DOI:10.26565/2312-4334-2024-1-41 ISSN 2312-4334

# THERMOGRAPHIC METHOD OF ACTIVATED CARBON PACKING QUALITY DIAGNOSTICS IN NPP AIR FILTERS

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Received November 1, 2023; revised December 7, 2023; accepted December 12, 2023

The work is devoted to the tasks of safe operation of nuclear power plants, namely the prevention of inert radioactive gases, iodine, and its compounds from entering the air. The latter is particularly dangerous because it can accumulate in the human body. One of the methods of air purification is the use of air filters filled with activated carbon granules that have undergone preliminary treatment of thermal expansion and impregnation. At the same time, there is a problem with evaluating the change in local aerodynamic resistance as a result of the shape change of granules and their compaction when activated carbon is filled into the filter. For this purpose, the model that calculates the spatial field of movement of ventilation gases through a chamber that simulates an adsorber of the AU-1500 type filled with carbon granules was created. To verify the model, it was necessary to develop approaches to the assessment of the topology of the intergranular space and to draw up ideas about the possible inhomogeneities of such topology due to inhomogeneities in the compaction of granules during backfilling and vibration effects during operation. Therefore, an experimental model based on the assumption that air passage channels are spatially contiguous with electric current passage channels if a potential difference is applied to the "input-output" sections was proposed. Clusters of areas with heterogeneous packing by measuring the temperature distribution, which is released in the form of Joule heat were identified. Correlations between the characteristics of the spread of temperature fields and modes of current trans-mission have been established. It is shown that the obtained experimental data correlate with theoretical calculations of the flow of ventilation gases. The created set of methods allows optimization of the aerodynamic characteristics of the filter to improve their functional properties.
**Keywords:** *Thermography; Air filters; Active carbon; Air flow; Current distribution*
**PACS:** 87.63.Hg, 81.05.U.

## INTRODUCTION

The development of technology, industry, and energy security is a key factor in raising people's living standards [1-3]. A lot of attention is paid to the prevention of environmental pollution and, a large number of effective technologies have been developed to reduce the level of pollution, including from industrial enterprises. Thus, one of the components of any industrial enterprise is such engineering structures as ventilation systems, which ensure the necessary sanitary standards in production premises, labor protection, and compliance with the norms of emissions into the environment [3-7]. Particular attention is paid to ventilation systems as the main source of emissions harmful to human health and the environment, industrial waste generated in the chemical, mining, construction, and energy industries, including nuclear [3].

The operation of nuclear power plants is necessarily associated with the need to control emissions and filter radioactive gases. Gaseous isotopes formed by nuclear reactions penetrate through imperfect seals and lead to increased radiation background in the working premises, the danger of which is that radioactive substances can penetrate the human body via the respiratory organs. Since it is impossible to avoid the release of radioactive gases in the first circuit with their subsequent entry into the working premises and then into the environment, iodine, and aerosol filters are used at the stations, which reduce the radiation load by several orders of magnitude. One of the ways iodine enters the coolant and its further spread is the destruction of the shells of heat-dissipating elements due to the manufacturing defects that develop as a result of the passage of high-energy particles, which causes local heating along the track and, as a result, delamination of the material [8, 9]. It is worth noting that even in the conditions of a cold shutdown of NPP power units, due to the fission of $^{235}$U, iodine isotopes are released and penetrate through discontinuities in the shells of nuclear fuel elements into the coolant and then into the environment. Also, the problem of identifying iodine compounds at the NPP, which was in a long-term shutdown is extremely non-trivial. In addition, the peculiarities of the distribution of the mentioned compounds in the conditions of an unprecedentedly long-term shutdown are almost unexplored. Problems

***Cite as:*** M. Azarenkov, V. Lytvynenko, I. Kolenov, O. Haluza, A. Chupikov, V. Sokolenko, O. Roskoshna, M. Kanishcheva, V. Shatov, East Eur. J. Phys. 1, 398 (2024), https://doi.org/10.26565/2312-4334-2024-1-41

of identification of accumulated radionuclides in nuclear energy materials are solved by various methods, among which the most precise are nuclear physical ones [10].

