ABSTRACT AND REFERENCES

APPLIED PHYSICS

**DOI: 10.15587/1729-4061.2017.118413**

## LASER OPTOACOUSTIC METHOD FOR INVESTIGATION OF SOME PHYSICAL PARAMETERS OF OIL AND OIL PRODUCTS (p. 4-8)

**Musaver Musaev**
Azerbaijan State Oil and Industry University, Baku, Azerbaijan
**ORCID**: http://orcid.org/0000-0001-8151-8159

**Ibrahim Abbasov**
Azerbaijan State Oil and Industry University, Baku, Azerbaijan
**ORCID**: http://orcid.org/0000-0001-8111-2642

**Gulshan Abdullaeva**
Azerbaijan State Oil and Industry University, Baku, Azerbaijan
**ORCID**: http://orcid.org/0000-0003-0168-9623

An operational laser optoacoustic method, which allows simultaneous determination of the light absorption coefficient and the speed of sound in oil and oil products is proposed and experimentally implemented. These values are the most important parameters of oil. The existing traditional methods for measuring these quantities are complex, as they involve the use of quartz converters, optics, etc. The method is based on investigating the front of the optoacoustic signal and measuring the speed of acoustic pulses in the samples. Acoustic pulses are produced by the thermo-optical mechanism of ultrasound excitation when the radiation pulse of a neodymium laser falls at a wavelength of 1.06 μm for ~20 ns on the surface of the medium. The resulting temperature gradient causes additional mechanical stresses. These stresses are the sources of acoustic waves that propagate from the heat-release zone. Since the leading edge of the pulse is formed by a straight wave propagating directly from the border, its profile repeats the spatial distribution of stress sources. For a homogeneous liquid, the theoretically calculated form of the thermo-acoustic compression pulse has a simple form $p' \sim \exp(-\alpha z)$ ($p'$ is the excess pressure in the depth $z$ of the medium, and $\alpha$ is the absorption coefficient of the laser radiation in the medium).

The measured values of the absorption coefficient for various oils were 2–40 $cm^{-1}$. Based on the proposed method, the method for determining the temperature coefficient of sound speed and oil tarness was developed.

**Keywords**: optoacoustic signal, light absorption coefficient, acoustic signal, sound speed.

**References**

1. Sigrist, M. W. (1986). Laser generation of acoustic waves in liquids and gases. Journal of Applied Physics, 60 (7), R83–R122. doi: 10.1063/1.337089
2. Karabutov, A. A., Podimova, N. B. (2010). Measuring the porosity of the thermal spray coating on a metal substrate by laser optical–acoustic method. Technical Acoustics, 15, 2–9.
3. Otremba, Z., Toczek, H. (2011). Optical properties of fuels and lubricants vs. aquatic environment protection issues. Journal of KONES Power train and Transport, 18 (4), 326–330.
4. Mirzajanzadeh, A. X. (1981). Paradoxes of oil physics. Baku: Azerbaijan state publishing house.
5. Ball, S. J., Trusler, J. P. M. (2001). Speed of Sound of n-Hexane and n-Hexadecane at Temperatures Between 298 and 373 K and Pressures up to 100 Mpa. International Journal of Thermophysics, 22 (2), 427–443. doi: 10.1023/a:1010770730612
6. Nozdrev, V. F., Fedorishenko, N. F. (1974). A molecular acoustics. Moscow: Higher school.
7. Karabutov, A. A., Karabutov, A. A., Sapozhnikov, O. A. (2010). Determination of the elastic properties of layered materials using laser excitation of ultrasound. Physics of Wave Phenomena, 18 (4), 297–302. doi: 10.3103/s1541308x10040126
8. Zhang, F., Krishnaswamy, S., Lilley, C. M. (2006). Bulk-wave and guided-wave photoacoustic evaluation of the mechanical properties of aluminum/silicon nitride double-layer thin films. Ultrasonics, 45 (1-4), 66–76. doi: 10.1016/j.ultras.2006.06.064
9. Cabrera, Marcano, Castellanos (2006). Absorption coefficient of nearly transparent liquids measured using thermal lens spectrometry. Condensed Matter Physics, 9 (2), 385. doi: 10.5488/cmp.9.2.385
10. Karabutov, A. A., Koboleva, L. I., Podymova, N. B., Chernyshova, T. A. (2008). Lazerniy optiko-akusticheskiy lokal'nogo izmereniya uprugih moduley kompozitsionnyh materialov, uprochnennyh chastitsami. Tekhnicheskaya akustika, 19, 1–15.
11. Robin, O., Berry, A., Doutres, O., Atalla, N. (2014). Measurement of the absorption coefficient of sound absorbing materials under a synthesized diffuse acoustic field. The Journal of the Acoustical Society of America, 136 (1), EL13–EL19. doi: 10.1121/1.4881321
12. Cruz, R. A., Marcano, A., Jacinto, C., Catunda, T. (2009). Ultrasensitive thermal lens spectroscopy of water. Optics Letters, 34 (12), 1882. doi: 10.1364/ol.34.001882
13. Nowruzi, H., Ghassemi, H. (2016). Using artificial neural network to predict velocity of sound in liquid water as a function of ambient temperature, electrical and magnetic fields. Journal of Ocean Engineering and Science, 1 (3), 203–211. doi: 10.1016/j.joes.2016.07.001
14. Qusev, V. E., Karabutov, A. A. (1991). Laser optoacoustics. Moscow: Science, 304.
15. Cutnell, J. D., Kenneth, W. J. (1997). Speed of Sound in Water – The Physics Factbook – Hypertextbook. Standardized Result. Physics. New York: Wiley, 468.
16. Diyarov, I., Batueva, I. Y., Sadikov, A. N., Solodova, N. L. (1990). Chemistry of oil. Leningrad: Chemistry, 240.

