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IMPROVEMENT OF TANK FOR GAS TRANSPORTATION IN COMPRESSED CONDITION AND COMPARATIVE EVALUATION CRITERIA

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The object of research is the design features of tanks for gas transportation in a compressed state and the criteria for their comparative evaluation. One of the most problematic places is the lack of a unified approach to the non-economic evaluation of the efficiency of transportation of compressed gas in high-pressure tanks. The issue is of particular importance in the conditions of gas transportation by sea and, in particular, produced on the shelf. This is due to the diversity of tank designs offered by manufacturers, characterized by different working pressures and design. To create the possibility of evaluation of the mass-dimensional perfection of high-pressure tanks, an analysis of the structures suitable for the formation of the cargo systems of marine vehicles, and the criteria for their comparative evaluation has been carried out. Also the design of multi-cavity high-pressure tanks of increased working tank is proposed. They consist of steel and fiberglass pipes and special connections with plug-in retaining elements. Considering that it is common to use normal cubic meters for gas metering, a new universal criterion is proposed for comparative evaluation of their perfection. It is determined by the ratio of the mass of the tank to the volume of gas transported in it to normal conditions. The criterion establishes the relationship between the amount of gas transported and the main parameter of the tanks, taking into account their inclusion in the freight systems of vehicles. According to the specified criterion, multi-cavity tanks are competitive in terms of their performance in the form of a lengthy design, limited by the parameters of the marine vehicle. Due to the universality of the proposed criterion, it is possible for manufacturers of high pressure vessels to use them in promoting products in various industries. For the perception of the new criterion by consumers, it is necessary to conduct its comparative analysis with the criteria used today for evaluation of perfection for tanks of various types and parameters.

Keywords: transportation of compressed natural gas, combined type tanks, criteria for the perfection of designs, tank mass, gas volume.

References

1. About. *KGTM Kelley GasTransportModules*. Available at: http://kelleygtm.com/about/
2. Stephen, G., Cano, G. (2006). CNG marine transport – demonstration project development. *Presented at the Offshore Technology Conference*. Houston. doi: http://dx.doi.org/10.4043/17780-ms
3. *EnerSea Transport Inc*. Available at: http://enersea.com
4. *Global Energy Ventures Ltd*. Available at: https://gev.com
5. *TransCanada Pipeline Ltd*. Available at: https://www.tcenergy.com/
6. TITAN® Specifications. *Hexagon*. Available at: http://www.hexagonlincoln.com/mobile-pipeline/titan/titan-specifications#
7. Paton, B. Ye., Kryzhanivskyi, Ye. I., Savytskyi, M. M., Shvydkyi, E. A., Zaitsev, V. V., Mandryk, O. M. (2012). Pat. No. 67664 UA. *Method for transportation of compressed natural gas by a movable pipeline*. MPK: F17C 5/00. No. u201114580; declareted: 08.12.2011; published: 27.02.2012, Bul. No. 4. Available at: http://uapatents.com/2-67664-sposib-transportuvannya-stisnutogo-prirodnogo-gazu-rukhomim-truboprovodom.html
8. Petrov, V. A., Petrov, A. V., Petrov, A. V. (2002). Pat. No. 2178113 C2 RU. *Rezervuar mnogopolostnii dlia transportirovki i khraneniia szhatykh gazov «PRETTI»*. MPK: F17C1/00. No. 98107129/12; declareted: 14.04.1998; published: 10.01.2002. Available at: https://findpatent.ru/patent/217/2178113.html
9. Blynkov, A. N., Vlasov, A. A., Lytsys, A. V., Shurpiak, V. K. (2007). CNG – novaia tekhnolohyia morskoi transportyrovky haza: sostoianye, perspektyvy, problemy. *Rossiiskii morskoi registr sudohodstva, 30,* 127–162.
10. Trudgeon, M. (2005). *An Overview of NGV Cylinder Safety Standards, production and in-Service Requirements*. Available at: https://apvgn.pt/wp-content/uploads/overview_of_ngv_cylinder_safety_standards.pdf
11. Komkov, M. A., Tarasov, V. A., Zarubyna, O. V. (2012). Analyz konstruktyvno-massovoho sovershenstva obolochek sosudov davlenyia. *Mashynostroenye, 3,* 11–18.
12. Dzhus, A. P. (2016). Zasoby dlia transportuvannia stysnutoho pyrodnoho hazu ta kryterii otsinky yikh doskonalosti. *Mashyny, obladnannia i materialy dlia naroshchuvannia vitchyznianoho vydobutku ta dyversyfikatsii postachannia nafty i hazu*. Ivano-Frankivsk, 224–228.
13. *Wavistrong Installation Guide for GRE Pipe Systems*. (2013). Available at: http://www.futurepipe.com/wp-content/uploads/2018/02/Wavistrong-Installation-Guide.pdf
14. McNamara, J. F., Connolly, A., Steen, J. (2000). High Pressure Composite Pipeline and Joints for Gas Distribution Network. *Proceedings of the 3rd International Pipeline Technology Conference*. Brugge, 681–694.
15. *Practice for Obtaining Hydrostatic or Pressure Design Basis for Fiberglass (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings*. ASTM International. doi: http://doi.org/10.1520/d2992-06
16. *DNAOP 0.00-1.07-94. Pravyla budovy i bezpechnoi ekspluatatsii posudyn, shcho pratsiuiut pid tyskom* (1994). Zatverdzheni nakazom Derzhnahliadokhoronpratsi Ukrainy No. 104. 18.10.1994. Available at: https://dnaop.com/html/88/doc-%D0%9D%D0%9F%D0%90%D0%9E%D0%9F_0.00-1.07-94
17. Pysarenko, H. V. (Ed.) (1979). *Soprotyvlenye materyalov*. Kyiv: Vyshcha shkola, 696.
18. Savytskyi, M. M., Savytskyi, O. M., Suprunenko, V. O., Zaitsev, V. V. (2013). Determination of internal circuit keels parameters of flexible skirt of amphibious hovercraft vessel. *NUS Journal. Electronic Editon, 1*. Available at: http://evn.nuos.edu.ua/article/view/19553/17209

