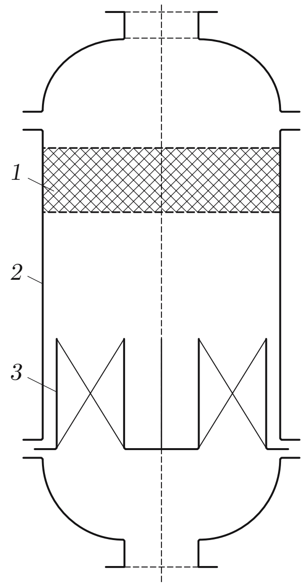


Fig. 1. FU section: 1) sorbing module; 2) housing; 3) aerosol filter.

The sorbing module is a bed of a "fizkhimin" silica-gel-based granulated sorbent with a total thickness of the layer equal to 250 mm. The porosity of the sorbent layer is 0.6, and the granule size is 3 to 6 mm.

In the post-accident regime, the heat release is 175 W on the filtering surface of the aerosol filter and 833 W on the sorbing surface. If the maximum temperature in the sorbing module exceeds 300°C, it becomes ineffective. Thus, the task is to prove that the FU structure proposed ensures heat removal that prevents excessive heating.

The temperature regime of the filtering unit was analyzed within the framework of a mathematical model based on three-dimensional equations of turbulent motion of a compressible gas in porous media, with the use of experimental data obtained for a full-scale model.

**Basic Experimental Results.** The effective thermal conductivity of the sorbent layer is one of the most important parameters determining the temperature regime of FU operation. It is difficult, however, to calculate this parameter theoretically; hence, experimental results were used for its estimation.

The thermal regime of the filtering unit during its cooling after an accident was studied with a full-scale model of the FU section made at the test complex of the closed joint-stock company "Progress-Ekologiya" in Obninsk. The unit (Fig. 2) consisted of a housing, a model of the aerosol filter, and a sorbing module. Volume heat release in the sorbent layer was modeled by an electric heater shaped as a flat disk and mounted in the middle of the sorbent layer. The temperatures of the gas, sorbent, and inner and outer surfaces of the wall were measured by thermocouples installed at different points of the model.

Based on the experimental distribution of temperature in the sorbent layer, we solved an inverse two-dimensional problem of heat conduction with a heat source and boundary conditions of the first kind. An effective value $\lambda_{\text{eff}} = 0.36$ W/(m · K) was chosen by the trial-and-error procedure, which provided the best agreement between numerical and experimental results. After that, an attempt was made to find the dependence of the effective thermal conductivity of the sorbent bed on temperature under the assumption that this dependence is approximated by straight lines on several temperature intervals. The criterion for choosing the approximation formula was the deviation of the calculated temperature in the sorbent layer from experimental data. As a result, the following dependence was chosen:

$$\lambda_{\text{eff}} = \begin{cases} 0.2208 + 2.73418 \cdot 10^{-4} T, & T \leqslant 149^\circ\text{C}, \\ 0.14533 + 7.81 \cdot 10^{-4} T, & 149^\circ\text{C} \leqslant T \leqslant 228^\circ\text{C}, \\ -0.03 + 1.55 \cdot 10^{-3} T, & 228^\circ\text{C} \leqslant T \leqslant 300^\circ\text{C}, \\ 0.83826 + 4.24 \cdot 10^{-3} T, & 300^\circ\text{C} \leqslant T \leqslant 386^\circ\text{C}. \end{cases} \tag{1}$$

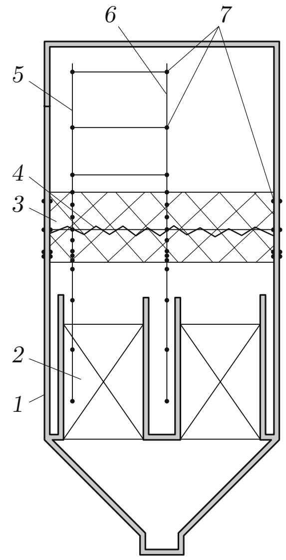


Fig. 2. Full-scale FU model: 1) housing; 2) aerosol filter; 3) sorbent; 4) electric heater; 5) side probe; 6) central probe; 7) thermocouples.