**DOI: 10.15587/1729-4061.2017.114038**

## CALCULATION OF SOUND POWER LEVEL OF TANDEM AXIAL FAN (p. 8-12)

**Ekaterina Doroshenko**
National Aviation University, Kyiv, Ukraine
**ORCID**: http://orcid.org/0000-0001-6495-3263

**Yuriy Tereshchenko**
National Aviation University, Kyiv, Ukraine
**ORCID**: http://orcid.org/0000-0003-4367-3232

**Ivan Lastivka**
National Aviation University, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0001-5226-9819

**Yuriy Tereshchenko**
National Aviation University, Kyiv, Ukraine
**ORCID**: http://orcid.org/0000-0002-1908-0923

A numerical simulation of the flow in axial fans with single and tandem geometrically equivalent blade rows was carried out. During the research, the sound power level of the fans was calculated. The acoustic characteristics of the single fan obtained in the numerical experiment were compared with the results of the physical experiment. The divergence between the results of the physical and numerical experiments on the sound power level for the first harmonic is 0.08 %, for the second harmonic – 0.35 %. In order to reduce the acoustic emission, a 3D model of the axial fan with the geometrically equivalent tandem row was constructed. The results showed that at the fan rotation frequency of 900 rpm, the sound power level on the first two harmonics is reduced by more than 7 dB. Also, the change in the total sound power level for axial single and tandem fans in the rotation frequency range of 900 to 1,500 rpm was investigated. The fan with the geometrically equivalent tandem blade row has the total sound power level by 6.9...7.4 dB lower than the single fan. The use of the tandem axial fan allows improving acoustic characteristics.

**Keywords**: flow simulation, sound power level, tandem fan, tonal noise.

**References**

1. Huenecke, K. (2003). Jet engine. Shrewsbury: Airlife Publishing Ltd, 242.
2. Zhang, X. (2012). Aircraft noise and its nearfield propagation computations. Acta Mechanica Sinica, 28 (4), 960–977. doi: 10.1007/s10409-012-0136-1
3. Jacob, M. C., Grilliat, J., Camussi, R., Gennaro, G. C. (2010). Aeroacoustic Investigation of a Single Airfoil Tip Leakage Flow. International Journal of Aeroacoustics, 9 (3), 253–272. doi: 10.1260/1475-472x.9.3.253
4. Lee, S., Kim, H.-J., Kim, J.-H., Song, S. J. (2004). Computation of turbulent flows and radiated sound from axial compressor cascade. KSME International Journal, 18 (2), 272–285. doi: 10.1007/bf03184737
5. Canepa, E., Cattanei, A., Zecchin, F. M. (2016). Analysis of tonal noise generating mechanisms in low-speed axial-flow fans. Journal of Thermal Science, 25 (4), 302–311. doi: 10.1007/s11630-016-0865-8
6. Hellmich, B., Seume, J. R. (2008). Causes of Acoustic Resonance in a High-Speed Axial Compressor. Journal of Turbomachinery, 130 (3), 031003. doi: 10.1115/1.2775487
7. De Laborderie, J., Soulat, L., Moreau, S. (2014). Prediction of Noise Sources in Axial Compressor from URANS Simulation. Journal of Propulsion and Power, 30 (5), 1257–1271. doi: 10.2514/1.b35000
8. Kameier, F., Neise, W. (1997). Experimental Study of Tip Clearance Losses and Noise in Axial Turbomachines and Their Reduction. Journal of Turbomachinery, 119 (3), 460. doi: 10.1115/1.2841145
9. Corsini, A., Rispoli, F., Sheard, A. G. (2009). Aerodynamic Performance of Blade Tip End-Plates Designed for Low-Noise Operation in Axial Flow Fans. Journal of Fluids Engineering, 131 (8), 081101. doi: 10.1115/1.3026723
10. Bianchi, S., Corsini, A., Rispoli, F., Sheard, A. G. (2009). Detection of aerodynamic noise sources in low-speed axial fans with tip end-plates. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 223 (6), 1379–1392. doi: 10.1243/09544062jmes1277
11. Brusilovskiy, I. V. (1984). Aehrodinamika osevyh ventilyatorov. Moscow: Mashinostroenie, 240.
12. Tereshchenko, Y. M., Doroshenko, E. V., Abolhassan zade, D. (2015). Influence research of profile chords ratio on aerodynamic characteristics of tandem compressor cascade. Eastern-European Journal of Enterprise Technologies, 5 (8 (77)), 9–13. doi: 10.15587/1729-4061.2015.50535

**DOI: 10.15587/1729-4061.2017.114110**

## SYNTHESIZING THE SCHEMES OF MULTIFUNCTIONAL MEASURING TRANSDUCERS OF THE FLUID PARAMETERS (p. 13-22)

**Yevhen Pistun**
Lviv Polytechnic National University, Lviv, Ukraine
**ORCID**: http://orcid.org/0000-0002-3120-1978

**Halyna Matiko**
Lviv Polytechnic National University, Lviv, Ukraine
**ORCID**: http://orcid.org/0000-0001-5482-2307

**Hanna Krykh**
Lviv Polytechnic National University, Lviv, Ukraine
**ORCID**: http://orcid.org/0000-0002-6539-400X

**Fedir Matiko**
Lviv Polytechnic National University, Lviv, Ukraine
**ORCID**: http://orcid.org/0000-0001-6569-2587

A procedure for mathematical description of throttle matrices of various sizes in a form of graphs was developed which makes it possible to get all possible schemes with various measuring channels based on a throttle matrix of a certain size. By applying the elements of combinatorics, formulas were derived for finding the number of connections of throttle elements in the matrix, the number of all measuring channels, the number of all variants of construction of the measuring transducers based on a throttle matrix of a certain size. A generalized mathematical model of the throttle matrix was worked out which forms the basis for analysis of functional capabilities of the measuring transducer schemes.