A particular problem is cleaning air flows from radioactive fission products of fuel elements during nuclear power plants (NPP) operation. The main gaseous radioactive components in the air at NPP are isotopes of xenon and krypton, as well as radioactive iodine vapor [11-13]. The $^{131}$I isotope (half-life 8.5 days) is particularly dangerous due to its ability to accumulate in the human body. Also, the permissible rate of volumetric activity of iodine in the air of premises of NPP with constant presence of personnel is $2\cdot10^{-12}$ Ci/l, and when air is released into the atmosphere at 1 operating unit of NPP – $2\cdot10^{-4}$ Ci/day [11]. One of the ways to clean the air from gaseous com-pounds of radioactive iodine is to trap them with sorption-filtering materials. In air emissions from nuclear reactors, radioactive iodine is contained in the form of aero-sols and gaseous compounds: vapors of molecular iodine ($I_2$), hydrogen iodide (HI), iodates, and various organic compounds, in particular, methyl iodide ($CH_3I$) [12-13]. In modern technology, to purify gases from radioactive iodine, various filtering and sorbing materials are used that are capable of capturing aero-dispersed and gaseous products of radioactive iodine. To capture iodine radionuclides in ventilation air flows at nuclear power plants, sorption bulk filters based on active carbons impregnated with various compounds are mainly used: iodides of various metals (K, Al, Zn, Pb, Sn, Ti, Ba); organic substances (derivatives of amines, phenol); silver and its com-pounds, as well as their mixtures [11-13].

One of the urgent tasks is to improve the operational properties of NPP sorption filters, in particular, the quality of filtration and increase the working life. Optimizing the operation of a ventilation system consists of finding a compromise between the cross-section of passage through the sorption material, sorption efficiency, and traction force of the blower. Many works are devoted to this issue [3, 14-19]. One of the ways to improve the above properties is to increase the uniformity of filling the filter layer (activated carbon granules) into the adsorber, which leads to a more uniform distribution of gas flow throughout the volume of the sorbent, more uniform wear, and, accordingly, an increase in service life. Therefore, to control the uniformity of the backfill of activated carbon granules, a simple method of non-destructive express testing is required. This work proposes a thermographic method for visualizing inhomogeneities in the backfill of activated carbon granules. The method is based on the assumption that the channels for the passage of air are spatially adjacent to the channels for the passage of electric current if a potential difference is applied to the "input-output" sections. Clusters of areas with inhomogeneous packing can be identified by measuring the distribution of the temperature released in the form of Joule heat. Next, we consider the research methods used in this work.

## METHODS OF THEORETICAL AND EXPERIMENTAL RESEARCH

To evaluate the capabilities of the proposed thermographic method for diagnosing the quality of the packaging of activated carbon granules and its influence on the distribution of airflow passing through it, computer modeling and comparison of 2 processes in the filter were carried out: 1) distribution of airflow in a carbon filter with homogeneous and non-uniform packaging of granules, 2) distribution of current density and temperature in a carbon filter with homogeneous and non-uniform packing of granules. Next, we will consider the theoretical basis for calculating airflow through a porous medium.

### Method for calculating airflow through a sorbent layer

The sorbent layer is a bath (basket) filled with activated carbon granules. In this work, activated carbon granules were used in the form of cylinders with a diameter of 4 mm and a length of 4-8 mm.

To select the correct mathematical airflow model, it is necessary to predict its nature (laminar or turbulent). To predict the nature of the airflow, a dimensionless value is used - the Reynolds number (*Re*). *Re* is the ratio of the inertial forces to the viscous force [20]. If $Re < Re_{cr}$ then the flow is laminar, but if $Re > Re_{cr}$ then the flow becomes turbulent. The $Re_{cr}$ threshold value depends on the flow geometry. For a porous medium consisting of porous granules it is equal to:

$$R_e = \frac{\rho v_s D_p}{(1-\varepsilon)\mu}, \tag{1}$$

where ρ is the airflow density, $v_s$ is the superficial velocity (the ratio of the volumetric flow rate of the phase to the cross-sectional area), $D_p$ is the cylinder diameter, $\mu$ is the dynamic viscosity of the flow, $\varepsilon$ is the porosity of the granule.

The main characteristics of the porous medium state are the porosity $\varepsilon_p$ and the permeability $k$. When calculating the porosity of a packed medium, the porosity of granules can be neglected and only the intergranular space can be taken into account [21, 22]:

$$\varepsilon_p = \frac{A}{(D_v/D_p)^n} + B, \tag{2}$$

where for cylindrical granules $A$ = 0.9198, $B$ = 0.3414, $n$ = 2, $D_v$ is the filter diameter, $D_p$ is the granule diameter. Work [18] provides formulas for calculating the porosity of packages for granules of various shapes. The formula for estimating the permeability of a porous medium is as follows [23]:

$$k = \varphi_s^2 \frac{\varepsilon_p^2 D_p^2}{180(1-\varepsilon_p)^2}, \tag{3}$$

where $\varphi_s$ is a parameter that takes into account the geometry of the granules.