TECHNOLOGY AND SYSTEM OF POWER SUPPLY

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IMPROVEMENT OF THERMOTECHNICAL PROPERTIES OF REFRIGERATOR'S EVAPORATOR USING NANOPARTICLES

page 9–14

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The paper presents information on the prospects for the use of nanoparticles to improve the thermotechnical characteristics of heat exchangers of the refrigerator operating on isobutane. The effect of nano additives is considered on the example of an experimental study of an evaporator. The object of research is the refrigerator's evaporator, working as part of the calorimetric stand. The parameters to which attention was paid in the experiment were the heat transfer coefficient and the heat loss coefficient. One of the most problematic places is the use of model manometers and thermometers, which required manual data removal. The problem can be solved by replacing analog devices with digital ones with constant parameter removal and automatic recording and processing by computer. It also took a long time to establish the regime.

During the study, data were obtained that when using nanofluids as a working medium, it is possible to increase the heat transfer coefficient by 21 % at a mode with a boiling point of –20 °C and a condensation temperature of 40 °C and also by 18.1 % at the mode with boiling point –15 °C. The heat loss coefficient in the evaporator can be increased to 7.5 %. This is due to the fact that the proposed method of introducing impurities of titanium oxide into the working fluid of the refrigerator leads to an increase in thermal conductivity, and hence to an improvement in heat transfer in heat exchangers. The use of nanofluids makes it possible to significantly increase the heat and mass transfer characteristics of the refrigerant, as compared with the means that require structural changes in the refrigerator circuit, to reduce temperature differences on the surfaces of the condenser and evaporator. And as a result, to reduce the ratio of boiling and condensing pressures, and, consequently, the electric power consumed by the refrigerator without adding additional elements to the apparatus. The industries of rational use of these additives are enterprises and the production of low-capacity refrigerators, including household appliances.

Keywords: isobutene refrigerator, nano additive, heat loss and heat transfer coefficients in the evaporator.

References

1. Saidur, R., Leong, K. Y., Mohammad, H. A. (2011). A review on applications and challenges of nanofluids. *Renewable and Sustainable Energy Reviews, 15 (3)*, 1646–1668. doi: http://doi.org/10.1016/j.rser.2010.11.035
2. Choi, S. U. S., Eastman, J. A. (1995). Enhancing thermal conductivity of fluids with nanoparticles. *Conference: 1995 International mechanical engineering congress and exhibition. San Francisco.* Available at: http://www.osti.gov/scitech/servlets/purl/196525
3. Strandberg, R., Das, D. K. (2010). Finned tube performance evaluation with nanofluids and conventional heat transfer fluids. *International Journal of Thermal Sciences, 49 (3)*, 580–588. doi: http://doi.org/10.1016/j.ijthermalsci.2009.08.008
4. Xuan, Y., Li, Q. (2003). Investigation on Convective Heat Transfer and Flow Features of Nanofluids. *Journal of Heat Transfer, 125 (1)*, 151–155. doi: http://doi.org/10.1115/1.1532008
5. Hamilton, R. L., Crosser, O. K. (1962). Thermal Conductivity of Heterogeneous Two-Component Systems. *Industrial & Engineering Chemistry Fundamentals, 1 (3)*, 187–191. doi: http://doi.org/10.1021/i160003a005
6. Xuan, Y., Roetzel, W. (2000). Conceptions for heat transfer correlation of nanofluids. *International Journal of Heat and Mass Transfer, 43 (19)*, 3701–3707. doi: http://doi.org/10.1016/s0017-9310(99)00369-5
7. Li, C. H., Peterson, G. P. (2006). Experimental investigation of temperature and volume fraction variations on the effective thermal conductivity of nanoparticle suspensions (nanofluids). *Journal of Applied Physics, 99 (8)*, 084314. doi: http://doi.org/10.1063/1.2191571
8. Li, C. H., Peterson, G. P. (2007). Mixing effect on the enhancement of the effective thermal conductivity of nanoparticle suspensions (nanofluids). *International Journal of Heat and Mass Transfer, 50 (23-24)*, 4668–4677. doi: http://doi.org/10.1016/j.ijheatmasstransfer.2007.03.015
9. Chon, C. H., Kihm, K. D. (2005). Thermal Conductivity Enhancement of Nanofluids by Brownian Motion. *Journal of Heat Transfer, 127 (8)*, 810. doi: http://doi.org/10.1115/1.2033316
10. Das, S. K., Choi, S. U. S., Patel, H. E. (2006). Heat Transfer in Nanofluids – A Review. *Heat Transfer Engineering, 27 (10)*, 3–19. doi: http://doi.org/10.1080/01457630600904593
11. Kim, S. H., Choi, S. R., Kim, D. (2007). Thermal Conductivity of Metal-Oxide Nanofluids: Particle Size Dependence and Effect of Laser Irradiation. *Journal of Heat Transfer, 129 (3)*, 298–307. doi: http://doi.org/10.1115/1.2427071
12. Lee, S., Choi, S. U.-S., Li, S., Eastman, J. A. (1999). Measuring Thermal Conductivity of Fluids Containing Oxide Nanoparticles. *Journal of Heat Transfer, 121 (2)*, 280–289. doi: http://doi.org/10.1115/1.2825978