Principles of synthesis of schemes of multifunctional hydrodynamic measuring transducers based on throttle matrices were worked out. In accordance with the proposed principles, a throttle matrix of a certain size is chosen taking into account the number of measured parameters, fluid properties and requirements to the transducer accuracy or sensitivity. The throttle matrix is represented as a loaded graph with transform functions for each of the measuring channels. On the basis of the obtained graph and the general mathematical model of the matrix, a scheme and a mathematical model of the multifunctional measuring transducer of specified parameters of the fluid were synthesized. The obtained results enable algorithmization of the process of the measuring transducer scheme synthesis.

The practical value of the performed studies consists in a synthesis of all possible schemes based on the throttle matrices with various measuring channels and a construction of measuring transducers with various functional capabilities and characteristics based on these matrices. By analyzing transform functions of each measuring channel of the throttle matrix of a certain size, one can choose an option for constructing a measuring transducer of one or more parameters with given functional capabilities and characteristics.

The developed principles of synthesis of measuring schemes based on the throttle matrix can be used for construction of mul-

tifunctional hydrogasdynamic measuring transducers of physical and mechanical parameters of various media.

**Keywords**: throttle matrix, graph theory, measuring scheme, hydrodynamic measuring transducer.

**References**


1. Schoff, C. K., Kamarchik, P. (2000). Rheological Measurements. Kirk-Othmer Encyclopedia of Chemical Technology. doi: 10.1002/0471238961.1808051519030815.a01
2. Principle of Fluid Dynamics. Module 7: Measurements in Fluid Mechanics. Available at: http://nptel.ac.in/courses/101103004/39
3. Webster, J. G., Eren, H. (Eds.) (2014). Measurement, Instrumentation, and Sensors Handbook. CRC Press, 1640. doi: 10.1201/b15474
4. Van der Wouden, E., Groenesteijn, J., Wiegerink, R., Lötters, J. (2015). Multi Parameter Flow Meter for On-Line Measurement of Gas Mixture Composition. Micromachines, 6 (4), 452–461. doi: 10.3390/mi6040452
5. Niedermayer, A. O., Voglhuber-Brunnmaier, T., Feichtinger, F., Heinisch, M., Jakoby, B. (2016). Monitoring Physical Fluid Properties Using a Piezoelectric Tuning Fork Resonant Sensor. BHM Berg- Und Hüttenmännische Monatshefte, 161 (11), 510–514. doi: 10.1007/s00501-016-0540-0
6. Reichel, E. K., Riesch, C., Weiss, B., Jakoby, B. (2008). A vibrating membrane rheometer utilizing electromagnetic excitation. Sensors and Actuators A: Physical, 145-146, 349–353. doi: 10.1016/j.sna.2007.10.056
7. Bikić, S., Bukurov, M., Babić, M., Tašin, S., Pavkov, I., Radojčin, M. (2010). Liquid Viscosity Determination by Coriolis Flow Meter. Journal on Processing and Energy in Agriculture, 14 (4), 178–182.
8. Matiko, H. F. (2011). Model hazodynamichnoho vymiriuvalnoho peretvoriuvacha skladu hazovykh sumishei na mostoviy droselniy skhemi. Teploenerhetyka. Inzheneriya dovkillia. Avtomatyzatsiya: Visnyk NU "LP", 712, 146–151.
9. Stasiuk, I. (2015). Dynamical Capillary Flowmeters of Small and Micro Flowrates of Gases. Energy Engineering and Control Systems, 1 (2), 117–126. doi: 10.23939/jeecs2015.02.117
10. Drevetskyi, V. V., Vorobiuk, S. P., Klepach, M. M. (2010). Bahatofunktsionalnyi analizator pokaznykiv yakosti naftoproduktiv. Visnyk inzhenernoi akademiy Ukrainy, 2, 208–212.
11. Drevetskyi, V. V., Klepach, M. M. (2011). Modeliuvannia informatsiyno-vymiriuvalnoi systemy fizyko-khimichnykh parametriv naftoproduktiv u realnomu chasi. Matematychni mashyny i systemy, 2, 81–84.
12. Pistun, Ye. P., Hrudetskyi, R. Ya. (2012). Avtomatyzovana systema pobudovy matematychnoi modeli hazohidrodynamichnykh droselnykh skhem. Zbirnyk naukovykh prats "Visnyk NTU "KhPI". Novi rishennia v suchasnykh tekhnolohiyakh, 33, 72–77.
13. Pistun, Ye. P., Matiko, H. F., Krykh, H. B. (2016). Modeliuvannia skhem vymiriuvalnykh peretvoriuvachiv iz zastosuvanniam teoriy mnozhyn. Metrolohiya ta prylady, 3, 53–61.
14. Domnin, L. N. (2007). Ehlementy teorii grafov. Penza: Izd-vo Penz. gos. Un-ta, 144.
15. Diestel, R. (2017). Graph Theory. Springer-Verlag, Heidelberg. doi: 10.1007/978-3-662-53622-3
16. Malkin, A. Ya., Isayev, A. I. (2017). Rheology: Concepts, Methods and Applications. ChemTec Publishing, 500.
17. Krykh, H. B. (2008). Matematychni modeli droselnykh elementiv hidrodynamichnykh vymiriuvalnykh peretvoriuvachiv parametriv neniutonivskykh ridyn. Teploenerhetyka. Inzheneriya dovkillia. Avtomatyzatsiya, 617, 122–129.
18. Steffe, J. F. (1996). Rheological methods in food process engineering. USA, Freeman Press, 418.