The temperature distribution in the sorbent layer with heat-removing steel ribs, which were mounted to increase the effective thermal conductivity in the sorbing module, was also studied in experiments. For this case, we also determined a constant value of the effective thermal conductivity $\lambda_{\text{eff}} = 0.48$ W/(m · K) and the temperature dependence

$$\lambda_{\text{eff}} = \begin{cases} 0.3208 + 2.73418 \cdot 10^{-4}T, & T \leqslant 149°\text{C}, \\ 0.24533 + 7.81 \cdot 10^{-4}T, & 149°\text{C} \leqslant T \leqslant 228°\text{C}, \\ 0.92751 + 5.93 \cdot 10^{-3}T, & T \geqslant 228°\text{C}. \end{cases} \tag{2}$$

**Mathematical Model of Heat Transfer in the FU Section.** Natural convective flows start to develop owing to heat release in the sorbing module and aerosol filter and owing to heat removal to the walls of the FU section, which are cooled from outside. The most intense flows are observed in the upper part of the section (above the sorbing module), because the gas in this region is heated from below and cooled from above. In the lower part of the section (under the aerosol filter), vice versa, natural heat convection degenerates, because the heat is released on the top, and heat transfer to the section walls in this region occurs through molecular thermal conductivity of the gas.

In addition to the gas thermal conductivity, the granulated sorbent layer also possesses the effective thermal conductivity in the solid phase. For this reason, there is additional heat transfer in the sorbing module to the side walls of the section adjacent to the module and also to the lower and upper boundaries of the module.

Emission from the heated surfaces of the sorbing module and aerosol filter to the FU section walls is another mechanism of heat removal in the system considered.

The mathematical model of heat-transfer processes in the FU section is based on three-dimensional unsteady equations for a viscous compressible fluid flow in a porous medium:

— continuity equation

$$\frac{\partial \beta_V \rho}{\partial t} + \frac{\partial \beta_{x_j} \rho u_j}{\partial x_j} = 0; \tag{3}$$

— momentum conservation equation

$$\frac{\partial \beta_V \rho u_i}{\partial t} + \frac{\partial \beta_{x_j} \rho u_i u_j}{\partial x_j} = -\beta_V \frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\Big[\mu \beta_{x_j}\Big(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\Big)\Big]$$
$$-\frac{2}{3}\,\delta_{ij}\,\frac{\partial}{\partial x_j}\Big[\beta_{x_j}\Big(\mu\,\frac{\partial u_k}{\partial x_k} + \rho k\Big)\Big] + \beta_V F_{x_i} - \beta_V \rho g_i; \tag{4}$$

— energy conservation equation

$$\frac{\partial \beta_V \rho h}{\partial t} + \frac{\partial \beta_{x_j} \rho u_j h}{\partial x_j} = \frac{\partial}{\partial x_j}\Big(\frac{\mu}{\sigma}\,\beta_{x_j}\,\frac{\partial h}{\partial x_j}\Big) + \beta_V (q_V + q_{\rm ex}). \tag{5}$$

Here $\rho$ is the gas density, $u_i$ is the component of gas velocity, $u_j$ is the air velocity, $p$ is the pressure, $h$ is the gas enthalpy, $k$ is the turbulent kinetic energy, $\mu$ is the viscosity, $\sigma$ is the Prandtl number, $F_{x_i}$ are the components of the force of gas friction on the porous medium, $g_i$ is the acceleration of gravity, $q_{\rm ex}$ is the intensity of heat transfer between the gas and the porous structures, and $q_V$ is the volume heat release.

The presence of porous regions, various internal structures, and constrictions is taken into account by the coefficients $\beta_V$ and $\beta_{x_i}$ ($\beta_V$ is the volume fraction occupied by the gas and $\beta_{x_i}$ is the fraction of the cross section perpendicular to the flow direction $x_i$, which is free from the solid phase). The volume and surface fractions can vary from zero (complete blockage) to unity (completely open area). Equations (3)–(5) include the viscosity $\mu = \mu_l + \mu_t$ ($\mu_l$ is the physical viscosity and $\mu_t$ is the turbulent viscosity, which characterizes the intensity of dissipative processes due to turbulence). We determined $\mu_t$ by using a two-parameter $k$–$\varepsilon$ model of turbulence ($\varepsilon$ is the dissipation rate) [3, 4]. For each of the quantities $k$ and $\varepsilon$, we solved the equation of convective diffusion with the corresponding source terms, which describe the rate of generation of turbulent energy on mean velocity gradients, rate of generation of turbulent energy by buoyancy forces, and the rate of volume dissipation of turbulent energy.