REPORTS ON RESEARCH PROJECTS

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EXPERIMENTAL STUDIES OF THE GRINDING PROCESS BY PLANETARY GRINDING HEAD

page 15–17

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The object of research is the process of creep feed grinding of parts of aircraft engines with hard-to-machine materials. In the aviation industry from such materials (steel 4Х5МФ1С, ХН53КВМТЮБ, etc.) blades and disks of turbines, segments

of nozzle apparatuses, sectors of input guide vanes, plungers, pistons, gears, etc. similar details are made. Blade processing methods are not very effective in creating such parts. Increased wear of technological equipment and tools leads to an increase in temperature in the cutting zone, adversely affects the quality indicators and reduces the life of the product as a whole. Constant sharpening, editing or changing the tool to a new, additional adjustment of the process equipment leads to an increase in the cost of manufacturing parts from difficult-to-work materials. The introduction of creep feed grinding in technological processes allows to avoid the above negative factors. The increase in the technological modes of grinding reduces the processing time, but it becomes a cause of burn in the surface layers and damage to the processed surface. Experimental studies of the process of creep feed grinding are carried out to determine the temperatures in the subsurface layers of the part during its processing and subsequent comparison with the theoretically obtained results of the developed mathematical model. Processing was performed on a surface grinding machine Jotes SPD-30b (Poland). The temperature is measured by the contact method (measuring instrument OBEH MBA 8, Russia) and contactless (using a pyrometer CT 3M, Germany). The results of the experimental temperature values are given in tabular form. According to the research results, it is found that the use of a planetary grinding head for the technology of creep feed grinding of machine-building and aviation parts of difficult-to-process, corrosion-resistant materials leads to a decrease in the power-process parameters. In addition, there is an improvement in the surface cleanliness class (surface roughness Ra is between 1.25–1.8 μm). The results suggest that the technology of creep feed grinding should be introduced into technological processes instead of milling, external pulling and traditional grinding.

Keywords: planetary grinding head, creep feed grinding, grinding temperature, subsurface layers of the part.

References

1. Yao, C. F., Jin, Q. C., Huang, X. C., Wu, D. X., Ren, J. X., Zhang, D. H. (2012). Research on surface integrity of grinding Inconel718. *The International Journal of Advanced Manufacturing Technology, 65 (5-8),* 1019–1030. doi: http://doi.org/10.1007/s00170-012-4236-7
2. Hood, R., Cooper, P., Aspinwall, D. K., Soo, S. L., Lee, D. S. (2015). Creep feed grinding of γ-TiAl using single layer electroplated diamond superabrasive wheels. *CIRP Journal of Manufacturing Science and Technology, 11,* 36–44. doi: http://doi.org/10.1016/j.cirpj.2015.07.001
3. Bi, X. F. (2013). Effects of Grinding Parameters on Creep Feed Grinding. *Advanced Materials Research, 658,* 255–258. doi: http://doi.org/10.4028/www.scientific.net/amr.658.255
4. *Ploskoshlifoval'nyy stanok s gorizontal'noy os'yu vrashheniya Jotes SPD-30b* (1975). Fabryka szlifierek «PONAR-Lódz». Zaklad «Jotes», 226.
5. Surdu, N. V. (2005). *Povyshenie effektivnosti shlifovaniya trudnoobrabatyvaemykh materialov za schet usovershenstvovaniya kinematiki protsessov*. Kharkiv: Institut problem mashinostroeniya im. A. N. Podgornogo NAN Ukrainy, 241.
6. Tarelin, A. A., Surdu, N. V., Telegin, A. V., Fistik, A. G. (2009). Sozdanie planetarnoy golovki dlya glubinnogo shlifovaniya trudno-obrabatyvaemykh materialov. *Eastern-European Journal of Enterprise Technologies, 4 (6 (40)),* 4–12. Available at: http://journals.uran.ua/eejet/article/view/22015/19522
7. *Lenze SMVector – preobrazovatel' chastoty.* Available at: https://saa.su/Manual/Lenze/SMV_IP31_IP65(RUS).pdf
8. Kurin, M. O. (2011). *Doslidzhennia tekhnolohii planetarnoho hlybynnoho shlifuvannia ploskykh poverkhon detalei aviatsiinykh dvyhuniv*. Kharkiv: NAU im. M. Ye. Zhukovskoho «KhAI», 179.
9. Zubchenko, A. S. (Ed.) (2003). *Marochnik staley i splavov*. Moscow: Mashinostroenie, 784.
10. Eliseev, Yu. S., Novikov, V. S., Starkov, V. K., Ryabtsev, S. A. (2001). Profil'noe glubinnoe shlifovanie zubchatykh koles. *Vestnik mashinostroeniya, 1,* 41–44.

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DETERMINATION OF THE ESSENTIAL EFFECT OF MODIFICATION IN THE COMPOSITION OF THE COMBINED VIBRATION TREATMENT TECHNOLOGY ON THE MECHANICAL PROPERTIES OF AK7 ALLOY

page 18–20

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The object of research is AK7 alloy, which is subjected to the complex action of vibration and modification in the process of producing cylindrical billets by means of casting in a metal mold. One of the most problematic places is the determination of rational modes of influence of technological factors on the alloy, ensuring the satisfaction of a given level of properties in terms of their competitive nature.