**DOI: 10.15587/1729-4061.2017.118725**

## RESEARCH INTO EFFECT OF ELECTROCHEMICAL ETCHING CONDITIONS ON THE MORPHOLOGY OF POROUS GALLIUM ARSENIDE (p. 22-31)

**Sergij Vambol**
National University of Civil Protection of Ukraine, Kharkiv, Ukraine
**ORCID**: http://orcid.org/0000-0002-8376-9020

**Ihor Bogdanov**
Berdyansk State Pedagogical University, Berdyansk, Ukraine
**ORCID**: http://orcid.org/0000-0002-3035-7989

**Viola Vambol**
National University of Civil Protection of Ukraine, Kharkiv, Ukraine
**ORCID**: http://orcid.org/0000-0002-8229-3956

**Yana Suchikova**
Berdyansk State Pedagogical University, Berdyansk, Ukraine
**ORCID**: http://orcid.org/0000-0003-4537-966X

**Hanna Lopatina**
Berdyansk State Pedagogical University, Berdyansk, Ukraine
**ORCID**: http://orcid.org/0000-0002-3920-6853

**Natalia Tsybuliak**
Berdyansk State Pedagogical University, Berdyansk, Ukraine
**ORCID**: http://orcid.org/0000-0003-2474-8614

The method for the formation of porous gallium arsenide in a solution of hydrochloric acid was improved. The goal of present research was to establish correlation between conditions of electrochemical etching of gallium arsenide crystals and morphology of low-dimensional structures. Porous layers were formed by the method of electrochemical etching in a solution of hydrochloric acid. The mode of electrolyte agitation was applied. This makes it possible to avoid the formation of bubbles on the surface of the crystal during etching and leads to the formation of regular porous space. Basic regularities in the formation of porous spaces were studied. It was shown that morphological properties of por-GaAs depend on etching conditions.

The effect was explored of current density on the thickness of a porous layer and diameter of pores. It was established that the composition and concentration of electrolyte correlate with surface porosity and affect the rate of crystal dissolution reaction. Etching time determines thickness of a porous layer and surface porosity. Chemical composition of por-GaAs was explored. An oxide layer was not formed on the surface of the examined samples; oxygen was present only in small concentrations. Stoichiometry of the samples was disrupted towards an excess of gallium atoms.

**Keywords**: gallium arsenide, electrochemical etching, morphology, porous semiconductors, etching conditions.

**References**


1. Langa, S., Carstensen, J., Christophersen, M., Steen, K., Frey, S., Tiginyanu, I. M., Föll, H. (2005). Uniform and Nonuniform Nucleation of Pores during the Anodization of Si, Ge, and III-

