ABSTRACT AND REFERENCES

ECOLOGY

DOI: 10.15587/1729-4061.2019.166571

CONSTRUCTION OF A GENERALIZED MODEL OF THE HARMFUL SUBSTANCES BIOCHEMICAL DESTRUCTION PROCESS KINETICS UNDER CONDITIONS OF SUBSTRATE INHIBITION USING THE METHODS OF SIMULATION MODELING (p. 6–16)

Ganna Bakharieva
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-0765-9943

Tetiana Falalieieva
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-0021-4917

Serhii Petrov
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0001-6500-5310

Iryna Mezentseva
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0001-7695-7982

Borys Kobylianskyi
Teaching and Research Professional Pedagogical Institute
of Ukrainian Engineering and Pedagogical Academy,
Bakhmut, Ukraine
ORCID: http://orcid.org/0000-0003-3226-5997

Ihor Tolkunov
National University of Civil Defense of Ukraine, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0001-5129-3120

Oleksandr Bondarenko
National University of Civil Defense of Ukraine, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-7544-3442

For the purpose of obtaining the complete range of solutions for substrate inhibition of varying intensity, the mechanism of enzyme kinetics in a biocell was modeled by a multi-channel queuing system. A full range of solutions is required to make a well-grounded choice of a unified generalizing formula. The process of biodegradation with substrate inhibition was described mathematically using the method of dynamics of averages. For specific destruction rate, a full range of solutions V_n of the system from minimum $n=2$ to limiting $n\to\infty$ order was found. It was established that the parameters of the curve shape for the solution with minimum inhibition intensity V_2 substantially stand out from the general series of the spectrum formulas. The value of the coordinate of function maximum ($n=2$) V_2 is by 1.42 times higher than that of dependence ($n=3$) V_3.

In the numerical experiment, the physical test was simulated by description with the help of the method of the least squares of the data, assigned by the calculation from the formulas of different structures, bearing in mind a sporadic random error. The series of numerical experiments demonstrated the capability of the formula of limiting order formula V_e to describe the dependences of the whole spectrum of solutions. During describing the intermediate ratio V_3 with the help of formulas V_2 and V_e, the benefit is the possible range of changing the concentrations, which is by 1.5–2 times larger at the same relative error for dependence V_e. For critical minimal order, an average relative error is sure not to exceed five percent. An increase in random error always result in statistical equality, in accuracy of describing by formulas of minimal V_2 and limiting orders V_e of the data, assigned by calculation of second-order dependences. Statistical equality is achieved at the ratio of a random error to the initial error equal to ≥2.4.

Collectively, the importance of the results of numerical modeling of a physical experiment involves proving the possibility of using the formula of limiting order V_e as unified when describing the biodegradation processes with different mechanisms of substrate inhibition. This conclusion is proved by the adequate (R^2=0.9396–0.9953) description with the help of the dependence of limiting order of experimental data on five harmful substances with varying inhibition degrees. A large amount of calculation allowed achieving a definite result – we obtained the unified formula that makes it possible to proceed to scientifically grounded design calculations for bio-treatment plants.

Keywords: biodegradation, substrate inhibition, queuing system, numerical experiment, unified formula.

References

1. Andrews, J. F. (1968). A mathematical model for the continuous culture of microorganisms utilizing inhibitory substrates. Biotechnology and Bioengineering, 10 (6), 707–723. doi: https://doi.org/10.1002/bit.260100602
2. Yano, T., Nakahara, T., Kamiyama, S., Yamada, K. (1966). Kinetic Studies on Microbial Activities in Concentrated Solutions. Agricultural and Biological Chemistry, 30 (1), 42–48. doi: https://doi.org/10.1080/00021369.1966.10858549
3. Yano, T., Koga, S. (1969). Dynamic behavior of the chemostat subject to substrate inhibition. Biotechnology and Bioengineering, 11 (2), 139–153. doi: https://doi.org/10.1002/bit.260110204
4. Webb, J. L. (1963). Enzyme and Metabolic Inhibitors. New York: Academic Press. doi: https://doi.org/10.5962/bhl.title.7320
5. Aiba, S., Shoda, M., Nagatani, M. (1968). Kinetics of product inhibition in alcohol fermentation. Biotechnology and Bioengineering, 10 (6), 845–864. doi: https://doi.org/10.1002/bit.260100610
6. Tseng, M. M.,Wayman, M. (1975). Kinetics of yeast growth: inhibition-threshold substrate concentrations. Canadian Journal of Microbiology, 21 (7), 994–1003. doi: https://doi.org/10.1139/m75-147
7. Luong, J. H. T. (1987). Generalization of monod kinetics for analysis of growth data with substrate inhibition. Biotechnology and Bioengineering, 29 (2), 242–248. doi: https://doi.org/10.1002/bit.260290215
8. Tsuji, S., Shimizu, K. (1987). Performance evaluation of ethanol fermentor systems using a vector-valued objective function. Biotechnology and Bioengineering, 30 (3), 420–426. doi: https://doi.org/10.1002/bit.260300313
9. Han, K., Levenspiel, O. (1988). Extended monod kinetics for substrate, product, and cell inhibition. Biotechnology and Bioengineering, 32 (4), 430–447. doi: https://doi.org/10.1002/bit.260320404
10. Edwards, V. H. (1970). The influence of high substrate concentrations on microbial kinetics. Biotechnology and Bioengineering, 12 (5), 679–712. doi: https://doi.org/10.1002/bit.260120504
11. Bakhareva, A., Shestopalov, O., Filenko, O., Kobilyansky, B. (2016). Development of universal model of kinetics of bioremediation stationary process with substrate inhibition. Eastern-European Journal of Enterprise Technologies, 2 (10 (80)), 19–26. doi: https://doi.org/10.15587/1729-4061.2016.65036
12. Nweke, C. O., Okpokwasili, G. C. (2014). Kinetics of growth and phenol degradation by Pseudomonas Species isolated from petroleum refinery wastewater. International Journal of Biosciences, 4 (7), 28–37. doi: https://doi.org/10.12692/ijb/4.7.28-37