The equation of turbulent kinetic energy transfer has the form

$$\frac{\partial \beta_V \rho k}{\partial t} + \frac{\partial \beta_{x_j} \rho u_j k}{\partial x_j} = \frac{\partial}{\partial x_j}\Big(\frac{\mu_t}{\sigma_k}\,\beta_{x_j}\,\frac{\partial k}{\partial x_j}\Big) + \beta_V (G_k - \rho\varepsilon + G_b), \tag{6}$$

and the equation of turbulent kinetic energy dissipation rate transfer is

$$\frac{\partial \beta_V \rho \varepsilon}{\partial t} + \frac{\partial \beta_{x_j} \rho u_j \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\Big(\frac{\mu_t}{\sigma_\varepsilon}\,\beta_{x_j}\,\frac{\partial \varepsilon}{\partial x_j}\Big) + \beta_V\,\frac{\varepsilon}{k}\,[(G_k + G_b)(1 + C_3 R_f)C_1 - C_2\rho\varepsilon], \tag{7}$$

where

$$G_b = \mu_t g_j\,\frac{1}{\rho}\,\frac{\partial \rho}{\partial x_j}, \qquad G_k = \mu_t\Big(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\Big)\frac{\partial u_i}{\partial x_j}, \qquad R_f = -\frac{G_b}{G_k}; \tag{8}$$

$$\mu_t = C_\mu \rho k^2/\varepsilon, \tag{9}$$

$C_1 = 1.44$, $C_2 = 1.92$, $C_\mu = 0.09$, $\sigma_k = 1$, $\sigma_\varepsilon = 1$, and $\sigma_t = 1$ form the known set of constants of the $k$–$\varepsilon$ model of turbulence. Equations (6) and (7) also involve the equation of state of an ideal gas.

System (1)–(9) was used to analyze the air flow inside the filtering unit shown schematically in Fig. 1.

*Modeling of the Sorbing Module.* The sorbing module is a layer of a granulated material based on silica gel. Heat release occurs on the granule surface, part of heat being removed to the air flow and part of heat being spent on granule heating. Heat transfer in the sorbent layer was modeled, based on the principles of mechanics of multiphase media [5]. Sorbent granules can be considered as the phase (skeleton) with a volume fraction $1 - \beta_V$, and the air inside the layer can be considered as the phase with a volume fraction $\beta_V$ ($\beta_V$ is the porosity of the layer of the granulated material). Assuming the temperature of air in the intergranular space to be close to the temperature of granules, we can derive the equation of heat transfer in the layer

$$\frac{\partial (\rho c)_{\rm eff} T}{\partial t} + \frac{\partial \beta_{x_j} \rho_a c_{p,a} T u_j}{\partial x_j} = \frac{\partial}{\partial x_j}\Big(\lambda_{\rm eff}\,\frac{\partial T}{\partial x_j}\Big) + q_V, \tag{10}$$

where $(\rho c)_{\rm eff} = (1 - \beta_V)\rho_s c_s + \beta_V \rho_a c_{p,a}$, $\lambda_{\rm eff} = \lambda_{\rm eff,s}(1 - \beta_V) + \lambda_{\rm eff,a}\beta_V$, $\rho_s$ is the sorbent density, $c_s$ is the specific heat of the sorbent, $\rho_a$ is the air density, $c_{p,a}$ is the specific heat of air at constant pressure, $\lambda_{\rm eff,s}$ is the effective thermal conductivity of the skeleton in the sorbent bed owing to emission and contact thermal conductivity, and $\lambda_{\rm eff,a}$ is the effective thermal conductivity of air in the sorbent bed owing to molecular and convective thermal conductivity.

It follows from Eq. (10) that heat transfer inside the bed occurs either owing to convective air flow or owing to effective thermal conductivity. To describe the motion of air in the bed, we used the equations of conservation of mass (3) and momentum (4) with allowance for the force of air friction on the bed. The friction force was determined by the formulas derived in [6]. The motion of air in the bed being assumed to be laminar, the corresponding values of molecular transfer coefficients were used in these equations.