The concept of the above characteristics and parameters was formulated by Henry Darcy. Darcy's experiments [20] showed that the total flow rate is directly proportional to the total pressure drop divided by the flow viscosity and the permeability of the medium. Darcy's law is widely used for laminar flow, i.e. in cases where $Re < 2000$. In our case, $Re = 3500$, i.e. the flow is turbulent. The equations used for transient and turbulent flow are derived from the basic Darcy equations. This work uses the Brinkman equation [24], which is widely used to analyze transitional flow in porous bulk media. The dependent variables in the Brinkman equations are Darcy's velocity and pressure. Flow in porous media is determined by a combination of the continuity equation and the momentum equation, which together form the Brinkmann equations:

$$\frac{\partial}{\partial t}(\varepsilon_p \rho) + \nabla \cdot (\rho \mathbf{u}) = Q_m, \tag{4}$$

$$\frac{\rho}{\varepsilon_p}\left(\frac{\partial \mathbf{u}}{\partial t} + \frac{1}{\varepsilon_p}(\mathbf{u}\cdot\nabla)\mathbf{u}\right) = -\nabla p + \nabla \cdot \left[\frac{1}{\varepsilon_p}\left\{\mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T) - \frac{2}{3}\mu(\nabla\cdot\mathbf{u})\boldsymbol{I}\right\}\right] - \left(\frac{\mu}{k} + \frac{Q_m}{\varepsilon_p^2}\right)\mathbf{u} + \mathbf{F}, \tag{5}$$

where $\mu$ is the dynamic viscosity of the liquid, $\mathbf{u}$ is the velocity vector, $\rho$ is the flow density, $p$ is pressure, $\varepsilon_p$ is porosity, $\kappa$ is the permeability of the porous medium, $Q_m$ is the flow rate. To take into account the influence of gravity and other volumetric forces, the term $\boldsymbol{F}$ is introduced.

Figure 1 shows the filter model, which was used to simulate the airflow through the sorbent layer.

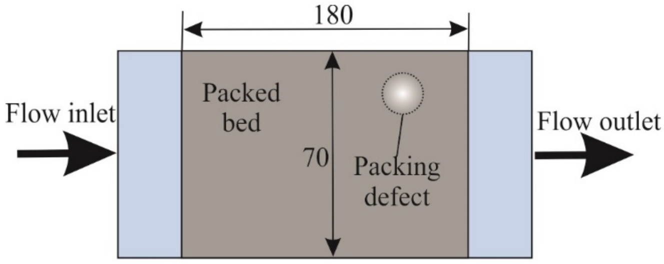


**Figure 1.** Schematic representation of the filter.

The model filter is a cylinder pipe with a diameter of 70 mm and a height of 240 mm. The flow inlet and outlet are at the beginning and at the end of pipe. Activated carbon granules are located in the middle part of the pipe. The layer thickness is 180 mm. The porosity and permeability calculated using formulas (2) and (3) were 0.3414 and $1.67\cdot10^{-8}$ m$^2$, respectively. Next, we will consider a method for calculating the distributions of current densities and the release of Joule heat in the sorbent layer.

**Method for calculating the distribution of current densities and the release of Joule heat in the sorbent layer**

When considering heat transfer in a porous medium at the microscopic level, two heat transfer equations can be established: for the solid and liquid phases. For undeformed stationary solids, the heat transfer equation has the form:

$$\rho C_p \frac{\partial T}{\partial t} - \nabla \cdot (k \nabla T) = \boldsymbol{J} \cdot \boldsymbol{E}, \tag{6}$$

where ρ is the density, $C_p$ is the specific heat capacity at constant stress, $T$ is the absolute temperature, the term $\boldsymbol{J}\cdot\boldsymbol{E}$ characterizes resistive heating (ohmic heating) due to the electric current, where $\boldsymbol{J}$ is the current density and $\boldsymbol{E}$ is the voltage electric field. This term also takes into account electromagnetic surface losses as a heat source.

Figure 2 shows the model according to which the current density and temperature distributions were calculated.