13. Prifti, T., Pinguli, L., Malollari, I. (2017). A comparative study of kinetic immobilized yeast parameters in batch fermentation processes. Europen Journal of Advanced Research in Biological and Life Sciences, 5 (3), 1–8.
14. Ahmad, F. (2011). Study of growth kinetic and modeling of ethanol production by Saccharomyces cerevisa. AFRICAN JOURNAL OF BIOTECHNOLOGY, 10 (81). doi: https://doi.org/10.5897/ajb11.2763
15. Olivera, S. C., Stremel, D. P., Dechechi, E. C., Pereira, F. M. (2017). Kinetic Modeling of 1-G Ethanol Fermentations. Fermentation Processes, 93–117. doi: https://doi.org/10.5772/65460
16. Dutta, K. (2015). Substrate Inhibition Growth Kinetics for Cutinase Producing Pseudomonas cepacia Using Tomato-peel Extracted Cutin. Chemical and Biochemical Engineering Quarterly, 29 (3), 437–445. doi: https://doi.org/10.15255/cabeq.2014.2022
17. Tazdaït, D., Abdi, N., Grib, H., Lounici, H., Pauss, A., Mameri, N. (2013). Comparison of different models of substrate inhibition in aerobic batch biodegradation of malathion. Turkish Journal of Engineering and Environmental Sciences, 37, 221–230. doi: https://doi.org/10.3906/muh-1211-7
18. De Prá, M. C., Kunz, A., Bortoli, M., Scussiato, L. A., Coldebella, A., Vanotti, M., Soares, H. M. (2016). Kinetic models for nitrogen inhibition in ANAMMOX and nitrification process on deammonification system at room temperature. Bioresource Technology, 202, 33–41. doi: https://doi.org/10.1016/j.biortech.2015.11.048
19. Agarry, S. E., Audu, T. O. K., Solomon, B. O. (2009). Substrate inhibition kinetics of phenol degradation by Pseudomonas fluorescence from steady state and wash-out data. International Journal of Environmental Science & Technology, 6 (3), 443–450. doi: https://doi.org/10.1007/bf03326083
20. Mounira, K. A., Serge, H., Nawel, O., Radia, C., Noreddine, K. C. (2017). Kinetic models and parameters estimation study of biomass and ethanol production from inulin by Pichia caribbica (KC977491). African Journal of Biotechnology, 16 (3), 124–131. doi: https://doi.org/10.5897/ajb2016.15747
21. Wei, Y.-H., Chen, W.-C., Chang, S.-M., Chen, B.-Y. (2010). Exploring Kinetics of Phenol Biodegradation by Cupriavidus taiwanesis 187. International Journal of Molecular Sciences, 11 (12), 5065–5076. doi: https://doi.org/10.3390/ijms11125065
22. Halmi, M. I. E., Shukor, M. S., Shukor, M. Y. (2014). Evoluation of several mathematical models for fitting the growth and kinetics of the Catechol-degrading Candida parapsilopsis: part 2. Journal of Environmental Bioremediation and Toxicology, 2 (2), 53–57.
23. Day, S., Mukherjee, S. (2014). A study of the kinetic coefficients and the rate of biodegradation of phenol by indigenous mixed microbial system. African Journal of Water Conservation and Sustainability, 2 (1), 099–107.
24. Chakraborty, B., Ray, L., Basu, S. (2015). Study of phenol biodegradation by an indigenous mixed consortium of bacteria. Indian Journal of Chemical Technology, 22 (5), 227–233.
25. Nsoe, M. N., Kofa, G. P., Ndi, K. S., Mohammadou, B., Heran, M., Kayem, G. J. (2018). Biodegradation of Ammonium Ions and Formate During Ammonium Formate Metabolism by Yarrowia lipolytica and Pichia guilliermondii in a Batch Reactor. Water, Air, & Soil Pollution, 229 (5). doi: https://doi.org/10.1007/s11270-018-3795-0
26. Deriase, S. F., Younis, S. A., El-Gendy, N. S. (2013). Kinetic evaluation and modeling for batch degradation of 2-hydroxybiphenyl and 2,2′-dihydroxybiphenyl byCorynebacterium variabilisSh42. Desalination and Water Treatment, 51 (22-24), 4719–4728. doi: https://doi.org/10.1080/19443994.2012.744950
27. Raghuvanshi, S., Gupta, S. (2012). Growth kinetics of acclimated mixed culture for degradation of Isopropyl Alcohol (IPA). Journal of Biotechnology and Biomaterials, s13. doi: https://doi.org/10.4172/2155-952x.s13-002
28. Dey, S., Mukherjee, S. (2012). Kinetic modelling for removal of *m*-cresol from wastewater using mixed microbial culture in batch reactor. Journal of Water Reuse and Desalination, 2 (3), 149–156. doi: https://doi.org/10.2166/wrd.2012.055
29. Taho Hemdi, A. (2001). Vvedenie v issledovanie operaciy. Moscow, Sankt-Peterburg, Kyiv: Izdatel'skiy dom «Vil'yams», 912.
30. Keleti, T. (1990). Osnovy fermentativnoy kinetiki. Moscow: Mir, 350.
31. Tikhonov, A. N. (1952). Systems of differential equations containing small parameters in the derivatives. Matematicheskiy sbornik, 31 (3), 575–586. Available at: http://www.mathnet.ru/links/672ece88e3cd9c1c4e2f0a144ca1951e/sm5548.pdf
32. Romanovskiy, Yu. M., Stepanova, N. V., Chernavskiy, D. S. (2003). Matematicheskoe modelirovanie v biofizike. Moscow, Izhevsk: Institut komp'yuternyh issledovaniy, 402.