V Semiconductors. Journal of The Electrochemical Society, 152 (8), C525. doi: 10.1149/1.1940847
2. Naddaf, M., Saloum, S. (2009). Nanostructuring-induced modification of optical properties of p-GaAs (100). Physica E: Low-Dimensional Systems and Nanostructures, 41 (10), 1784–1788. doi: 10.1016/j.physe.2009.06.086
3. Naddaf, M., Saad, M. (2013). Novel optical and structural properties of porous GaAs formed by anodic etching of n+-GaAs in a HF:C2H5OH:HCl:H2O2:H2O electrolyte: effect of etching time. Journal of Materials Science: Materials in Electronics, 24 (7), 2254–2263. doi: 10.1007/s10854-013-1087-4
4. Khrypunov, G., Vambol, S., Deyneko, N., Sychikova, Y. (2016). Increasing the efficiency of film solar cells based on cadmium telluride. Eastern-European Journal of Enterprise Technologies, 6 (5 (84)), 12–18. doi: 10.15587/1729-4061.2016.85617
5. Mangla, O., Roy, S. (2015). A study on aberrations in energy band gap of quantum confined gallium arsenide spherical nanoparticles. Materials Letters, 143, 48–50. doi: 10.1016/j.matlet.2014.12.083
6. Lebib, A., Ben Amara, E., Beji, L. (2017). Structural and luminescent characteristics of porous GaAs. Journal of Luminescence, 188, 337–341. doi: 10.1016/j.jlumin.2017.04.023
7. Suchikova, Y. (2016). Provision of environmental safety through the use of porous semiconductors for solar energy sector. Eastern-European Journal of Enterprise Technologies, 6 (5 (84)), 26–33. doi: 10.15587/1729-4061.2016.85848
8. Dubey, R. S. (2013). Electrochemical Fabrication of Porous Silicon Structures for Solar Cells. Nanoscience and Nanoengineering, 1 (1), 36–40.
9. Suchikova, Y. A., Kidalov, V. V., Konovalenko, A. A., Sukach, G. A. (2010). Blue shift of photoluminescence spectrum of porous InP. ECS Transactions, 25 (24), 59–64. doi: 10.1149/1.3316113
10. Beckemper, S. (2011). Generation of Periodic Micro- and Nanostructures by Parameter-Controlled Three-beam Laser Interference Technique. Journal of Laser Micro/Nanoengineering, 6 (1), 49–53. doi: 10.2961/jlmn.2011.01.0011
11. Md Taib, M. I., Zainal, N., Hassan, Z. (2014). Improvement of Porous GaAs (100) Structure through Electrochemical Etching Based on DMF Solution. Journal of Nanomaterials, 2014, 1–7. doi: 10.1155/2014/294385
12. Tiginyanu, I., Monaico, E., Sergentu, V., Tiron, A., Ursaki, V. (2014). Metallized Porous GaP Templates for Electronic and Photonic Applications. ECS Journal of Solid State Science and Technology, 4 (3), P57–P62. doi: 10.1149/2.0011503jss
13. Suchikova, Y. A., Kidalov, V. V., Sukach, G. A. (2010). Influence of the Carrier Concentration of Indium Phosphide on the Porous Layer Formation. Journal of Nano- and Electronic Physics, 2 (4), 142–147.
14. Rajendran, V. (2009). Development of Nanomaterials from Natural Resources for Various Industrial Applications. Advanced Materials Research, 67, 71–76. doi: 10.4028/www.scientific.net/amr.67.71
15. Efros, A. L., Nesbitt, D. J. (2016). Origin and control of blinking in quantum dots. Nature Nanotechnology, 11 (8), 661–671. doi: 10.1038/nnano.2016.140
16. Suchikova, Y. A., Kidalov, V. V., Sukach, G. A. (2009). Influence of type anion of electrolit on morphology porous inp obtained by electrochemical etching. Journal of Nano- and Electronic Physics, 1 (4), 111–118.
17. Mangla, O., Srivastava, M. P. (2012). GaN nanostructures by hot dense and extremely non-equilibrium plasma and their characterizations. Journal of Materials Science, 48 (1), 304–310. doi: 10.1007/s10853-012-6746-y
18. Malhotra, Y., Roy, S., Srivastava, M. P., Kant, C. R., Ostrikov, K. (2009). Extremely non-equilibrium synthesis of luminescent zinc oxide nanoparticles through energetic ion condensation in a dense plasma focus device. Journal of Physics D: Applied Physics, 42 (15), 155202. doi: 10.1088/0022-3727/42/15/155202
19. Srivastava, A., Nahar, R. K., Sarkar, C. K., Singh, W. P., Malhotra, Y. (2011). Study of hafnium oxide deposited using Dense Plasma Focus machine for film structure and electrical properties as a MOS device. Microelectronics Reliability, 51 (4), 751–755. doi: 10.1016/j.microrel.2010.12.002
20. Mangla, O., Srivastava, A., Malhotra, Y., Ostrikov, K. (2013). Lanthanum oxide nanostructured films synthesized using hot dense and extremely non-equilibrium plasma for nanoelectronic device applications. Journal of Materials Science, 49 (4), 1594–1605. doi: 10.1007/s10853-013-7842-3
21. Suchikova, Y. A., Kidalov, V. V., Sukach, G. A. (2011). Influence of dislocations on the process of pore formation in n-InP (111) single crystals. Semiconductors, 45 (1), 121–124. doi: 10.1134/s1063782611010192
22. Lodahl, P., Mahmoodian, S., Stobbe, S. (2015). Interfacing single photons and single quantum dots with photonic nanostructures. Reviews of Modern Physics, 87 (2), 347–400. doi: 10.1109/piers.2016.7735045
23. Beattie, N. S., Zoppi, G., See, P., Farrer, I., Duchamp, M., Morrison, D. J. et. al. (2014). Analysis of InAs/GaAs quantum dot solar cells using Suns- V oc measurements. Solar Energy Materials and Solar Cells, 130, 241–245. doi: 10.1016/j.solmat.2014.07.022
24. Mei, L., Chen, Y., Ma, J. (2014). Gas Sensing of SnO2 Nanocrystals Revisited: Developing Ultra-Sensitive Sensors for Detecting the $H_2S$ Leakage of Biogas. Scientific Reports, 4 (1). doi: 10.1038/srep06028
25. Shukla, S., Oturan, M. A. (2015). Dye removal using electrochemistry and semiconductor oxide nanotubes. Environmental Chemistry Letters, 13 (2), 157–172. doi: 10.1007/s10311-015-0501-y
26. Monaico, E., Tiginyanu, I., Volciuc, O., Mehrtens, T., Rosenauer, A., Gutowski, J., Nielsch, K. (2014). Formation of InP nanomembranes and nanowires under fast anodic etching of bulk substrates. Electrochemistry Communications, 47, 29–32. doi: 10.1016/j.elecom.2014.07.015
27. Gerngross, M.-D., Carstensen, J., Föll, H. (2014). Electrochemical growth of Co nanowires in ultra-high aspect ratio InP membranes: FFT-impedance spectroscopy of the growth process and magnetic properties. Nanoscale Research Letters, 9 (1), 316. doi: 10.1186/1556-276x-9-316
28. Suchikova, Y. A., Kidalov, V. V., Sukach, G. A. (2010). Preparation of nanoporous n-InP(100) layers by electrochemical etching in HCI solution. Functional Materials, 17 (1), 131–134.
29. Vambol, S., Bogdanov, I., Vambol, V., Suchikova, Y., Kondratenko, O., Hurenko, O., Onishchenko, S. (2017). Research into regularities of pore formation on the surface of semiconductors. Eastern-European Journal of Enterprise Technologies, 3 (5 (87)), 37–44. doi: 10.15587/1729-4061.2017.104039
30. Suchikova, Y. A., Kidalov, V. V., Balan, O. S., Sukach, G. A. (2010). Texturation of the Phosphide Indium Surface. Journal of Nano- and Electronic Physics, 2 (1), 50–53.
31. Lazarenko, A. S. (2011). Model of Formation of Nano–Sized Whiskers Out of Channels of the Triple Junctions of Grain Boundaries of Polycrystal. Journal of Nano- and Electronic Physics, 3 (4), 59–64.