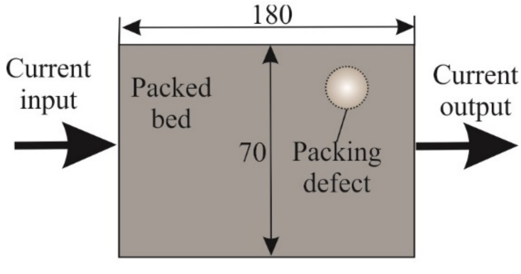


**Figure 2.** Scheme of passing current through the sorbent layer.

To visualize the distribution of airflow passing through the filter between the upper and lower parts of the sorbent, a potential difference is applied. Since both the distribution of airflow velocity and the distribution of current density are related to the quality of packaging (density) of the sorbent, these two parameters must correlate with each other. The correlation should also be displayed on sorbent thermograms and characterize the airflow distribution in the filter.

**An experimental method for identifying inhomogeneity in AC granules packing in air filters.**

For the experiment, a specialized cylindrical flask was constructed, shown in Figure 3a. Activated carbon granules 4 were poured into flask 3, transparent to IR radiation. Next, the compaction procedure and fixation with covers 2 and 5 were carried out. At the same time, denser packing was ensured in the area of lid 5. The current was passed through contacts 1 and 6. Diameter d and height h of the layer of packaged activated carbon were 70 mm and 180 mm, respectively.

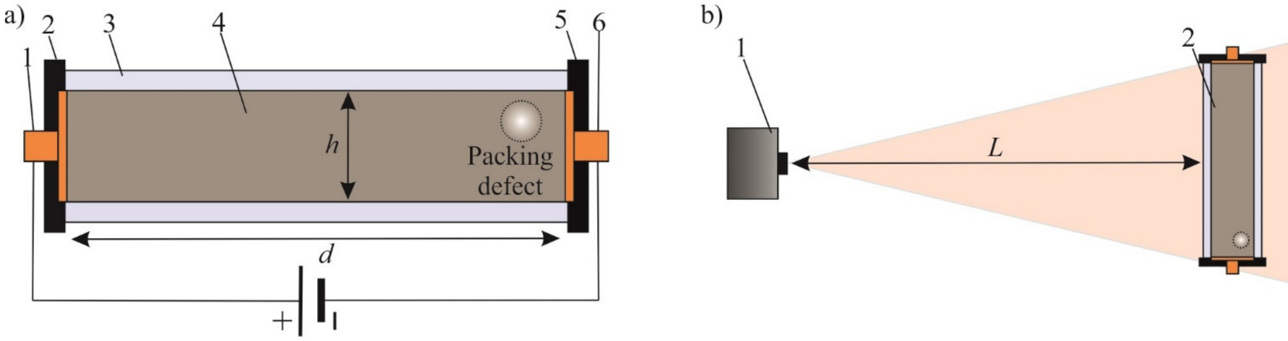


**Figure 3.** Schematic representation of the object under study (a): 1 – + power supply, 2 and 5 – covers, 3 – transparent flask for IR, 5 - activated carbon granules, 6 – – power supply. Experiment scheme (b): 1 – thermal imager, 2 – the object under study

The experimental scheme is shown in Figure 3b. The relative position of the thermal imager (1) and the sample (2) is shown in Figure 3b. A direct current was passed through the volume with activated carbon granules. As the volume warmed up, thermograms were recorded using a Fluke Ti31I thermal imager. Next, we consider the simulation and experimental results.

**SIMULATION AND EXPERIMENTAL RESULTS.**

To qualitatively illustrate the flow distribution in a layer of activated carbon, two packaging options were considered: 1) uniform packaging of activated carbon granules, and 2) non-uniform packing with the decreased density of granules at the top right corner. The calculation results are shown in Figure 4.

Figure 4 shows that in the case of a homogeneous backfill, the flow is uniformly distributed over the entire cross-section of the filter. In the case of non-uniform packaging (Figure 4b), the airflow velocity is higher through an area of lower density and lower through the adjacent filter areas, which should lead to faster filter wear and deterioration in filtration quality. Next, we will consider the results of calculations with current passing through filters.

Two cases with uniform and non-uniform packaging of activated carbon granules in the filter were also considered. In the case of uniform packaging, the electrical conductivity is the same throughout the entire cross-section of the filter. A decrease in packaging density should lead to a decrease in electrical conductivity due to a decrease in the number of contacts between granules. Therefore, in the second case is with gradually decreased conductivity in the top right corner, according to the same law as the packing density of activated carbon granules. The calculation results are shown in Figure 5.