DOI: 10.15587/1729-4061.2019.170200

USE OF FLY ASH FOR CONDITIONING THE EXCESS ACTIVATED SLUDGE DURING DELIQUEFACTION AT CHAMBER-MEMBRANE FILTER PRESSES (p. 17–23)

Oleh Zlatkovskyi
PRODEKO-ELK Sp.zo.o., Elk, Poland
ORCID: http://orcid.org/0000-0002-2350-5955

Andrii Shevchenko
PRODEKO-ELK Sp.zo.o., Elk, Poland
ORCID: http://orcid.org/0000-0002-9576-282X

Tamara Shevchenko
O. M. Beketov National University of Urban Economy in Kharkiv, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-4513-6759

Results of experimental studies of deliquefaction of excess activated sludge from municipal wastewater treatment facilities in chamber-membrane filter presses were presented. To condition the sludge, fly ash from thermal power plants was added as a mineral additive. Experimental studies have shown high efficiency of deliquefaction of the excess activated sludge with addition of fly ash. Increase in the dose of fly ash has led to an overall increase in filtration capacity and a decrease in moisture content in the filter cake. It was found that in the case of adding fly ash in an amount of 2 wt. % of the initial sludge, deliquefaction efficiency did not increase significantly. In this case, filtering time was reduced only by 15 % and specific capacity increased by 12 %. In the case of increasing the proportion of fly ash to 6 wt. % of initial sludge, a more intensive acceleration of the process was observed. Filtering duration was reduced from 100 to 10 min, specific capacity increased from 87 to 400 $l/m^2 \cdot hr$.

Experimental studies have shown that addition of fly ash to sediments of municipal wastewater treatment facilities as a mineral component provides the possibility of deliquefaction of the suspensions obtained using a chamber-membrane filter press. With optimal doses of 4–5 wt. % of the mass of initial sludge, filter capacity is expected to be 350–400 $l/m^2 \cdot hr$. The resulting filter cake had moisture content of about 60 %, a dense, dry structure making it possible to transport it in bulk.

Keywords: chamber-membrane filter press, conditioning, fly ash, deliquefaction, filtering duration, activated sludge.

References

1. Sizykh, M. R. (2013). Conditioning of sewage sludge. Vestnik Buryatskogo gosudarstvennogo universiteta, 3, 17–19.
2. Wójcik, M., Stachowicz, F., Masłoń, A. (2017). The Possibility of Sewage Sludge Conditioning and Dewatering with the Use of Bio-

mass Ashes. Engineering and Protection of Environment, 20 (2), 153–164. doi: https://doi.org/10.17512/ios.2017.2.1
3. Bazzaoui, R., Fraikin, L., Groslambert, S., Salmon, T., Crine, M., Léonard, A. (2011). Impact of Sludge Conditioning on Mechanical Dewatering and Convective Drying. European Drying Conference – EuroDrying'2011, Palma. Balearic Island. Available at: http://www.uibcongres.org/imgdb/archivo_dpo11043.pdf
4. Długosz, J., Gawdzik, J. (2014). The Content of Heavy Metals in Sewage Sludge Conditioned CaO. Archives of Waste Management and Environmental Protection, 16 (2), 49–56.
5. Zhou, W., Lu, Y., Jiang, S., Xiao, Y., Zheng, G., Zhou, L. (2018). Impact of sludge conditioning treatment on the bioavailability of pyrene in sewage sludge. Ecotoxicology and Environmental Safety, 163, 196–204. doi: https://doi.org/10.1016/j.ecoenv.2018.07.088
6. Dieudé-Fauvel, E., Dentel, S. K. (2011). Sludge Conditioning: Impact of Polymers on Floc Structure. Journal of Residuals Science & Technology, 8 (3), 101–108.
7. Cao, X., Jiang, Z., Cui, W., Wang, Y., Yang, P. (2016). Rheological Properties of Municipal Sewage Sludge: Dependency on Solid Concentration and Temperature. Procedia Environmental Sciences, 31, 113–121. doi: https://doi.org/10.1016/j.proenv.2016.02.016
8. Yang, G. C. C., Lin, C.-K. Effects of Conditioning and Electrokinetics on Sewage Sludge Dewatering. Available at: http://uest.ntua.gr/athens2017/proceedings/pdfs/Athens2017_Gordon_Yang_Lin.pdf
9. Lu, Y., Zhang, C., Zheng, G., Zhou, L. (2018). Improving the compression dewatering of sewage sludge through bioacidification conditioning driven by Acidithiobacillus ferrooxidans: dewatering rate vs. dewatering extent. Environmental Technology, 1–14. doi: https://doi.org/10.1080/09593330.2018.1465129
10. Wójcik, M., Stachowicz, F., Masłoń, A. (2017). The Evaluation of the Effectiveness of Sewage Sludge Conditioning with the Application of Biomass Ashes. Engineering and Protection of Environment, 20 (3), 295–304.
11. Zhvakina, O. A., Gelfand, E. D. (2002). On joint treatment of waste waters sludge of ppm with ash from heat-and-power station. Izvestiya vysshih uchebnyh zavedeniy. Lesnoy zhurnal, 3, 114–121.
12. Leont'ev, N. E. (2009). Osnovy teorii fil'tratsii. Moscow: Izd-vo TSPI pri mekhaniko-matematicheskom fakul'tete MGU, 24–29.
13. Bahvalov, N. S., Panasenko, G. P. (1984). Osrednenie protsessov v periodicheskih sredah. Moscow: Nauka, 164–169.
14. Belyaev, A. Yu. (2004). Usrednenie v zadachah teorii fil'tratsii. Moscow: Nauka, 76–127.

DOI: 10.15587/1729-4061.2019.166375

DESIGN OF FIRE-RESISTANT HEAT- AND SOUNDPROOFING WOOD WOOL PANELS (p. 24–31)

Yuriy Tsapko
National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine
Kyiv National University of Construction and Architecture, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0003-0625-0783

Denys Zavialov
National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0002-9532-0060

Olga Bondarenko
Kyiv National University of Construction and Architecture, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0002-8164-6473

Olena Pinchevs'ka
National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0001-8123-5490

Nataliia Marchenco
National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0003-1826-930X

Sergii Guzii
Kyiv National University of Construction and Architecture, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0003-0147-5035