During the study, the methods of regression analysis were used and identified as promising methods of analysis of variance to improve the accuracy of the findings. In particular, the results of the regression analysis of experimental and industrial research data on the vibration treatment technology with a frequency of 100–150 Hz with an additional input of the ultradisperse modifier into the melt are presented. The results are obtained concerning the confirmation of the hypothesis about the significance of the influence of the modifier on the increase of the mechanical properties of the alloy: HB, $\sigma_{0.2}$, σ_s, δ_s, ψ. This is important because attempts to improve the properties of the alloy using the combined technological solutions invariably cause the expenditure of energy and material resources. This ensures the possibility of energy and resource savings in the process. The obtained results show that the use of modification as an additional component of the technological process increases only ψ, but reduces HB and δ_s. In the vibration frequency range of 100–140 Hz, modification has a positive effect on $\sigma_{0.2}$, and an increase in the frequency above this value leads to a deterioration in the result. The opposite effect is observed with respect to δ_s – with an increase in the vibration frequency of more than 140 Hz, modifying increases this alloy characteristic, in the range of 100–140 Hz, the introduction of a modifier can be considered justified. Thus, it is found that the modification has an ambiguous effect on the properties of the alloy, therefore, in order to select a rational technological regime, a solution to the compromise problem is necessary. This is due to the revealed fact of competing properties. It is proposed to use the methods of analysis of variance to refine the obtained results.

Keywords: vibration treatment technologies, modification effect, AK7 alloy, regression analysis, variance analysis.

References

1. Skorobagat'ko, Yu. P., Slazhnev, N. A., Berezina, A. L., Monastyrskaia, T. A., Davidenko, A. A., Spuskanyuk, V. Z. (2010). Kompleksnaia obrabotka splavov sistemy Al-Si v magnitodinamicheskoi ustanovke s posleduyuschei intensivnoi plasticheskoi deformatsiei: vliianie na svoistva i strukturu. *Protsessy lit'ia, 5,* 83–88.
2. Dotsenko, Yu. V., Seliverstov, V. Yu. (2012). Osobennosti zatverdevaniia otlivok iz alyuminievyh splavov pri narastayuschem davlenii i modifitsirovanii. *Eastern-European Journal of Enterprise Technologies, 1 (5 (55)),* 18–22.
3. Ramesh Babu, N., Ramesh, M., Kiran Aithal, S., Kotresh, K. (2018). Effect of Lateral Vibrations during Directional solidification on Mechanical Properties of Al-18%wt Si Alloys. *Materials Today: Proceedings, 5 (2),* 6954–6962. doi: http://doi.org/10.1016/j.matpr.2017.11.358
4. Dommaschk, C. (2003). *Beitrag zur Gefügebeeinflussung erstarrender Metallschmelzen durch Vibration.* TU Bergakademie Freiberg, 134.
5. Buxmann, K. (1972). Auswirkung von Schock, Vibration und Strömung auf die Erstarrung von Metallen. *Zeitschrift Metallkunde, 63 (9),* 516–521.
6. Kotova, Yu. V., Kotov, R. N., Bast, Yu. (2010). Vnedrenie i analiz vibratsii pri neprereryvnom lit'e zagotovok iz dragotsennyh metallov. *Vestnik Permskogo gosudarstvennogo tekhnicheskogo universiteta. Mashinostroenie, materialovedenie, 12 (4),* 80–84.
7. Akimov, O. V., Chibichik, O. A., Red'kina, A. V. (2014). Sovershenstvovanie tekhnologicheskih protsessov izgotovleniia lityh detalei rotorov dlia povysheniia ekspluatatsionnyh harakteristik tiagovogo elektroprivoda. *Problemy mashinostroeniia, 16 (5),* 7–12.
8. Chibichik, O. A., Martynenko, V. F., Akimov, O. V., Shishko, A. E. (2011). Metodologiia konstruktorsko-tekhnologicheskogo proektirovaniia i izgotovleniia korotkozamknutogo litogo rotora dlia asinhronnyh elektrodvigatelei. *Metall i lit'e Ukrainy, 2 (213),* 30–34.
9. Selyverstov, V. Yu., Dotsenko, Yu. V., Dotsenko, N. V. (2018). Kompleksnyi vplyv modyfikuvannia ultradyspersnym preparatom ta vibratsiieiu na vlastyvosti metalu vylyvkiv iz splavu systemy Al–Si. *Spetsialna metalurhiia: vchora, sohodni, zavtra*. Kyiv: KPI im. Ihoria Sikorskoho, 336–345.
10. Charykov, A. K. (1984). *Matematicheskaia obrabotka rezul'tatov himicheskogo analiza.* Leningrad: Himiia, 168.
11. Demin, D. A., Pelikh, V. F., Ponomarenko, O. I. (1998). Complex alloying of grey cast iron. *Litejnoe Proizvodstvo, 10,* 18–19.
12. Demin, D. A. (1998). Change in cast iron's chemical composition in inoculation with a Si-V-Mn master alloy. *Litejnoe Proizvodstvo, 6,* 35.

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REGULATION OF ELECTROPHYSICAL PROPERTIES OF FIREPROOF POLYMER COMPOSITIONS FILLED WITH HYDROMAGNESITE FOR CABLE PRODUCTS

page 21–23

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The level of electrophysical properties of fireproof polymer compositions, depending on the influence of ingredients, has not been sufficiently studied. This is especially true of the effect of the modifier on the properties of the insulation and sheath of cable products. Therefore, the object of research is the electrophysical properties of fireproof composite materials: ethylene-vinyl acetate copolymer, filled with hydromagnesite. Composition of the copolymer with a melt flow index of 2.5 and 5 g/10 min, hydromagnesite with an average median particle diameter of 1.4 μm, aminosilanes with a dynamic viscosity of 2 MPa·s and 2.5 MPa·s are investigated. An isolation test apparatus, an insulation resistance meter, an AC bridge are used. Electrophysical characteristics are obtained, which allow to determine the composition that provides the optimal values for insulating materials and materials of cable sheaths with increased fire safety requirements. The methods of electrophysical studies are used to determine the effect of the properties of the ingredients of polymer compositions on the electrical strength, specific volume electrical resistance, the dielectric loss tangent, and dielectric constant. Electric strength increases when using the polymer matrix EVA-1 and modifier 1 from 21 to 40 kV/mm; when using the polymer matrix EVA-2 and modifier 2 from 22.5 to 42 kV/mm. The specific volume electrical resistance increases significantly for polymer compositions filled with hydromagnesite, using the polymer matrix EVA-1 and modifier 1. Its value increases from $1 \cdot 10^{13}$ to $6.6 \cdot 10^{14}$ Ohm·cm. Using the polymer matrix EVA-1 results to reduce the dielectric constant. A significant decrease in this indicator from 4.1 to 3.6 is observed when using modifier 1 with a lower dynamic viscosity (2 MPa·s). The tangent of dielectric loss angle also decreases from 0.013 to 0.0046 when using the modifier 1. It is advisable to use the results of the research to develop the composition of fireproof polymer compositions for cable products.