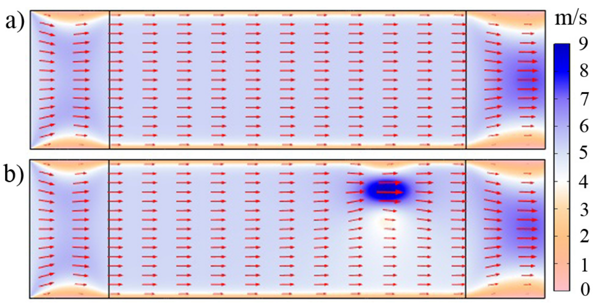


**Figure 4.** Results of modeling air flow with a uniform distribution of activated carbon granules (a) and with a non-uniform distribution of granules (b)

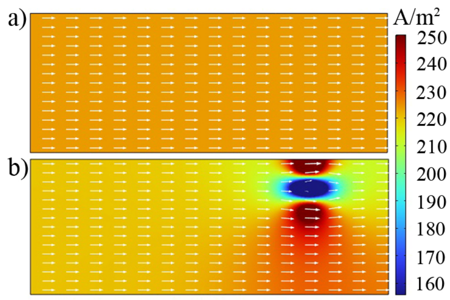


**Figure 5.** Results of modeling the current density distribution with a uniform distribution of activated carbon granules (a) and with a non-uniform distribution of granules (b)

Figure 5 shows that the current density decreased in the region with lower electrical resistance. Figure 6 shows the calculated thermograms of sections with a uniform distribution of granules (a) and with a reduced density of granules in the top right corner (b).

One can see from the figure that a region with a lower density will have a lower temperature compared to a denser packing. The low temperature around the perimeter of the sample is associated with heat exchange with the environment. Next, we consider the results of experimental studies.

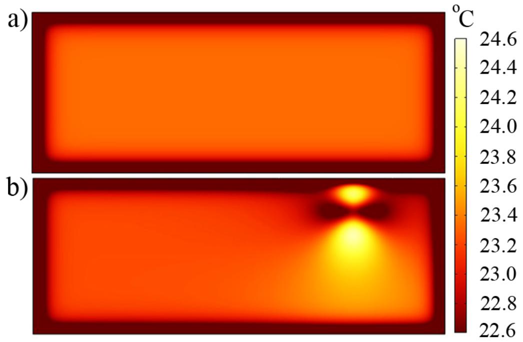


**Figure 6.** Results of modeling the temperature distribution in a filter with a uniform distribution of activated carbon granules (a) and in a filter with a non-uniform distribution of granules (b).

Figure 7a shows a thermogram of a flask filled with active carbon granules. Also, Fig. 7b shows temperature distribution profiles along lines C1 and C2 for better clarity.

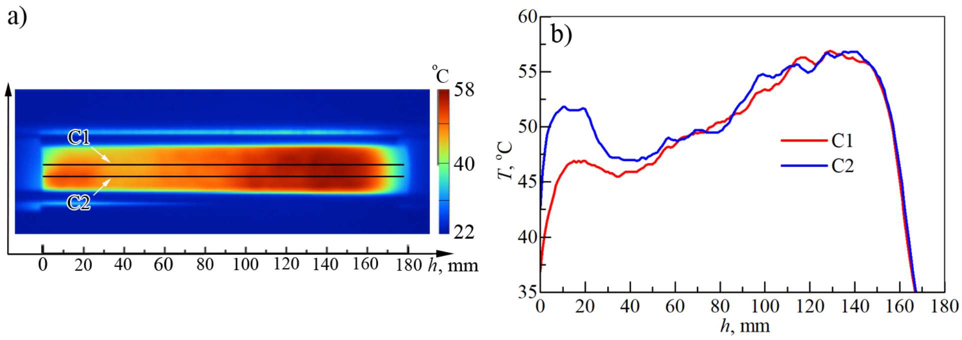


**Figure 7.** Thermogram of a flask filled with active carbon granules (a) and temperature distribution profiles along sections C1 and C2 (b)

One can see from the above thermogram, that a higher temperature is observed near one of the lids (where a denser package was created). At the same time, the heterogeneity of heating of the internal area is 4-10 ºC (Fig. 7b). It is clear from the thermogram that a smaller contact area between the granules entails an increase in electrical resistance and a decrease in current density in these areas, as a result, these areas on the thermogram are colder. Closer contact of granules leads to a decrease in electrical resistance, an increase in current density, and heating of the sorbent area. Consequently, the greater the heating of the sorbent area, the less airflow this area can allow, which leads to uneven wear of the sorbent.