*Modeling of the Aerosol Filter.* In the steady-state regime, the heat (175 W) released in the aerosol filter passes into the air; hence, the equation of energy of the air in the area occupied by the aerosol filter is supplemented by the volume heat release $q_V = 175/V$ W/m$^3$, where $V$ is the filter volume.

For the friction force between the air in the aerosol filter and the filtering surfaces, we used a quadratic law in terms of velocity. The friction coefficient was determined on the basis of available experimental data on the pressure difference in the aerosol filter.

*Radiative Heat Transfer.* The mathematical model takes into account the heat transfer due to radiation between the surfaces of various internal structures of the examined object. For this purpose, each structure considered (housing walls, sorbing module surfaces, and aerosol filter) was divided into elementary areas. The radiative heat flux between the elementary areas is calculated by the formula [7, 8]

$$Q_{i,j-i1,j1} = \varepsilon_r \sigma_0 (T_{i,j}^4 - T_{i1,j1}^4) S_{ij} \frac{\cos\theta_1 \cos\theta_2}{\pi R_{i,j-i1,j1}^2} S_{i1,j1}, \tag{11}$$

where $i$ and $j$ are the subscripts corresponding to the first elementary area, $i1$ and $j1$ are the subscripts corresponding to the second elementary area, $Q$ is the heat flux, $S$ is the area, $\sigma_0$ is the Stefan–Boltzmann constant, $\varepsilon_r$ is the reduced emissivity, $R$ is the distance between the centers of the elementary areas, $\theta_1$ is the angle between the straight line connecting the centers of the areas and the normal to the area $i, j$, and $\theta_2$ is the angle between the straight line connecting the centers of the areas and the normal to the area $i1, j1$. For the area $i, j$, we performed summation over all areas $i1, j1$ with which radiative heat transfer proceeds:

$$Q_{i,j} = \sum_{i1,j1} Q_{i,j-i1,j1}. \tag{12}$$

The quantity $Q_{i,j}$ is considered as a source term in the heat balance equation for the calculated control volume with the face $i, j$; otherwise, it is taken into account through boundary conditions of the computational domain.

The method used in the present work is based on calculating the radiative heat transfer via quantities characterizing the final effects of heat transfer between the elements of this radiating system. The method is similar to the net radiation method [8]. In contrast to the method of multiple reflections, the method used in the present work does not describe the physical pattern of radiative heat transfer in detail, but yet allows one to take into account the basic effects (including screening by virtue of multiple reflections) and to obtain required numerical data in a simple way.

As the filtering unit is filled by dry air, the assumption that this gas medium is transparent for radiation is justified [7, 8].

*Boundary Conditions.* The no-slip conditions for gas velocity are set on the inner walls of the FU section. The wall temperature is determined from the equality of the heat flux on the inner surface of the walls and the outward heat transfer. To describe the momentum and heat transfer processes in the near-wall region, we use an approach based on introduction of special near-wall functions that relate the parameters in the computational node nearest to the wall to conditions on the wall surface. A universal logarithmic law of the wall is used [3]. The condition on the outer surface of the FU walls is the coefficient of heat transfer to the ambient medium, which is determined by the emission and convection processes.

*Numerical Method.* To solve system (1)–(12), we used a numerical method [9] developed for integrating the Navier–Stokes equations describing essentially subsonic flows of a reacting gas. It should be noted that the development of this numerical method [9] and its application for studying the interaction of three-dimensional unsteady turbulent flows of a reacting gas with water droplets resulted in creation of an IFIS code (interaction of fire and sprinklers) [10], which was used for implementation of the mathematical model proposed here (blocks for the description of radiative heat transfer and motion of air in a porous medium were added).

**Analysis of Experimental Results.** The calculations were performed on a uniform grid with a spatial step in each direction equal to 3 cm. The initial condition was a quiescent gas with a temperature equal to the temperature of the ambient medium, then heat release was added, and the calculations were performed until a steady state was reached (the characteristic time step of integration was 0.015–0.025 sec).