32. Koshevoi, V. L., Belorus, A. O. (2017). Study of producing sensors based on porous layers of GaP: Te semiconductors with the use of electrodiffusion contacts. 2017 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus). doi: 10.1109/eiconrus.2017.7910833
33. Makhnij, V. P., German, I. I., Sklarchuk, V. M. (2015). Optical properties of microporous n-GaAs. Telecommunications and Radio Engineering, 74 (16), 1467–1472. doi: 10.1615/telecomradeng.v74.i16.60
34. Monaico, E., Colibaba, G., Nedeoglo, D., Nielsch, K. (2014). Porosification of III–V and II–VI Semiconductor Compounds. Journal of Nanoelectronics and Optoelectronics, 9 (2), 307–311. doi: 10.1166/jno.2014.1581
35. Vambol, S., Vambol, V., Sychikova, Y., Deyneko, N. (2017). Analysis of the ways to provide ecological safety for the products of nanotechnologies throughout their life cycle. Eastern-European Journal of Enterprise Technologies, 1 (10 (85)), 27–36. doi: 10.15587/1729-4061.2017.85847
36. Wloka, J., Mueller, K., Schmuki, P. (2005). Pore Morphology and Self-Organization Effects during Etching of n-Type GaP(100) in Bromide Solutions. Electrochemical and Solid-State Letters, 8 (12), B72. doi: 10.1149/1.2103507
37. Chai, X., Weng, Z., Xu, L., Wang, Z. (2015). Tunable Electrochemical Oscillation and Regular 3D Nanopore Arrays of InP. Journal of the Electrochemical Society, 162 (9), E129–E133. doi: 10.1149/2.0341509jes
38. Bioud, Y. A., Boucherif, A., Belarouci, A., Paradis, E., Drouin, D., Arès, R. (2016). Chemical Composition of Nanoporous Layer Formed by Electrochemical Etching of p-Type GaAs. Nanoscale Research Letters, 11 (1). doi: 10.1186/s11671-016-1642-z
39. Steele, J. A., Lewis, R. A., Sirbu, L., Enachi, M., Tiginyanu, I. M., Skuratov, V. A. (2015). Optical reflectance studies of highly specular anisotropic nanoporous (111) InP membrane. Semiconductor Science and Technology, 30 (4), 044003. doi: 10.1088/0268-1242/30/4/044003
40. Ulin, V. P., Konnikov, S. G. (2007). Electrochemical pore formation mechanism in III–V crystals (Part I). Semiconductors, 41 (7), 832–844. doi: 10.1134/s1063782607070111
41. Sychikova, Y. A., Kidalov, V. V., Sukach, G. A. (2013). Dependence of the threshold voltage in indium-phosphide pore formation on the electrolyte composition. Journal of Surface Investigation. X-Ray, Synchrotron and Neutron Techniques, 7 (4), 626–630. doi: 10.1134/s1027451013030130
42. Dzhafarov, T.; Morales-Acevedo, A. (Ed.) (2013). Silicon Solar Cells with Nanoporous Silicon Layer. Solar Cells – Research and Application Perspectives. doi: 10.5772/51593
43. Heidari, M., Yan, J. (2017). Ultraprecision surface flattening of porous silicon by diamond turning. Precision Engineering, 49, 262–277. doi: 10.1016/j.precisioneng.2017.02.015
44. Hooda, S., Khan, S. A., Satpati, B., Uedono, A., Sellaiyan, S., Asokan, K. et. al. (2016). Nanopores formation and shape evolution in Ge during intense ionizing irradiation. Microporous and Mesoporous Materials, 225, 323–330. doi: 10.1016/j.micromeso.2016.01.006
45. Ching, C. G., Ooi, P. K., Ng, S. S., Ahmad, M. A., Hassan, Z., Abu Hassan, H., Abdullah, M. J. (2013). Fabrication of porous ZnO via electrochemical etching using 10wt% potassium hydroxide solution. Materials Science in Semiconductor Processing, 16 (1), 70–76. doi: 10.1016/j.mssp.2012.06.017
46. Hamann, E., Koenig, T., Zuber, M., Cecilia, A., Tyazhev, A., Tolbanov, O. et. al. (2015). Performance of a Medipix3RX Spectroscopic Pixel Detector With a High Resistivity Gallium Arsenide Sensor. IEEE Transactions on Medical Imaging, 34 (3), 707–715. doi: 10.1109/tmi.2014.2317314
47. Takamoto, T., Washio, H., Juso, H. (2014). Application of InGaP/GaAs/InGaAs triple junction solar cells to space use and concentrator photovoltaic. 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC). doi: 10.1109/pvsc.2014.6924936
48. Dai, X., Zhang, S., Wang, Z., Adamo, G., Liu, H., Huang, Y. et. al. (2014). GaAs/AlGaAs Nanowire Photodetector. Nano Letters, 14 (5), 2688–2693. doi: 10.1021/nl5006004
49. Jin, Z., Guo, L., Xiao, L., Liang, R., Wang, J. (2016). Epitaxial growth of GaN on porous Si (111) substrate. 2016 5th International Symposium on Next-Generation Electronics (ISNE). doi: 10.1109/isne.2016.7543306
50. Suchikova, Y. A. (2015). Synthesis of indium nitride epitaxial layers on a substrate of porous indium phosphide. Journal of Nano- and Electronic Physics, 7 (3), 03017-1–03017-3.
51. Trindade, T., O'Brien, P., Pickett, N. L. (2001). Nanocrystalline Semiconductors: Synthesis, Properties, and Perspectives. Chemistry of Materials, 13 (11), 3843–3858. doi: 10.1021/cm000843p
52. Suchikova, Y. O. (2017). Sulfide Passivation of Indium Phosphide Porous Surfaces. Journal of Nano- and Electronic Physics, 9 (1), 01006-1–01006-4. doi: 10.21272/jnep.9(1).01006
53. Yana, S. (2015). Porous Indium Phosphide: Preparation and Properties. Handbook of Nanoelectrochemistry, 283–305. doi: 10.1007/978-3-319-15266-0_28
54. Bechambi, O., Chalbi, M., Najjar, W., Sayadi, S. (2015). Photocatalytic activity of ZnO doped with Ag on the degradation of endocrine disrupting under UV irradiation and the investigation of its antibacterial activity. Applied Surface Science, 347, 414–420. doi: 10.1016/j.apsusc.2015.03.049
55. Wu, X. S., Miao, R., Si, Y. D., Lou, C. M., Xu, D. X., Chu, X. N. (2014). Surface Spot Defects Inspection of Multi-Crystalline Silicon Wafers Based on HALCON. Advanced Materials Research, 1081, 241–245. doi: 10.4028/www.scientific.net/amr.1081.241
56. Vikhrov, S. P., Bodyagin, N. V., Larina, T. G., Mursalov, S. M. (2005). Growth processes of noncrystalline semiconductors from positions of the self–organizing theory. Semiconductors, 39 (8), 953–959.