The conducted research revealed the possibility to manufacture heat- and soundproofing materials for the arrangement of buildings. Wood fibers, which are produced in the form of flat panels, are the raw materials for their production. The mechanisms for the process of heat- and soundproofing during energy transfer through the material, which enables influencing this process, were established. It was proved that they are related to the porosity of the material. Thus, at a decrease in volume weight of the material, thermal conductivity and sound transmission are reduced, and vice versa. In addition, heat- and soundproofing building materials from wood should meet the following requirements: to have stable thermal insulation and acoustic indicators within the whole operation period and to be fire resistant, not to give off hazardous substances into the environment. Experimental research proved that the material based on wood wool and inorganic binder at the ratio of 1:1 belongs to combustible materials, because there was its smoldering during the temperature exposure. Thus, under thermal exposure for 90 seconds, the sample caught fire, the flame propagated around the first three zones within 41 s. At the same time, an increase in the amount of the binder on inorganic base and application of organic-mineral binder does not lead to the ignition of material, the maximum temperature of flue gases made up around 120 °C and flammability index amounted to 0. This became possible due to the decomposition of fire retardants under the influence of temperature with emitting non-combustible gases, inhibiting the processes of material oxidation and significantly increasing the formation of the heat protective layer of coke on the surface of the material. This leads to inhibition of heat transfer of high-temperature flame to the material. This made it possible to determine the conditions for fire-resistance of the material through the formation of a thermal conductivity barrier. This makes it possible to argue about the relevance of the detected mechanism of formation of properties of the material based on wood wool and inorganic or organic-mineral binder, as well as practical attractiveness of the proposed technological solutions. The latter, in particular, relate to determining the amount of the binder component (the ratio of wood wool to the binder is not less than 1:2), because in small quantities (ratio 1:1), the burning process occurs. Thus, there are the grounds to argue about the possibility of directional regulation of the processes of formation of heat- and soundproofing wood materials through the use of wood wool and the binder. In this case, it was proposed to use the inorganic and organic-mineral coatings as a binder, which can form a fireproofing film at the surface of the material.

Keywords: heat- and soundproofing materials, wood wool, thermal conductivity, soundproofing, inorganic and organic-mineral binder.

References

1. Tsapko, Y., Tsapko, A. (2017). Establishment of the mechanism and fireproof efficiency of wood treated with an impregnating solution and coatings. Eastern-European Journal of Enterprise Technologies, 3 (10 (87)), 50–55. doi: https://doi.org/10.15587/1729-4061.2017.102393
2. Tsapko, Y., Tsapko, A. (2018). Modeling a thermal conductivity process under the action of flame on the wall of fireretardant reed.

Eastern-European Journal of Enterprise Technologies, 2 (10 (92)), 50–56. doi: https://doi.org/10.15587/1729-4061.2018.128316

3. Tsapko, Y., Guzii, S., Remenets, M., Kravchenko, A., Tsapko, O. (2016). Evaluation of effectiveness of wood fire protection upon exposure to flame of magnesium. Eastern-European Journal of Enterprise Technologies, 4 (10 (82)), 31–36. doi: https://doi.org/10.15587/1729-4061.2016.73543
4. Tsapko, Y., Kyrycyok, V., Tsapko, A., Bondarenko, O., Guzii, S. (2018). Increase of fire resistance of coating wood with adding mineral fillers. MATEC Web of Conferences, 230, 02034. doi: https://doi.org/10.1051/matecconf/201823002034
5. Babashov, V. G., Bespalov, A. S., Istomin, A. V., Varrik, N. M. (2017). Heat and Sound Insulation Material Prepared Using Plant Raw Material. Refractories and Industrial Ceramics, 58 (2), 208–213. doi: https://doi.org/10.1007/s11148-017-0082-3
6. Danilov, V., Ayzenshtadt, A., Makhova, T. (2018). Obtaining and characterization of wood-mineral Composites. 18th International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 18, 347–354. doi: https://doi.org/10.5593/sgem2018/6.1/s24.047
7. Brencis, R., Pleiksnis, S., Skujans, J., Adamovics, A., Gross, U. (2017). Lightweight composite building materials with hemp (Cannabis sativa L.) additives. Chemical Engineering Transactions, 57, 1375–1380. doi: http://doi.org/10.3303/CET1757230
8. Li, Z., Ma, J., Ma, H., Xu, X. (2018). Properties and Applications of Basalt Fiber and Its Composites. IOP Conference Series: Earth and Environmental Science, 186, 012052. doi: https://doi.org/10.1088/1755-1315/186/2/012052
9. Zaryoun, M., Hosseini, M. (2018). Lightweight fiber-reinforced clay as a sustainable material for disaster resilient architecture of future buildings. Architectural Engineering and Design Management, 1–15. doi: https://doi.org/10.1080/17452007.2018.1540968
10. Alabdulkarem, A., Ali, M., Iannace, G., Sadek, S., Almuzaiqer, R. (2018). Thermal analysis, microstructure and acoustic characteristics of some hybrid natural insulating materials. Construction and Building Materials, 187, 185–196. doi: https://doi.org/10.1016/j.conbuildmat.2018.07.213
11. Grickus, A., Guseynov, S. E. (2015). On one Mathematical Model for Dynamics of Propagation and Retention of Heat over New Fibre Insulation Coating. Environment. Technology. Resources. Proceedings of the International Scientific and Practical Conference, 3 (82). doi: https://doi.org/10.17770/etr2015vol3.504
12. Chen, H., Yuan, J., Zhong, Q., Li, K. (2017). Optimization for heat and sound insulation of honeycomb sandwich panel in thermal environments. Vibroengineering PROCEDIA, 11, 161–166. doi: https://doi.org/10.21595/vp.2017.18481
13. Erdoğan, Y. (2016). Production of an insulation material from carpet and boron wastes. Bulletin of the Mineral Research and Exploration, 152, 197–202. doi: https://doi.org/10.19111/bmre.74700
14. Apostoliuk, S. O., Dzhyhyrei, V. S., Sokolovskyi, I. A. et. al. (2012). Promyslova ekolohiya. Kyiv: Znannia, 430.
15. Bobrov, Yu. L., Ovcharenko, E. G., Shoyhet, B. M., Petuhova, E. Yu. (2003). Teploizolyacionnye materialy i konstrukcii. Moscow: INFRA-M, 268.
16. Konstruktsiyi budynkiv ta sporud. Teplova izoliatsiya budivel: DBN V.2.6-31:2006. zi Zminoiu No. 1 vid 1 lypnia 2013 roku (2006). Kyiv: Minbud Ukrainy, 70.
17. DSTU B EN ISO 1716:2011. Vyprobuvannia vyrobiv shchodo reaktsiyi na vohon. Vyznachennia vyshchoi (nyzhchoi) teploty zghoriannia (EN ISO 1716:2010, IDT) (2012). Kyiv: Minrehionbud Ukrainy, 37.
18. Tsapko, Y. (2013). Effect of surface treatment of wood on the fire resistance of wooden structures. Eastern-European Journal of Enterprise Technologies, 5 (5 (65)), 11–14. Available at: http://journals.uran.ua/eejet/article/view/18104/15850