Two series of calculations were performed for the experiment with a standard sorbing module (without steel ribs). A constant effective thermal conductivity $\lambda_{\text{eff}} = 0.36$ W/(m·K) was used in the first series, and the

TABLE 1

Results Calculated on the Basis of Model Experiments

| Calculation variant | $\alpha$, W/(m$^2$·K) | $\lambda_{\mathrm{eff}}$, W/(m·K) | $T_{\max}$, °C |
|---|---|---|---|
| 1 | 5 | 0.36 | 371 |
| | | Formula (1) | 355 |
| 2 | 10 | 0.36 | 356 |
| | | Formula (1) | 350 |
| 3 | 15 | 0.36 | 351.5 |
| | | Formula (1) | 348 |
| 4 (with radiation ignored) | 10 | Formula (1) | 404 |

dependence of the effective thermal conductivity on temperature (1) obtained by processing experimental results was used in the second series. Each series included three calculations with the coefficient of heat transfer from the outer walls of the housing to the ambient medium $\alpha = 5$, 10, and 15 W/(m$^2$·K). Good agreement was reached between the calculations and experiments, especially for $\alpha = 10$ and 15 W/(m$^2$·K). Allowance for the temperature dependence $\lambda_{\mathrm{eff}}(T)$ allowed us to improve this agreement.

An analysis of experimental results with the use of the IFIS code showed that radiation plays an important role in heat transfer from the sorbent layer to the walls of the FU housing. This follows from calculations of the experimental results with radiation being ignored. The maximum temperature in the sorbent layer increased by 48°C and reached 404°C. Heat transfer from the upper surface of the sorbent layer to the housing walls occurs through convection and radiation; under the conditions considered, the contributions of both mechanisms is approximately identical; therefore, artificial interruption of one of them (radiation) leads to only insignificant changes in the calculated temperature profiles. The main mechanism of heat transfer from the lower surface of the sorbent layer is radiation, because natural convection cannot develop under these conditions, and molecular thermal conductivity of the gas is negligibly small. For this reason, drastic deterioration of heat removal from the lower surface of the sorbent layer after interruption of radiation resulted in additional heating of the lower part of the layer; as a result, the calculated values of temperature in this region were much higher than the experimental results.

The calculated maximum temperatures are summarized in Table 1 (the maximum temperature in the experiment was 351°C). Figure 3 shows the calculated and experimental profiles of temperature in the sorbent layer ($h = 0$ corresponds to the middle of the sorbent layer).

In the next experiment, heat-removing ribs were mounted in the sorbent bed, and the volume of the upper part of the housing (above the sorbent bed) was increased. The results of this experiment were calculated by the IFIS code, the dependence of the effective thermal conductivity on temperature (2) was used, and the coefficient of heat transfer to the ambient medium was assumed to be 5 W/(m$^2$·K). The calculated maximum temperature (301°C) turned out to be slightly lower than the experimental value (303°C).

**Analysis of the Filtering Unit.** Calculations of the filtering unit were performed with variations of the coefficient of heat transfer from the housing to the ambient medium, effective thermal conductivity of the sorbent, and the volume of the upper part of the FU housing. The heat release in the aerosol filter was 175 W, the heat release in the sorbent layer was 833 W, and the ambient temperature was assumed to be 70°C.

*Variant* FU-1. We consider an FU with a distance of 150 mm between the lower boundary of the sorbent layer and the upper boundary of the aerosol filter, a distance of 750 mm between the lower boundary of the layer and the lower boundary of the aerosol filter, and a height of the upper part of the housing between the sorbent layer and elliptical cover equal to 500 mm. There are no heat-removing ribs in the sorbing module.

*Variant* FU-2. The FU geometry is the same as in the previous case, but heat-removing ribs are mounted in the sorbing module. The effective thermal conductivity is determined by formula (2).

*Variant* FU-3. We consider the simultaneous effect on the FU temperature regime of the heat-removing ribs in the sorbent bed and of the increase in the height of the upper part of the housing above the sorbent bed by 880 mm.