Keywords: composite materials, ethylene-vinyl acetate copolymer, electrophysical properties of fireproof polymer compositions.

References

1. Mikhaylin, Yu. A. (2011). Pokazateli ognestoykosti polimernykh materialov i metody ikh opredeleniya. *Polimernye materialy, 7,* 26–31.
2. *EN 50363-7:2005. Insulating, sheathing and covering materials for low voltage energy cables. Part 7: Halogen-free, thermoplastic insulating compounds.* Available at: https://shop.bsigroup.com/ProductDetail/?pid=000000000030065332
3. Chuleeva, E. V., Zolotarev, V. M., Chuleev, V. L. (2016). Napolnytely-antypyrenы. Teplofyzycheskye svoistva. *Khimichna promyslovist Ukrainy, 3-4 (134-135),* 65–69.
4. Herbiet, R. (2005). Mineral Flame Retardants: Market Outlook and Latest Developments. *High Performance Filler, 4,* 20.
5. Cárdenas, M. A., García-López, D., Gobernado-Mitre, I., Merino, J. C., Pastor, J. M., Martínez, J. de D. et. al. (2008). Mechanical and fire retardant properties of EVA/clay/ATH nanocomposites – Effect of particle size and surface treatment of ATH filler. *Polymer Degradation and Stability, 93 (11),* 2032–2037. doi: http://doi.org/10.1016/j.polymdegradstab.2008.02.015
6. Formosa, J., Chimenos, J. M., Lacasta, A. M., Haurie, L. (2011). Thermal study of low-grade magnesium hydroxide used as fire retardant and in passive fire protection. *Thermochimica Acta, 515 (1-2),* 43–50. doi: http://doi.org/10.1016/j.tca.2010.12.018
7. Chang, M.-K., Hwang, S.-S., Liu, S.-P. (2014). Flame retardancy and thermal stability of ethylene-vinyl acetate copolymer nanocomposites with alumina trihydrate and montmorillonite. *Journal of Industrial and Engineering Chemistry, 20 (4),* 1596–1601. doi: http://doi.org/10.1016/j.jiec.2013.08.004
8. Lujan-Acosta, R., Sánchez-Valdes, S., Ramírez-Vargas, E., Ramos-DeValle, L. F., Espinoza-Martinez, A. B., Rodriguez-Fernandez, O. S. et. al. (2014). Effect of Amino alcohol functionalized polyethylene as compatibilizer for LDPE/EVA/clay/flame-retardant nanocomposites. *Materials Chemistry and Physics, 146 (3),* 437–445. doi: http://doi.org/10.1016/j.matchemphys.2014.03.050

9. Chulieieva, O. (2017). Development of directed regulation of rheological properties of fire retardant composite materials of ethylene vinyl acetate copolymer. *Technology Audit and Production Reserves, 2 (1 (40))*, 25–31. doi: http://doi.org/10.15587/2312-8372.2018.129699
10. Chulieieva, O., Zolotaryov, V. (2019). Investigation of electrophysical properties of nanomodified fireproof eva polymer compositions. *Technology audit and production reserves, 1 (1 (45))*, 31–38. doi: http://doi.org/10.15587/2312-8372.2019.157581

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ANALYSIS OF THE SPECIAL FEATURES OF HYDRODYNAMICS IN THE BOUNDARY LAYER OF THE NOZZLE OF THE DEVELOPED SURFACE

page 24–26

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The object of research is the hydrodynamics of the boundary layer of the nozzle element of the proposed design. In the course of the study, computer simulation methods were used in the ANSYS environment, in particular the CFX block, which includes a set of physical, mathematical and numerical methods designed to calculate the characteristics of streaming processes. The analysis of the influence of the fluid velocity in the packed bed bioreactor on the magnitude of the hydraulic resistance for the following values of the fluid velocity: 0.1 m/s; 1 m/s; 2 m/s. The obtained data almost repeat the value of experimental studies, confirms the correctness of the construction of a computer model. A simulation of the hydrodynamics of a single nozzle of the proposed design for a longitudinal and transverse flow of fluid is done. Changes in the hydraulic resistance during transverse flow around the nozzle are insignificant, the maximum value lies within 101.3 kPa, for longitudinal washing the value of the pressure differential lies in the range from 98.96 to 102.7 kPa. Diagrams of the distribution of fields and velocity vectors in the boundary layer of the nozzle are obtained. When transversal washing of the nozzle, the magnitude of the velocities is in the range from 0 to 1.511 m/s, for longitudinal washer it ranges from 0 to 1.968 m/s. The distribution of the shear rate in the boundary layer is established, for the transverse washing of the nozzle, the magnitude of the shear flow rate ranges from 3.1 to $4.27 \cdot 10^3$ s^{-1}, for a longitudinal washing of the nozzle, this indicator ranges from 5.6 to $1.25 \cdot 10^4$ s^{-1}. Through the use of the proposed nozzle, it is possible to obtain large specific surface areas for the immobilization of microorganisms, provided that the critical parameters of the cultivation process are in accordance with permissible maximum deviations. Compared with the methods of determining the optimal parameters experimentally, a computer model is proposed that provides the following advantages: a significant reduction in the material costs of introducing a new nozzle design and a quick optimization of the process parameters when the initial data changes.