We will also consider thermograms depending on the heating time. Figure 8 shows thermograms taken at regular intervals (20 seconds).

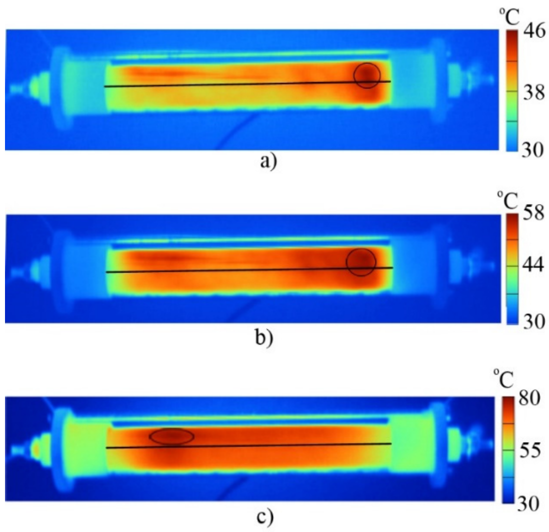


**Figure 8.** Experimental thermograms of the sample taken at time intervals of 20 seconds (a), 40 seconds (b), and 60 seconds (c)

It is clear from the figures that more heated regions in the samples can be identified (indicated by circles and ellipses), which indicates a higher current density in this region and, accordingly, a higher packing density. In Figure 8(a) and 8(b), the hotter region corresponds to the denser region. For better visualization of the temperature distribution, graphs of temperature versus coordinate *h* were plotted (Figure 8). The sections are shown as solid lines in Figure 8 and were made in the center of the cylinders.

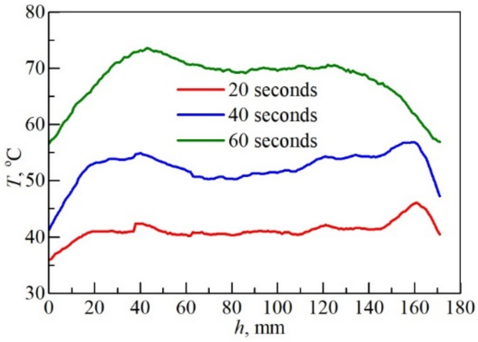


**Figure 9.** Temperature distributions in selected sample cross-sections for different heating times

Figure 9 shows that there is local temperature inhomogeneity at a length of 40 mm in all dependences. Local temperature inhomogeneity, corresponding to the created packing defect, is present at 160 mm when the sample is heated for 20 and 40 seconds. When heated for 60 seconds, this heterogeneity is not distinguishable, apparently due to a greater temperature gradient between the center of the sample and the body. It is worth noting that all graphs have a local minimum in the center. The temperature inhomogeneities described above are associated with the quality of packing of activated carbon granules and, as shown above, a higher temperature can characterize a denser packaging.

## CONCLUSIONS

The work assessed the possibility of thermographic control of the uniformity of the packaging of activated carbon granules in the filter. The correlation between the distributions of gas flow, current density, and temperature is theoretically shown and experimentally confirmed. Thus, more air flows through a less dense area of the package, but a lower current density can flow, resulting in less heating.

The possibility of identifying areas with non-uniform packaging of activated carbon granules has been experimentally confirmed. It was found that the duration of heating affects the resolution of the method: prolonged heating leads to a decrease in the contrast of these areas.

The approach proposed in the work can be used to debug and control the process of packaging activated carbon granules in a filter, which will improve their performance characteristics. At the same time, the method has ample opportunities for further development.

**Acknowledgements**

The research presented in this article was financially supported by the Ukrainian government budget program «Government support for priority scientific research and scientific & technical (experimental) developments» (budget financial Code 6541230) and Simons Foundation Program: Presidential Discretionary-Ukraine Support Grants, Award No 1030287.