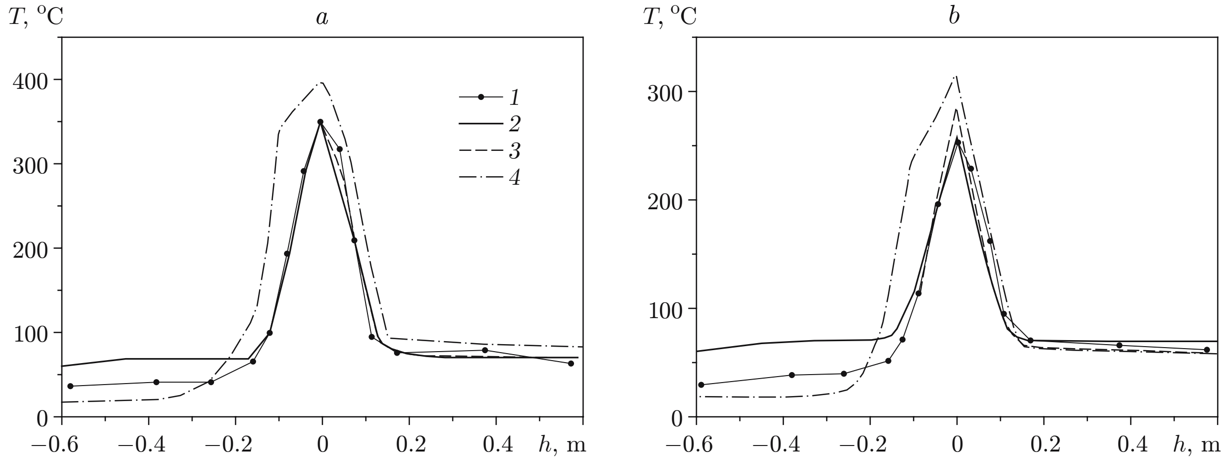


Fig. 3. Experimental (1) and calculated (2–4) distributions of temperature along the central probe (a) and side probe (b) in the sorbent layer: 2) $\lambda_{\text{eff}} = 0.36$ W/(m·K) and $\alpha = 10$ W/(m$^2$·K); 3) $\lambda_{\text{eff}} = f(T)$ and $\alpha = 10$ W/(m$^2$·K); 4) $\lambda_{\text{eff}} = f(T)$ and $\alpha = 10$ W/(m$^2$·K) with radiative heat transfer being ignored.

TABLE 2

Results Calculated for the Filtering Unit

| FU variant | Calculation variant | $\alpha$, W/(m$^2$·K) | $\lambda_{\text{eff}}$, W/(m·K) | $T_{\max}$, °C |
|---|---|---|---|---|
| FU-1 | 1 | 5 | 0.36 | 271 |
| | | | Formula (1) | 281 |
| | 2 | 10 | 0.36 | 255.5 |
| | | | Formula (1) | 270 |
| | 3 | 15 | 0.36 | 250 |
| | | | Formula (1) | 267 |
| FU-2 | 1 | 5 | Formula (2) | 254 |
| | | 10 | | 244 |
| FU-3 | 1 | 5 | Formula (2) | 250 |

The calculation parameters and the maximum temperatures are listed in Table 2. It should be noted that the use of the dependence of the effective thermal conductivity on temperature (1) in the first variant of the filtering unit (FU-1) yields higher values of the maximum temperature of the sorbent for the following reasons. Because of uniform heat release in the sorbent layer under the FU conditions, the temperature regimes in the sorbent bed are less severe than those in the experiment. As a result, the mean temperature of the sorbent layer decreases, and the effective thermal conductivity $\lambda_{\text{eff}}(T)$ also decreases correspondingly. Thus, in FU calculations, the mean value of $\lambda_{\text{eff}}(T)$ is smaller than $\lambda_{\text{eff}} = 0.36$ W/(m·K) obtained in the experiment for higher temperatures. It should be noted that dependence (1) was obtained for a rather wide range of temperatures ($70°\text{C} \leqslant T \leqslant 386°\text{C}$) corresponding to the temperature regime of the filtering unit. For this reason, the use of formula (1) is preferable for FU calculations over the value $\lambda_{\text{eff}} = 0.36$ W/(m·K).

The calculated temperature profiles along the FU centerline are plotted in Fig. 4. The spatial flow pattern and the temperature distribution for FU-3 are shown in Fig. 5.