**DOI: 10.15587/1729-4061.2017.118930**

## DEVELOPMENT OF THE METHOD OF APPROXIMATE SOLUTION TO THE NONSTATIONARY PROBLEM ON HEAT TRANSFER THROUGH A FLAT WALL (p. 31-40)

**Olexander Brunetkin**
Odessa National Polytechnic University, Odessa, Ukraine
**ORCID**: http://orcid.org/0000-0002-6701-8737

**Maksym Maksymov**
Odessa National Polytechnic University, Odessa, Ukraine
**ORCID**: http://orcid.org/0000-0002-7536-2570

**Oksana Maksymova**
Odessa National Academy of Food Technologies, Odessa, Ukraine
**ORCID**: http://orcid.org/0000-0003-3986-0991

**Anton Zosymchuk**
Odessa National Polytechnic University, Odessa, Ukraine
**ORCID**: http://orcid.org/0000-0002-3604-3948

In the present work, we propose a method for approximate analytical solution to the nonstationary problem of heat transfer

through a flat wall in the concentrated statement. In the course of the study, three issues were consistently addressed:

1) symmetrical heating of a body,

2) asymmetrical heating,

3) nonstationary heat transfer.

At the first stage, we solved in approximate analytical statement the problem on symmetrical heating of a plate. The solution obtained has an error. The availability in the scientific literature of exact analytical solution, in a distributed (one-dimensional) statement, allowed us to assess the accuracy of the obtained approximate solution. It does not exceed the limits permissible for engineering calculations. A special feature of the developed method is the possibility of its application as an integral part in solving the problems on nonstationary heat transfer.

At the second stage, we solved a problem on asymmetrical heating of a plate. By using numerical study, the character of displacement of the minimum in temperature profile for thickness of the plate was identified. This made it possible, when applying the method developed at the previous stage, to obtain a solution to the problem on asymmetrical heating of the body. A special feature of the solutions is the developed approach to determining position of the temperature minimum for thickness of the plate. Such an approach was employed as another constituent part for solving a problem on nonstationary heat transfer.

At the third stage, numerical study allowed us to identify a characteristic point of varying temperature profile and the trajectory of its motion in the process of nonstationary heat transfer. Based on these data and applying the developed method, we demonstrated the possibility of approximate analytical solution to the problem on nonstationary heat transfer through a flat wall.

In all cases, when the exact solutions were lacking, assessment of error in approximate representation was conducted by comparing with the results of numerical calculations. The error did not exceed 6 %.

**Keywords**: non-stationary heat transfer, energy accumulation, flat wall, analytical calculation, approximate solution.