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## REFERENCES

[1] S. Gössling, C. Meyer-Habighorst, and A. Humpe, "A global review of marine air pollution policies, their scope and effectiveness. Ocean Coast. Manag," **212**, 105824 (2021). https://doi.org/10.1016/j.ocecoaman.2021.105824
[2] H. Chen, B.G. Oliver, A. Pant, A. Olivera, P. Poronnik, C.A. Pollock, and S. Saad, "Effects of air pollution on human health – Mechanistic evidence suggested by in vitro and in vivo modelling," Environ. Res. **212** Part C, 113378 (2022). https://doi.org/10.1016/j.envres.2022.113378
[3] L. Blankenship, and R. Mokaya, "Modulating the porosity of carbons for improved adsorption of hydrogen, carbon dioxide, and methane: a review," Mater. Adv. **3**(4), 1905-1930 (2022). https://doi.org/10.1039/D1MA00911G
[4] A. Roy, C. Mishra, and N. Solanki, "A review of general and modern methods of air purification," J. Therm. Eng. **5**, 22-28 (2018). http://dx.doi.org/10.18186/thermal.529054
[5] G. Peters, R. Andrew, J. Canadell, S. Fuss, R. Jackson, J.I. Korsbakken, C. Le Quéré, and N. Nakicenovic, "Key indicators to track current progress and future ambition of the Paris Agreement," Nat. Clim. Change **7**, 118-122 (2017). https://doi.org/10.1038/nclimate3202
[6] C. Lin, R. He, and W. Liu, "Considering multiple factors to forecast CO2 emissions: a hybrid multivariable forecasting and genetic programming approach," Energies **11**, 3432 (2018). http://dx.doi.org/10.3390/en11123432
[7] A.M.F. Mohammed, I.A. Saleh, Y.H. Ibrahim, and N.R.G. Mohamed, "Theory and technology of air filtration: review," Material Sci & Eng. **6(1)**, 6-12 (2022). https://medcraveonline.com/MSEIJ/MSEIJ-06-00173.pdf

[8] A.Yu. Didyk, V.I. Slisenko, P.A. Selishchev, and A.Yu. Lyashenko, "Change in sample surface area during formation of cylindrical tracks as a result of high-energy heavy-ion irradiation," Metallofiz. Noveishie Tekhnol. **32(3)**, 357–363 (2010).
[9] V.I. Slisenko, O.E. Zoteev, O.A. Vasylkevych, V.O. Zoteev, and V.V. Krotenko, "The Dynamics of Crystal Lattice of Solid Solutions Based on Zirconium Dioxide," J. Phys. Stud. **25(4)**, 4601-1-4601-6 (2021). https://doi.org/10.30970/jps.25.4601
[10] V.A. Zheltonozhsky, D.E. Myznikov, V.I. Slisenko, M.V. Zheltonozhskaya, and A.P. Chernyaev, "Determination of the long-lived 10Be in construction materials of nuclear power plants using photoactivation method," J. Environ. Radioact. **227**, 106509 (2021). https://doi.org/10.1016/j.jenvrad.2020.106509
[11] Strategy for the management and disposal of used nuclear fuel and high-level radioactive waste. U.S. Department of Energy, Washington DC, (2013).
[12] S.U. Nandanwar, K. Coldsnow, V. Utgikar, P. Sabharwall, and D.E. Aston, "Capture of harmful radioactive contaminants from off-gas stream using porous solid sorbents for clean environment – A review," Chem. Eng. J. **306**, 369-381 (2016). https://doi.org/10.1016/j.cej.2016.07.073
[13] B. Riley, J. Vienna, D. Strachan, J. McCloy, and J. Jerden, "Materials and processes for the effective capture and immobilization of radioiodine: A review," J. Nucl. Mater. **470**, 307-326 (2016). https://doi.org/10.1016/j.jnucmat.2015.11.038
[14] M. Yadollahi, H. Hamadi, and V. Nobakht, "Capture of iodine in solution and vapor phases by newly synthesized and characterized encapsulated $Cu_2O$ nanoparticles into the TMU-17-$NH_2$ MOF," J. Hazard. Mater. **399**, 122872 (2020). https://doi.org/10.1016/j.jhazmat.2020.122872
[15] J. Zhou, S. Hao, and Y. Zhang, "Study on adsorption performance of coal based activated carbon to radioactive iodine and stable iodine," Ann. Nucl. Energy **72**, 237-241 (2014). https://doi.org/10.1016/j.anucene.2014.05.028
[16] H. Zhu, B. Wang, W. Zhu, T. Duan, G. He, Y. Wei, D. Sun, and J. Zhou, "Space and structure activation of collagen fiber for high efficient capture iodine in off-gas," Colloids Surf. A: Physicochem. Eng. **617**, 126389 (2021). https://doi.org/10.1016/j.colsurfa.2021.126389
[17] A. Belyaeva, A.A. Galuza, V.F. Klepikov, V.V. Litvinenko, A.G. Ponomarev, M.A. Sagajdachny, K.A. Slatin, et al., "Spectral ellipsometric complex for early diagnostics of metall and alloy transformations," Probl. At. Sci. Technol. **2**(60), 191-197 (2009). https://vant.kipt.kharkov.ua/ARTICLE/VANT_2009_2/article_2009_2_191.pdf (in Russian)
[18] A.I. Belyaeva, A.A. Galuza, I.V. Kolenov, and A.A. Savchenko, "Multipurpose optical setup for studying radiation-induced transformations of metals and alloys surface," PAST, **2**(90), 174-179 (2014). https://vant.kipt.kharkov.ua/ARTICLE/VANT_2014_2/article_2014_2_174.pdf
[19] E.M. Prohorenko, V.F. Klepikov, V.V. Lytvynenko, N.I. Bazaleev, T.G. Prohorenko, and A.I. Morozov, "Application of IR-radiometric diagnostic for control of vacuum connections of electrophysical installation," Probl. At. Sci. Technol. **1(113)**, 212-217 (2018). https://vant.kipt.kharkov.ua/ARTICLE/VANT_2018_1/article_2018_1_212.pdf
[20] V. Pozzobon, J. Colin, and P. Perre, "Hydrodynamics of a packed bed of non-spherical poly-disperse particles: A fully virtual approach validated by experiments," Chem. Eng. J. **354**, 126-136 (2018), https://doi.org/10.1016/j.cej.2018.07.214
[21] A.S. Pushnov, "Calculation of average bed porosity," Chem. Petrol. Eng. **42**, 14–17 (2006). https://doi.org/10.1007/s10556-006-0045-x
[22] W. Zhang, K.E. Thompson, A.H. Reed, and L. Beenken, "Relationship between packing structure and porosity in fixed beds of equilateral cylindrical particles," Chem. Eng. Sci. **61(24)**, 8060-8074 (2006). https://doi.org/10.1016/j.ces.2006.09.036
[23] R. Chhabra, and M.G. Basavaraj, editors, *Coulson and Richardson's Chemical Engineering Volume 2a: Particulate Systems and Particle Technology*, (Butterworth-Heinemann, 2019).
[24] F.J. Valdes-Parada, J.A. Ochoa-Tapia, and J. Alvarez-Ramirez, "On the effective viscosity for the Darcy–Brinkman equation," Physica A, **385**(1), 69-79 (2007). https://doi.org/10.1016/j.physa.2007.06.012