DOI: 10.15587/1729-4061.2019.170079

DEVELOPMENT OF A METHOD FOR OPTIMIZATION CALCULATION OF A GROUP OF SOUND-INSULATING PANELS FOR AIRBORN NOISE PROTECTION (p. 32–38)

Oleksandr Mamontov
Kharkiv National University of Radio Electronics, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-1464-8644

Tatiana Stytsenko
Kharkiv National University of Radio Electronics, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-4530-0253

Various designs and procedures for calculating soundproof panels for protecting premises against airborne noise were considered. These procedures make it possible to calculate single-layer, two-layer and three-layer panels. Single-layer panels may consist of homogeneous solid and thin materials. Two-layer panels may consist of two thin layers of different thickness and an air gap. Three-layer panels can be made of two thin layers of different thickness and a sound-absorbing material between them. These procedures enable calculation and optimization of individual structures of sound-proofing panels independently of each other. The problem of simultaneous penetration of noise from one source into several adjacent rooms was considered. When using the procedures considered in references, maximum effect is unattainable. In this regard, a method of optimization calculation of a group of sound-proofing panels aimed at achievement of the most advantageous value of the objective function was proposed.

The method is based on a random search resting on random distribution of typical structures and procured materials among panels. Choice of the best result is made proceeding from a result of checking fulfillment of limiting conditions.

The following options of the objective function were proposed: the excessive noise load, the total index of noise reduction in rooms, the total cost of sound-proofing panels and the number of panels made. Recommendations were given on the choice of the objective function option taking into account concrete production conditions.

The result of optimization consists in the choice of design of the panel for each room and distribution of available materials among them. Formulation of the optimization problem with various options of the objective function and limitations has been considered. Efficiency of using this method was confirmed by almost 24 % lower cost of panels compared to the separate panel designing using conventional methods.

Keywords: noise, multilayer panels, sound insulation, optimization calculation, calculation algorithm, objective function.

References

1. World Health Organization. Available at: https://www.who.int/healthinfo/statistics/en/
2. Patinha, S., Cunha, F., Fangueiro, R., Rana, S., Prego, F. (2014). Acoustical Behavior of Hybrid Composite Sandwich Panels. Key Engineering Materials, 634, 455–464. doi: https://doi.org/10.4028/www.scientific.net/kem.634.455
3. Ehsan Moosavimehr, S., Srikantha Phani, A. (2017). Sound transmission loss characteristics of sandwich panels with a truss lattice core. The Journal of the Acoustical Society of America, 141 (4), 2921–2932. doi: https://doi.org/10.1121/1.4979934
4. Khalkhali, A., Narimanzadeh, N., Khakshournia, S., Amiri, S. (2014). Optimal design of sandwich panels using multi-objective genetic algorithm and finite element method. International Journal of Engineering, 27 (3), 395–402. Available at: http://www.ijeir.info/article_72266_adb3b989a7941894512bf7c6927b94ed.pdf

5. Cameron, C. J., Lind Nordgren, E., Wennhage, P., Göransson, P. (2014). On the balancing of structural and acoustic performance of a sandwich panel based on topology, property, and size optimization. Journal of Sound and Vibration, 333 (13), 2677–2698. doi: https://doi.org/10.1016/j.jsv.2014.01.025
6. Leite, P., Thomas, M., Simon, F., Bréchet, Y. (2015). Optimal Design of a Multifunctional Sandwich Panel With Foam Core: Lightweight Design for Flexural Stiffness and Acoustical Transmission Loss. Advanced Engineering Materials, 17 (3), 311–318. doi: https://doi.org/10.1002/adem.201400075
7. Wang, T., Li, S., Nutt, S. R. (2009). Optimal design of acoustical sandwich panels with a genetic algorithm. Applied Acoustics, 70 (3), 416–425. doi: https://doi.org/10.1016/j.apacoust.2008.06.003
8. Li, Q., Yang, D. (2018). Mechanical and Acoustic Performance of Sandwich Panels With Hybrid Cellular Cores. Journal of Vibration and Acoustics, 140 (6), 061016. doi: https://doi.org/10.1115/1.4040514
9. Belikov, A. S., Sokolov, I. A., Shalomov, V. A., Mamontov, A. V. (2017). Improving safety in workplaces when operating the compressor units for the account of improving the calculation of sound absorption coatings. Heotekhnichna mekhanika, 135, 246–257.
10. Kliuchnik, I., Mamontov, A., Umiarov, R., Shalayeva, V. (2018). Methods of modular type rotors optimal complexing in the process of the composition. Metrology and Instruments, 1, 53–57.
11. Soundproofing materials and acoustic Solutions. Available at: http://www.keepitquiet.co.uk/
12. Kiseleva, E. G. (2011). Raschet zvukoizolyatsii ograzhdayuschih konstruktsiy zhilyh i obschestvennyh zdaniy. Moscow, 52.
13. Mistakidis, E. S., Stavroulakis, G. E. (2013). Nonconvex Optimization in Mechanics: Algorithms, Heuristics and Engineering Applications by the F.E.M. New York: Springer.
14. Gurskiy, D., Turbina, E. (2006). Vychisleniya v MATHCAD 12. Sankt-Peterburg: Piter, 544.
15. Rybalko, O. M. (2014). Vyshcha matematyka (spetsialni rozdili). Osnovy teoriyi imovirnostei z elementamy matematychnoi statystyky. Kharkiv, 359.