Keywords: packed bioreactor, shear stress, computer simulation in the ANSYS environment, hydraulic resistance, flow shear rate.

References

1. Zhang, C., Li, Y. (2017). Thermodynamic analysis on theoretical models of cycle combined heat exchange process: The reversible heat exchange process. *Energy, 124,* 565–578. doi: http://doi.org/10.1016/j.energy.2017.02.103
2. Obodovych, O. M., Ruzhynska, L. I., Kostyk, S. I., Bulakh, N. M. (2016). Osoblyvosti teploviddachi pry vymushenii konvektsii v rotorno-dyskovomu plivkovomu vyparnomu aparati. *Promishlennaia teplotekhnyka, 6 (37),* 22–28.
3. Song, J., Liu, Z., Ma, Z., Zhang, J. (2017). Experimental investigation of convective heat transfer from sewage in heat exchange pipes and the construction of a fouling resistance-based mathematical model. *Energy and Buildings, 150,* 412–420. doi: http://doi.org/10.1016/j.enbuild.2017.06.025
4. Lanzafame, R., Mauro, S., Messina, M., Brusca, S. (2017). Heat Exchange Numerical Modeling of a Submarine Pipeline for Crude Oil Transport. *Energy Procedia, 126,* 18–25. doi: http://doi.org/10.1016/j.egypro.2017.08.048
5. Zhao, C.-R., Zhang, Z., Jiang, P.-X., Bo, H.-L. (2017). Influence of various aspects of low Reynolds number k–ε turbulence models on predicting in-tube buoyancy affected heat transfer to supercritical pressure fluids. *Nuclear Engineering and Design, 313,* 401–413. doi: http://doi.org/10.1016/j.nucengdes.2016.12.033
6. Jafari, M., Farhadi, M., Sedighi, K. (2017). Thermal performance enhancement in a heat exchanging tube via a four-lobe swirl generator: An experimental and numerical approach. *Applied Thermal Engineering, 124,* 883–896. doi: http://doi.org/10.1016/j.applthermaleng.2017.06.095
7. Shybetskiy, V., Semeniuk, S., Kostyk, S. (2017). Design of consrtuction and hydrodynamic modeling in a roller bioreactor with surface cultivation of cell cultures. *ScienceRise, 7 (36),* 53–59. doi: http://doi.org/10.15587/2313-8416.2017.107176
8. Zakomornyi, D. M., Kutovyi, M. H., Kostyk, S. I., Povodzynskyi, V. M., Shybetskyi, V. Yu. (2016). Hydrodynamics of fermenter with multi-shaft stirrer. *ScienceRise, 5 (2 (22)),* 65–70. doi: http://doi.org/10.15587/2313-8416.2016.69451
9. Kostyk, S. I., Ruzhynska, L. I., Shybetskyi, V. Yu., Revtov, O. O. (2016). Mathematical simulation of hydrodynamics of the mixing device with magnetic drive. *ScienceRise, 4 (2 (21)),* 27–31. doi: http://doi.org/10.15587/2313-8416.2016.67275
10. Shi, Z., Graber, Z. T., Baumgart, T., Stone, H. A., Cohen, A. E. (2018). Cell Membranes Resist Flow. *Cell, 175 (7),* 1769. doi: http://doi.org/10.1016/j.cell.2018.09.054

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INFLUENCE OF VENTILATED ENCLOSING STRUCTURES ON THE REGULATION OF HOUSE ENERGY SUPPLY

page 27–30

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The object of research is calculation of the value of the course of changes in the internal temperature in the investigated house with ventilated (VPS) and unventilated enclosing structures, where the two-stage regulation of the operation time of the heat point was used.

Complex analysis of energy efficiency of the house, and first of all, of the enclosing structures, has been carried out. It has been demonstrated that regulation of the central heating can be used for additional energy savings. It is also possible to regulate depending on the climatic conditions, that is, the thermal power of the boiler or the heating point will depend on the change in the temperature of the air outside.

It has been established that the use of scientifically substantiated proposals offered in the work significantly increases the thermal inertia of the enclosing structures.

Due to this, when the heating system is switched off, the house is slowly cooled and heated relatively quickly. Thus, it is possible to get savings, as the structure elements of the building accumulate heat. The essence of optimum temperature control has been established, which is controlling the supply of heat energy in the room in such a way that the corresponding internal air temperature has been reached over a certain period of time. It has been found out that in order to achieve high energy efficiency of a building, in addition to its thermo-modernization, it is necessary to maintain the appropriate climatic conditions inside the heating premises. The factors that influence the ability to regulate the temperature inside the premises, depending on the change in the temperature of the air outside, have been established. The coefficient of thermal accumulation of the building with the VPS use has been defined, which characterizes the ability of the overall structure of the building to accumulate heat and reduce the temperature fluctuations in the heated premises.

In the course of the study, a technique for heating premises has been developed, which allows to determine the consistent change in the temperature of air in the premises. With the help of mathematical models developed in the work, it is possible to predict and optimize thermal processes in the investigated objects.

Keywords: thermal inertia of enclosing structures, ventilated facades, heat exchange in enclosing structures.