## ТЕРМОГРАФІЧНИЙ МЕТОД ДІАГНОСТИКИ ЩІЛЬНОСТІ ЗАСИПКИ АКТИВОВАНОГО ВУГІЛЛЯ В ПОВІТРЯНИХ ФІЛЬТРАХ АЕС

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Робота присвячена задачам безпечної експлуатації атомних електростанцій, а саме запобіганню потрапляння в повітря інертних радіоактивних газів, йоду та його сполук. Останній особливо небезпечний, оскільки може накопичуватися в організмі людини. Одним із способів очищення повітря є використання повітряних фільтрів, наповнених гранулами активованого вугілля, які пройшли попередню обробку термічного розширення та імпрегнування. Водночас виникає проблема оцінки зміни локального аеродинамічного опору внаслідок зміни форми гранул та їх ущільнення при засипці активованого вугілля у фільтр. Для цього створено модель, що розраховує просторове поле руху вентиляційних газів через камеру, що імітує адсорбер типу АУ-1500, наповнений гранулами активованого вугілля. Для верифікації моделі необхідно було розробити підходи до оцінки топології міжзернового простору та сформулювати уявлення про можливі неоднорідності такої топології через неоднорідності ущільнення гранул під час засипки та вібраційних впливів під час експлуатації. Тому була запропонована експериментальна модель, заснована на припущенні, що повітряні канали просторово суміжні з каналами проходження електричного струму, якщо різниця потенціалів прикладена до ділянок «вхід-вихід». Кластери областей з неоднорідною упаковкою шляхом вимірювання розподілу температури, яка виділяється у вигляді джоулева тепла, були виявлені. Встановлено кореляції між характеристиками поширення температурних полів і режимами пропускання струму. Показано, що отримані експериментальні дані корелюють з теоретичними розрахунками потоку вентиляційних газів. Створений комплекс методів дозволяє оптимізувати аеродинамічні характеристики фільтрів для покращення їх функціональних властивостей.
**Keywords:** *термографія; повітряні фільтри; активоване вугілля; потік повітря; розподіл струму*