DOI: 10.15587/1729-4061.2019.170510

ASSESSMENT AND PREVENTION OF THE PROPAGATION OF CARBON MONOXIDE OVER A WORKING AREA AT ARC WELDING (p. 38–49)

Viacheslav Berezutskyi
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-7318-1039

Inna Hondak
Kharkiv National University of Radio Electronics, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0001-6644-9968

Nataliia Berezutska
Kharkiv National University of Radio Electronics, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-2573-9031

Vitaly Dmitrik
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-1085-3811

Veronika Gorbenko
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-2538-6830

Viktoriia Makarenko
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-5380-8439

This paper reports a study of air environment at industrial premises where welding processes take place, with special attention paid to the formation of carbon monoxide (oxide) (CO) in the working environment in the process of manual arc welding. We have given the classification of basic harmful substances generated during welding and related processes in terms of the character of negative influence on the body of a welder. A mathematical model of the dynamics of change in the concentration of carbon monoxide in the air of a working area has been constructed, based on the amount of a harmful substance (m) in the air at premises at a time point, the intensity of its release into air, and the air exchange rate. A given mathematical model includes the propagation of carbon monoxide in the air, considering the air exchange between the overall volume of a premise and the local volumes of working zones.

There are not enough studies into the formation of carbon monoxide during welding processes, which is why examining this process is a priority.

Out experimental study has confirmed that the concentration of carbon monoxide outside the local volumes of local ventilation devices, that is in the air of working zones, remains constant (to 0.01 mg/m^3) and does not exceed MPC (20 mg/m^3). A failure or the absence of general ventilation leads to a rapid increase in the concentration of carbon monoxide (CO) in line with an exponential dependence (from 150 to 200 mg/m^3 over 0.5–0.6 hours) within a small closed workspace (1 m^3), and can quickly spread throughout the entire premise.

However, a failure or the absence of general ventilation leads to a rapid increase in the concentration of carbon monoxide (CO) in line with an exponential dependence. This indicates that general ventilation is important, but it does not warrant safety for welders and other workers from gas poisoning. Therefore, the use of local ventilation must be ensured, as well as respiratory protection for all present when conducting welding processes. The derived mathematical models make it possible to assess risks during welders' operations, to take into consideration CO emissions when calculating ventilation systems in working areas, to adjust the system that manages risks and labor safety.

Keywords: arc welding, carbon monoxide, harmful emissions, workspace, gas poisoning.

References

1. Markiv, B. Umovy pratsi zvarnykiv. Vplyv shkidlyvykh vyrobnychykh faktoriv. Available at: http://te.dsp.gov.ua/umovy-pratsi-zvarnykiv-vplyv-shkidlyvyh-vyrobnychyh-faktoriv/
2. Welding fume hazards. Safety+Health. Available at: https://www.safetyandhealthmagazine.com/articles/14291-welding-fume-hazards&prev=search
3. Horbokon, A. V. (2017). Zvariuvalnyi aerozol ta zasoby zmenshennia yoho shkidlyvoho vplyvu. Unyversytetskaia nauka – 2017: materialy mezhdunar. nauk.-tekhn. konf. Vol. 1. Mariupol, 293–294.
4. Shkidlyvi rechovyny pry zvariuvanni i navishcho potribno filtroventyliatsiine obladnannia. Available at: http://sammit.dp.ua/articles/svarka_vred.htm
5. Grishagin, V. M., Lugovtsova, N. Yu. (2011). Svarochnyy aerozol' kak osnovnaya ekologicheskaya problema sovremennogo svarochnogo proizvodstva v mashinostroenii. Vestnik nauki Sibiri, 1, 726–728.
6. Levchenko, O. H., Bulat, A. V., Bezushko, O. M. (2010). Vplyv vydu elektrodnoho pokryttia na hihienichni kharakterystyky aerozoliv, shcho utvoriuiutsia pry zvariuvanni vysokolehovanykh stalei. Visnyk NTU «KPI». Seriya «Hirnytstvo», 19, 171–177.