References

1. Dolinskyi, A. A., Basok, B. I. (2014). Stvorennia eksperymentalnoho enerhoefektyvnoho budynku pasyvnoho typu. *Enerhetychna bezpeka na transporti: pidvyshchennia enerhoefektyvnosti, znyzhennia zalezhnosti vid pryrodnoho hazu*. Kyiv, 26–30.
2. Bozhko, I. K., Lysenko, O. N., Goncharuk, S. M., Kalinina, M. F. (2018). Passive houses in Ukraine and countries of UIC. *Industrial Heat Engineering, 37 (1),* 69–81. doi: http://doi.org/10.31472/ihe.1.2015.09
3. Zhao, J., Chen, B., Liu, J., Wang, Y. (2008). Dynamic Thermal Performance Simulation of an Improved Passive Solar House with Trombe Wall. *Proceedings of ISES World Congress 2007 (Vol. I – Vol. V)*. Beijing, 2234–2239. doi: http://doi.org/10.1007/978-3-540-75997-3_451
4. Boyer, H., Miranville, F., Bigot, D., Guichard, S., Ingar, I. et. al. (2011). Heat Transfer in Buildings: Application to Solar Air Collector and Trombe Wall Design. *Evaporation, Condensation and Heat Transfer,* 227–244. doi: http://doi.org/10.5772/23025
5. Lobna, M., Dehmani, L. (2014). A numerical study of heating and cooling by a Trombe wall in Tunisia. *The fifth International Renewable energy congress*. Tunisia: Hammamet. doi: http://doi.org/10.1109/irec.2014.6826940
6. Basok, B. I. (2014). Eksperymentalnyi budynok pasyvnoho typu. *Enerhoefektyvnist v budivnytstvi ta arkhitekturi, 6,* 3–8.
7. Basok, B. I., Nakorchevskii, A. I. (2014). Modelirovanie teploperedachi cherez naruzhnoe ograzhdenie zdanii s uchetom nepreryvnogo deistviia klimaticheskikh faktorov. *Stroitelnye konstruktsii, 80,* 113–120.
8. Dolyin, A. A. (2014). Creation of an experimental energy-efficient passive type Building. *Energy Security in Transport: Enhancing Energy Efficiency, Decreasing Dependence on Natural Gas*. Kyiv, 26–30.
9. Honcharuk, S. M., Kalinina, M. F., Bozhko, I. K., Kuzhel, L. M., Lysenko, O. M. (2014). Stvorennia eksperymentalnoho enerhoefektyvnoho budynku pasyvnoho typu «nul enerhii». *Promyslova Teplotekhnika, 36 (3),* 88–95.
10. Ratushniak, H. S., Anokhina, K. V. (2007). Analiz metodiv matematychnoho modeliuvannia dlia vyznachennia teploperedachi cherez bahatosharovi zakhysni konstruktsii. *Suchasni tekhnolohii, materialy i konstruktsii v budivnytstvi*. Vinnytsia: UNIVERSUM-Vinnytsia, 137–141.
11. Protasevich, A. S., Kalina, L. M., Krutilin, A. B. (2003). Voprosy teplotekhnicheskogo rascheta naruzhnykh teploizolirovannykh sten zdanii s ekranom i ventiliruemoi prosloikoi. *Stroitelnii rynok, 20,* 1–5.

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DEVELOPMENT OF METHODS OF PROCESSING SENSOR SIGNAL

page 31–33

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The object of research is the process of processing the signal of the primary converter by a certain method. In carrying out measurements on the primary converter of the measuring system, in addition to the action parameter measurement, there are many secondary influences. One of them is the change in the temperature of the environment. This leads to the appearance in the measured signal of such a component as an additional constant level. It is caused by the generation of the primary converter in the absence of influence on the object of measurement of additional charge, potential. That is, in the absence of action on the side of the measurement parameter there is a shift in the zero level of the signal of the primary converter. Thus the fluctuations of the temperature of the medium result in the appearance of a non-informative component in the measurement signal. That is, we get an increase in the error of the measurement result. The principle of the method used to process the signal of the primary converter is presented on the example of measuring the vibration with a piezoelectric accelerometer. The proposed method of processing the signal of measurement allows to distinguish a constant component of the complex signal of measurement. This is achieved by supplying a measuring signal to two parallel channels, in one of which the signal is delayed by phase for half of the period relative to the second, followed by processing on the adder. Since the signal from the primary converter has a wide frequency band, it is necessary to ensure the accuracy of the delay in the phase. This is achieved by reconfiguring a constant time phase filter phase. The reconfiguration is carried out using a frequency-voltage converter that tracks the frequency of the measured signal. Since changes in temperature over time compared with the frequency of measured vibrations are much slower, then the inaccuracy of the scheme is practically absent. That is, the inaccuracy of determining the constant component in the complex signal will be determined by the difference in the amplitudes of adjacent half-lives. The obtained results allow to assert that this method can be used both for correction of the primary transformer itself (by influence on its transfer function), and for correction of the results of measurements in general.

Keywords: primary converter, lining of the piezoelement, piezoelectric accelerometer, first-order phase filter, phase shift.

References

1. Sharapov, V. M., Polishchuk, E. S., Koshevoi, N. D. et. al.; Sharapov, V. M., Polishchuk, E. S. (Eds.) (2012). *Datchiki*. Moscow, 624.
2. Osadchii, E. P. Tikhonov, A. I., Karpov, V. I., Zhuchkov, A. I., Volkov, V. A., Novickii, P. V. et. al.; Osadchego, E. P. (Ed.) (1979).