Let us estimate the accuracy of FU calculations performed. In the calculation with the maximum heating of the sorbent layer in FU-1, we obtain the maximum temperature equal to 281°C. A similar calculation for the experimental unit yields $T_{\max} = 355$°C, the maximum temperature in the experiment being 351°C. As the experiment was performed with an absolutely full-scale model and the calculation scheme of the IFIS code is identical for the experimental unit and FU, the natural maximum temperature of the sorbent layer in FU-1 should stay within 277°C, which provides a more than 20°C reserve (at a temperature of 300°C, the sorbent layer becomes ineffective).

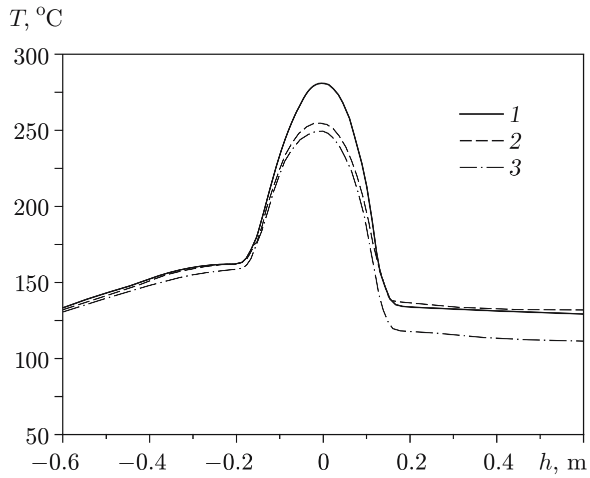


Fig. 4

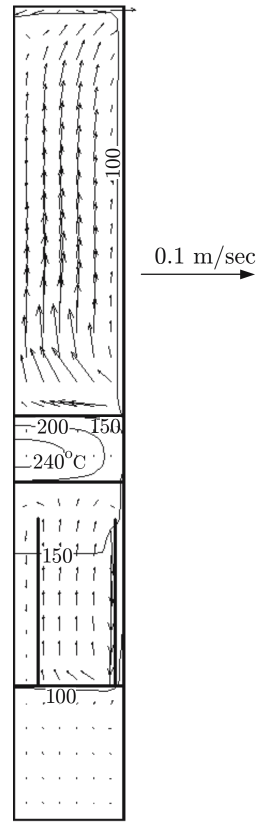


Fig. 5

Fig. 4. Calculated temperature distribution along the FU centerline for $\lambda_{\text{eff}} = f(T)$ and $\alpha = 5$ W/(m$^2\cdot$K): curves 1, 2, and 3 refer to FU-1, FU-2, and FU-3, respectively.

Fig. 5. Distributions of gas velocity and temperature in FU-3.

A similar estimate was also obtained for FU-3. The calculation of experimental results corresponding to FU-3 yields $T_{\max} = 301$°C (in the experiment, $T_{\max} = 303$°C). The maximum temperature of the sorbent layer for FU-3 is assumed to stay within 252°C, and the reserve is approximately 50°C.

**Conclusions.** The process of cooling of a filtering unit after an NPP accident is analyzed. The filtering unit structure variants considered are proved to ensure an acceptable temperature regime for the sorbing module (less than 300°C). A three-dimensional mathematical model of the turbulent gas flow inside the unit housing with allowance for various structural elements, aerosol filter, and sorbing module is developed. The most important parameters exerting a significant effect on the thermal processes in the unit is the effective thermal conductivity of the sorbing module, which is a bed of granules 3–6 mm in size. This parameter was determined by processing experimental data obtained for a full-scale FU model.

The mathematical model proposed is implemented by an IFIS code. Parametric calculations are performed for various variants of the FU structure with variations of the coefficient of heat transfer from the FU housing to the ambient medium and the effective thermal conductivity of the sorbent. For all three FU variants considered, the maximum temperature in the sorbing module stays within 300°C.

The accuracy of the results obtained was estimated by comparing the maximum temperatures in the sorbent obtained in experiments for a full-scale FU model and the results calculated on the basis of experimental data. The deviation between the calculated and experimental values was smaller than 4°C.

Thus, the analysis performed shows that, among the variants considered, FU-1 has the smallest reserve in terms of temperature (≈20°C), and FU-3 with heat-removing ribs mounted in the sorbing module and the height of the upper part of the housing being increased has the greatest reserve in terms of temperature (≈50°C).

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