7. Hariri, A., Paiman, N. A., Leman, A. M., Yusof, M. Z. Md. (2014). Development of Welding Fumes Health Index (WFHI) for Welding Workplace's Safety and Health Assessment. Iran J Public Health, 43 (8), 1045–1059. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4411901/
8. Savytskyi, O. M., Mandryk, O. M. (2014). Ekolohichna skladova duhovoho zvariuvannia ta napriamok yii pidvyshchennia. Naukovyi visnyk IFNTUNH, 1 (36), 66–73. Available at: http://elar.nung.edu.ua/bitstream/123456789/2544/1/3450p.pdf
9. Mistry, P. K. J. (2015). Impact of Welding Processes on Environment and Health. International Journal of Advanced Research in Mechanical Engineering & Technology (IJARMET), 1 (1), 17–20. Available at: http://ijarmet.com/wp-content/themes/felicity/issues/vol1issue1/pankaj1.pdf
10. Meneses, V. A. de, Leal, V. S., Scotti, A. (2016). Influence of Metal Transfer Stability and Shielding Gas Composition on CO and CO_2 Emissions during Short-circuiting MIG/MAG Welding. Soldagem & Inspeção, 21 (3), 253–268. doi: https://doi.org/10.1590/0104-9224/si2103.02
11. Qin, J., Liu, W., Zhu, J., Weng, W., Xu, J., Ai, Z. (2014). Health Related Quality of Life and Influencing Factors among Welders. PLoS ONE, 9 (7), e101982. doi: https://doi.org/10.1371/journal.pone.0101982
12. Kirichenko, K. Yu., Rogulin, R. S., Drozd, V. A., Gridasov, A. V., Holodov, A. S., Il'yaschenko, D. P. et. al. (2018). Otsenka rasprostraneniya chastits svarochnogo aerozolya v prostranstve rabochey zony svarschika v zavisimosti ot vremeni. Ekologicheskaya bezopasnost' stroitel'stva i gorodskogo hozyaystva, 2, 42–51. doi: http://doi.org/10.24411/1816-1863-2018-12042
13. Ignatova, A. M., Ignatov, M. N. (2012). Otsenka morfologii, dispersnosti, struktury i himicheskogo sostava tverdoy sostavlyayuschey svarochnyh aerozoley posredstvom sovremennyh metodov issledovaniy. Nauchno-tekhnicheskiy vestnik Povolzh'ya, 3, 133–138.
14. Kuznetsov, D. A., Simonovich, A. L., Naumov, S. V., Ignatova, A. M. (2012). Issledovanie fiziko-himicheskih harakteristik tverdoy sostavlyayuschey svarochnyh aerozoley. Aerozoli Sibiri: sb. tez. dokl. XIX Rab. gruppy konf. Tomsk, 78.
15. Bykovskyi, O. H., Lazutkin, M. I. (2012). Okhorona pratsi pry vyrobnytstvi konstruktsiy z kolorovykh metaliv i splaviv. Visnyk Nats. tekhn. un-tu «KhPI», 1, 128–136.
16. Demchina, M. (2012). Vpliv komponentiv zvaryuval'nogo aerozolyu na zdorov'ya lyudini. Available at: https://city-adm.lviv.ua/news/society/emergency/233003-vplyv-komponentiv-zvariuvalnoho-aerozoliu-na-zdorovia-liudyny
17. Logvinov, Y. V. (2016). Ecological management, and decision of a concrete question of welding aerosol localization and neutralization at surfacing. Visnyk Pryazovskoho derzhavnoho tekhnichnoho universytetu. Seriya: Tekhnichni nauky, 33, 193–197.
18. Hranychno dopustymi kontsentratsiyi \HDK\ ta orientovni bezpechni rivni diyannia \OBRD\ zabrudniuiuchykh rechovyn v atmosfernomu povitri naselenykh mists. Available at: http://www.mcl.kiev.ua/wp-content/uploads/2017/10/OBRV-2017.pdf
19. Li, H., Hedmer, M., Kåredal, M., Björk, J., Stockfelt, L., Tinnerberg, H. (2015). A Cross-Sectional Study of the Cardiovascular Effects of Welding Fumes. PLOS ONE, 10 (7), e0131648. doi: https://doi.org/10.1371/journal.pone.0131648
20. Levchenko, O. G., Demetska, O. V., Lukyanenko, A. O. (2016). Cytotoxicity of welding fumes generated in welding with covered electrodes. Ukrainskyi zhurnal z problem medytsyny pratsi, 3, 30–35.
21. Hihienichna klasyfikatsiya pratsi za pokaznykamy shkidlyvosti ta nebezpechnosti faktoriv vyrobnychoho seredovyshcha, vazhkosti ta napruzhenosti trudovoho protsesu. Hihienichni normatyvy HN 3.3.5-8-6.6.1 2002 r. (2001). Kyiv, 46.
22. Opara, N. M., Dudar, N. I. Chadnyi haz: vplyv na orhanizm liudyny, sposoby indyvidualnoho zakhystu i bezpechnoi povedinky. Available at: http://dspace.pdaa.edu.ua:8080/bitstream/123456789/798/1/Чадний%20газ%20%20вплив%20на%20організм%20людини%2C%20способи%20індивідульного%20захисту%20і%20безпечної%20поведінки.pdf
23. Okys vuhletsiu (chadnyi haz). Available at: https://empendium.com/ua/chapter/B27.II.20.10
24. Entsiklopediya po ohrane i bezopasnosti truda. Available at: http://base.safework.ru/iloenc
25. Ukraina lidyruie za kilkistiu pidpryiemstv derzhavnoi formy vlasnosti (2017). Available at: https://konkurent.in.ua/publication/14844/ukrayina-lidiruye-za-kilkistyu-pidpriyemstv-derzhavnoyi-formi-vlasnosti-/
26. Dozor S M Signalizator-analizator gazov mnogokomponentniy individual'nyy. Rukovodstvo po ekspluatatsii AGAT RE. Available at: https://docplayer.ru/53460271-Dozor-s-m-signalizator-analizator-gazov-mnogokomponentnyy-individualnyy-rukovodstvo-po-ekspluatacii-agat-re.html
27. Pachurin, G. V., Shevchenko, S. M., Galka, N. V., Galka, A. G. Dangerous and harmful factors of production processes in snack food establishment. Fundamental research, 11, 69–73. Available at: https://www.fundamental-research.ru/ru/article/view?id=40929
28. Zaets, Yu. L., Belyaeva, V. V. (2008). Raschet obrazovaniya vzryvoopasnoy kontsentratsii v pomeschenii pri avariynoy utechke gaza. Visnyk Dnipropetrovskoho natsionalnoho universytetu zaliznychnoho transportu imeni akademika V. Lazariana, 20, 91–93. Available at: http://nbuv.gov.ua/UJRN/vdnuzt_2008_20_21
29. Tolstyh, V. K. (2010). Programmirovanie v srede Mathcad. Donetsk: DonNU, 128.
30. Rybalko, O. M. (2014). Vyshcha matematyka (spetsialni rozdili). Osnovy teoriyi ymovirnostei z elementamy matematychnoi statystyky. Kharkiv: Kolehium, 359.
31. Kir'yanov, D. V. (2012). Mathcad 15/MathcadPrime 1.0. Sankt-Peterburg: BHV-Peterburg, 432.
32. Makarov, E. G. (2011). Inzhenernye raschety v Mathcad 15. Uchebniy kurs. Sankt-Peterburg: BGTU-Voenmekh, 345.

DOI: 10.15587/1729-4061.2019.170134

DEVELOPMENT OF A HIGHLY EFFICIENT COMBINED APPARATUS (A COMBINATION OF VORTEX CHAMBERS WITH A BIN) FOR DRY DEDUSTING OF GASES (p. 49–55)

Inna Pitak
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-5073-2942

Valery Shaporev
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-1652-4688

Serhii Briankin
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-0444-9107

Bohdana Komarysta
National Technical University of Ukraine
«Igor Sikorsky Kyiv Polytechnic Institute», Kyiv, Ukraine
ORCID: http://orcid.org/0000-0001-9542-6597

Dmytro Nechyporenko
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-5570-1061

The use of dust collectors of a new type which combine the operation principle of centrifugal and louvre-vortex apparatuses was considered. The use of a heterogeneous reactor for gas-solid systems with two streams in a cyclone, a direct-flow cyclone with a chamber of preliminary collision of gas-dust flows, as well as improved designs of vortex chambers was considered.

A combined dust collector was presented in a form of the Rankine vortex tube in combination with a bin in which louvre-vortex devices are installed. The combined deduster under study provides an organized supply of a gas-dispersed system at adjustable hydrodynamic conditions to louvre-vortex devices used as the dedusting apparatus. It was assumed that the processes of coagulation of particles under appropriate hydrodynamic conditions as well as partial destruction of harmful gas impurities in a continuous phase will take place in the vortex tube. Thus, development of a substantiated physical model (of a design) of a combined dust collector for specified initial conditions and operability of the design were considered on the basis of theoretical and experimental provisions.