Proektirovanie datchikov dlia izmereniia mekhanicheskikh velichin. Moscow, 480.
3. Second IFAC Workshop on Adaptive Systems in Control and Signal Processing 1986 (1987). *Adaptive Systems in Control and Signal Processing 1986*. Elsevier, 454. doi: http://doi.org/10.1016/b978-0-08-034085-2.50004-3
4. Dorf, R. C., Bishop, R. H. (2016). *Modern Control Systems*. Pearson, 1032 p.
5. Antonenko, A. M., Kudzin, A. Iu., Gavshin, M. G. (1997). Vliianie domennoi struktury na elektromekhanicheskie svoistva segnetokeramiki CTS i MNVT. *Fizika tverdogo tela, 39 (5),* 920–921.
6. Kaplunov, I. A., Malyshkina, O. V., Golovnin, V. A., Inozemcev, N. V., Dolnikov, G. G. (2014). Pat. RU 2533539. *Pezoelektricheskii datchik udara*. MPK G01P 15/09, H01L41/083. declareted: 27.05.2013; published: 20.11.2014, 9.
7. Kleckers, T. (2012). Force sensors for strain gauge and piezoelectric crystal-based mechatronic systems- a comparison. *2012 IEEE International Instrumentation and Measurement Technology Conference Proceedings. IEEE*. doi: http://doi.org/10.1109/i2mtc.2012.6229515
8. Pat. RU 2410704 (2011). *Mekhanicheskii filtr dlia pezoakselerometra*. MPK G01P 15/09; declareted: 02.02.2009; published: 27.01.2011, 12.
9. Gorish, A. V., Dudkevich, V. P., Kupriianov, M. F.; Gorish, A. V. (Ed.) (1999). *Pezoelektricheskoe priborostroenie*. Moscow, 367.
10. Ageikin, D. I., Kostina, E. N., Kuznecov, N. N. (1965). *Datchiki kontrolia i regulirovaniia*. Moscow, 914.

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ANALYSIS OF THE HEAT EXCHANGE PROCESSES OF THE REMOTE MEASUREMENT DEVICE OF MECHANICAL VALUES

page 34–37

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The object of research is a model of the thermal state of a remote measurement device, determined by the operating conditions and caused by the need to confirm the operation of the device in ambient conditions according to the requirements of the specification. During the research, the physical formulation of the problem of determining the thermal state of a remote measurement device under various operating conditions and their mathematical description were used. The choice of strategy is based on the solution of technological problems that ensure the optimal process of control. The thermal and mathematical model of the thermal mode of the device is developed to calculate the multidimensional temperature fields of the elements of the device. The model of the thermal mode of the remote measurement device is obtained. The proposed method allows to determine the temperature regimes of the nodes in the preparation mode and the main work at different ambient temperatures. In particular, determine the emitting power at the design state and changes over time. The model takes into account the geometric parameters of the main structural elements of the device. At the same time, in order to maintain the heat balance and the adequacy of the model to the main elements of the device, additional characteristics of these components are introduced in the mathematical model. So, the radiation heat exchange between the external surfaces of the device and the compartment structures surrounding it is taken into account. The regularity of changes in ambient temperature depending on the operation mode of the device is taken into account. The non-stationary thermal state of a remote measurement device is considered, taking into account the radiation-convective heat exchange of the external surfaces of the device with the environment. According to the conducted studies, the thermophysical characteristics of the materials used in the model are determined with two options of the temperature conditions of operation of the remote measurement device. The model is implemented in the STAR-CCM program code based on the control volume method. This technique simplifies the development of a numerical three-dimensional model from the control volumes of a remote measurement device for computer analysis. These studies are an integral part in the design, development and use of a remote measurement device based on a gyro sensor in various temperature conditions.

Keywords: measurement strategy, thermal state model, remote measurement, time temperature pattern, gyro sensor readiness.

References

1. Bekintis, Z. N., Kasparaitis, A. Iu., Kumetaitis, Iu. P. (1981). Novye avtomatizirovannye koordinatnye izmeritelnye mashiny. *Stanki i instrument, 4,* 12–15.
2. Bolotov, M. A., Lezin, I. A. (2011). Modeli i metody optimizatsii metodik izmereniia detalei GTD pri ikh kontrole na koordinatno izmeritelnykh mashinakh. *Vestnik Samarskogo gosudarstvennogo aerokosmicheskogo universiteta imeni akademika S. P. Koroleva, 2 (26),* 28.
3. Hruboi, O. P., Shoful, A. K., Kliuchnykov, O. O., Fedorenko, H. M., Kensytskyi, O. H. (2012). Modeliuvannia nahrivu elementiv statora y rotora hidroheneratora-dvyhuna Dnistrovskoi HAES. *Problemy bezpeky atomnykh elektrostantsii i Chornobylia, 18,* 77–87.
4. Solovev, V. V., Lysenko, V. G., Briankin, S. Iu., Kononogov, S. A., Luskinovich, P. N. (2010). Pretsizionnye izmereniia v mashinostroenii. *Zakonodatelnaia i prikladnaia metrologiia, 5 (111),* 38–50.
5. Kobrinskii, A. A., Kobrinskii, A. E. (1985). *Manipuliatsionnye sistemy robotov.* Moscow: Nauka, 343.
6. Coordinate measuring machine (1995). *Advanced Mathematical Tools in Metrology II, 27 (45),* 45.
7. Measuring system automatically recognizes geometric features (1996). *Modern machine shop, 69 (3),* 484.
8. Ernst, M. (1994). 3D-Koordinen – Messtechnik der Zukunst. *Masehinenbau, 23 (12),* 21.
9. Modestov, M. B. (1976). Issledovanie tochnosti modulnykh golovok dlia koordinatno-izmeritelnykh mashin s CHPU. *Modelirovanie zadach mashinostroeniia na EVM*. Moscow: Nauka, 17–20.
10. Serkov, H. A. (1982). Izmerenie prostranstvenno-slozhnykh poverkhnostei na koordinatnykh izmeritelnykh mashinakh. *Stanki i instrument, 11,* 20–24.
11. CMM for precise operation (1995). *American machine, 139 (3),* 73.