It has been established that creation of hydrodynamic conditions in centrifugal devices and pipelines is the most promising direction of increasing the degree of dedusting of a gas-dispersed flow. These conditions must ensure supply of the gas-dispersed system to the centrifugal apparatus to ensure agglomeration of fine particles.

Design of a dedusting apparatus in which intense collision of dust particles in a special chamber and their agglomeration and subsequent separation supposed to proceed in a chamber which is actually a cyclone is an expedient and effective solution. It provides the degree of purification of the gas and dust flow at a level of 98–99 % regardless of particle size.

Keywords: vortex tube, hydrodynamic conditions, cleaning efficiency, dust separation, combined apparatus, dust flow.

References

1. Shaporev, V., Pitak, I., Pitak, O., Briankin, S. (2017). Study of functioning of a vortex tube with a two-phase flow. Eastern-European Journal of Enterprise Technologies, 4 (10 (88)), 51–60. doi: https://doi.org/10.15587/1729-4061.2017.108424
2. Selih, J., Campos, L. M. S., Trierweiller, A. C., Carvalho, D. N. de. (2016). Environmental management systems in the construction industry: a review. Environmental Engineering and Management Journal, 15 (2), 453–460. doi: https://doi.org/10.30638/eemj.2016.048
3. Shaporev, V., Pitak, I., Pitak, O., Briankin, S. (2017). Investigation of the functioning of a vortex tube in supply of disperse flow (gas – dust particles) to the tube. Technology audit and production reserves, 4 (3 (36)), 14–21. doi: https://doi.org/10.15587/2312-8372.2017.109172
4. Pitak, I., Shaporev, V., Briankin, S., Pitak, O. (2017). Justification of the calculation methods of the main parameters of vortex chambers. Technology audit and production reserves, 5 (3 (37)), 9–13. doi: https://doi.org/10.15587/2312-8372.2017.112782
5. Pitak, I., Briankin, S., Pitak, O., Shaporev, V., Petrukhin, S. (2017). Influence of the inlet flow swirler construction on hydrodynamics and efficiency of work. Technology audit and production reserves, 5 (3 (37)), 14–22. doi: https://doi.org/10.15587/2312-8372.2017.112786
6. Vasil'ev, M. I., Shaporev, V. P. (2009). Issledovanie struktury mnogofaznogo zakruchennogo potoka v krivolineynom kanale i matematicheskaya model' gazozhidkostnogo reaktora. Vestnik NTU «KhPI», 37, 3–12.
7. Li, Z., Li, D. (2017). Study on the Dehumidification and Indoor Air Cleaning Performance of Rotary Desiccant Rotor. Procedia Engineering, 205, 497–502. doi: https://doi.org/10.1016/j.proeng.2017.10.402
8. Li, Y., Xu, L., Zhou, Y., Li, B., Liang, Z., Li Y. (2018). Effects of throughput and operating parameters on cleaning performance in air-and-screen cleaning unit: A computational and experimental study. Computers and Electronics in Agriculture, 152, 141–148. doi: https://doi.org/10.1016/j.compag.2018.07.019
9. D'yachenko, N. N., D'yachenko, L. I. (2010). Matematicheskaya model' techeniya polidispersnogo ansamblya tverdyh chastits v uskoryayuschihsya potokah. Vestnik Tomskogo gosudarstvennogo universiteta, 3, 95–99.
10. Shim, J., Joe, Y.-H., Park, H.-S. (2017). Influence of air injection nozzles on filter cleaning performance of pulse-jet bag filter. Powder Technology, 322, 250–257. doi: https://doi.org/10.1016/j.powtec.2017.09.016
11. Mines, R. O. (2014). Environmental engineering: principles and practice. Wiley-Blackwell, 662.
12. Serebryanskiy, D. A., Gorgolyuk, V. V., Plashihin, S. V., Semenyuk, N. V. (2014). Dvuhurovneviy tsentrobezhniy fil'tr dlya ochistki gazov ot pyli. Ekologiya i promyshlennost', 2, 36–40.
13. Singh, G., Saini, D., Chandra, L. (2016). On the evaluation of a cyclone separator for cleaning of open volumetric air receiver. Applied Thermal Engineering, 97, 48–58. doi: https://doi.org/10.1016/j.applthermaleng.2015.10.087
14. Chelnokov, A. A., Mironchik, A. F., Zhmyhov, I. N. (2016). Inzhenernye metody ohrany atmosfernogo vozduha. Minsk: Vysheyshaya shkola, 397.
15. Akhmetov, D. G., Akhmetov, T. D. (2015). Swirl flow in vortex chamber. Science Bulletin, 4, 109–120. doi: https://doi.org/10.17117/nv.2015.04.109
16. Barsky, E. (Ed.) (2015). Entropic Invariants of Two-Phase Flows. Elsevier Science, 266. doi: https://doi.org/10.1016/c2013-0-23121-4
17. Tsakiridis, P. E., Oustadakis, P., Moustakas, K., Agatzini, S. L. (2016). Cyclones and fabric filters dusts from secondary aluminium flue gases: a characterization and leaching study. International Journal of Environmental Science and Technology, 13 (7), 1793–1802. doi: https://doi.org/10.1007/s13762-016-1014-3
18. Konovalov, V. I., Orlov, A. Yu., Gatapova, N. Ts. (2010). Drying and Other Engineering Processes with Ranque-Hilsch Vortex Tube: Possibilities and Experimental Technique. Vestnik TGPU, 16 (4), 803–825.
19. Sazhin, B. S., Sazhina, M. B., Sazhin, V. B., Aparushkina, M. A., Osmanov, Z. N., Kushpanov, E. R., Peskovoy, V. V. (2012). Analiz gidrodinamicheskih osobennostey vihrevyh apparatov s tsel'yu utochneniya oblasti ih ratsional'nogo primeneniya. Uspekhi v himii i himicheskoy tekhnologii, XXVI (1 (130)), 99–103.