**References**

1. Brunetkin, A. I., Maksymov, M. V. (2015). Method for determining the composition of combustion gases when burned. Naukovyi visnyk Natsionalnho hirnychoho universytetu, 5, 83–90.
2. Carslaw, H. S., Jaeger, J. C.; Pomerantsev, A. A. (Ed.) (1964). Conduction of heat in solids. Moscow: Nauka, 488.
3. Lykov, A. V. (1967). The theory of heat conduction. Moscow: Higher School, 600.
4. Grysa, K., Maciag, A., Adamczyk-Krasa, J. (2014). Trefftz Functions Applied to Direct and Inverse Non-Fourier Heat Conduction Problems. Journal of Heat Transfer, 136 (9), 091302. doi: 10.1115/1.4027770
5. Hoshan, N. A. (2009). The triple integral equations method for solving heat conduction equation. Journal of Engineering Thermophysics, 18 (3), 258–262. doi: 10.1134/s1810232809030084
6. Zarubin, V. S., Kuvyrkin, G. N., Savelyeva, I. Y. (2018). Two-sided thermal resistance estimates for heat transfer through an anisotropic solid of complex shape. International Journal of Heat and Mass Transfer, 116, 833–839. doi: 10.1016/j.ijheatmasstransfer.2017.09.054
7. Damle, R. M., Ardhapurkar, P. M., Atrey, M. D. (2016). Numerical investigation of transient behaviour of the recuperative heat exchanger in a MR J–T cryocooler using different heat transfer correlations. Cryogenics, 80, 52–62. doi: 10.1016/j.cryogenics.2016.09.003
8. Kang, Z., Zhu, P., Gui, D., Wang, L. (2017). A method for predicting thermal waves in dual-phase-lag heat conduction. International Journal of Heat and Mass Transfer, 115, 250–257. doi: 10.1016/j.ijheatmasstransfer.2017.07.036
9. Karvinen, R. (2012). Use of Analytical Expressions of Convection in Conjugated Heat Transfer Problems. Journal of Heat Transfer, 134 (3), 031007. doi: 10.1115/1.4005129
10. Shupikov, A. N., Smetankina, N. V., Svet, Y. V. (2007). Nonstationary Heat Conduction in Complex-Shape Laminated Plates. Journal of Heat Transfer, 129 (3), 335. doi: 10.1115/1.2427073
11. Brunetkin, O., Maksymov, M., Lysiuk, O. (2017). A simplified method for the numerical calculation of nonstationary heat transfer through a flat wall. Eastern-European Journal of Enterprise Technologies, 2 (5 (86)), 4–13. doi: 10.15587/1729-4061.2017.96090
12. Profos, P.; Davydov, N. I. (Ed.) (1967). Regulirovanie parosilovyh ustanovok. Moscow: Energiya, 368.
13. Brunetkin, O. I., Gusak, A. V. (2015). Determining the range of variation of convective heat transfer coefficient during the combustion of alternative kinds of gaseous fuels. Odes'kyi Politechnichnyi Universytet. Pratsi, 2 (46), 79–84. doi: 10.15276/opu.2.46.2015.15
14. Kuznetsov, Y. N. (1989). Heat transfer in the problem of the safety of nuclear reactors. Moscow: Energoizdat, 296.
15. Marcenyuk, E. V., Zeleniy, Yu. A., Reznik, S. B. et. al. (2015). Identifikatsiya granichnyh usloviy teploobmena turbiny po rezul'tatam ispytaniy [Identification of turbine heat transfer boundary conditions by using test results]. Vestnik NTU «KhPI», 41 (1150), 72–76.
16. Brunetkin, O., Maksymov, M., Maksymova, O., Zosymchuk, A. (2017). Development of a method for approximate solution of nonlinear ordinary differential equations using pendulum motion as an example. Eastern-European Journal of Enterprise Technologies, 5 (4 (89)), 4–11. doi: 10.15587/1729-4061.2017.109569

**DOI: 10.15587/1729-4061.2017.118252**

## DEVELOPMENT OF PROPERTIES OF SPRAY FLOW AND NATURE OF PRESSURE DISTRIBUTION IN ELECTRIC ARC METALIZATION (p. 41-49)

**Vyacheslav Royanov**
Priazovskiy State Technical University, Mariupol, Ukraine
**ORCID**: http://orcid.org/0000-0001-5379-9096

**Irina Zakharova**
Priazovskiy State Technical University, Mariupol, Ukraine
**ORCID**: http://orcid.org/0000-0002-3492-0134

**Elena Lavrova**
Priazovskiy State Technical University, Mariupol, Ukraine
**ORCID**: http://orcid.org/0000-0001-6030-0986

The results of the research on electric arc metallization in the form of a technique and installation, which allow modeling various positions of the electrodes in the spray jet are presented. Direct measurements of the total pressure in the local zone between the ends of the electrodes used for arc metallization are made.

The research allows obtaining coatings with refractory oxides, with a large number of alloying elements. These measures will increase their wear resistance.

Thus, for 2.4 mm electrodes with a gas pressure at the spraying system inlet of the arc spraying pistol $P_{inlet}$=0.5± ±0.05 MPa and the absence of a gap between the inner parts

of the electrode ends in the center of the interelectrode gap, rarefaction is created. The rarefaction value reaches 0.044 MPa. With the gap increase, the degree of pressure drop decreases: when the gap varies from 0 to 1.0 mm, the pressure in the center between the electrode ends varies within 0.044...0.16 MPa. With a gap between the electrode ends of 2 mm or more, the pressure drop is negligible. The characteristic changes in the spray jet structure in the presence of electrodes are confirmed by the results of shadow photography. The results obtained allowed making adjustments to the process flow diagram of electric arc metallization, with the specification of the presence of the zone of air flow around the electrodes and pressure drop in the interelectrode gap. Optimum conditions for the arc functioning are achieved with such a ratio of the rates of feeding and melting of the electrodes, when the gap between the inner surfaces of the ends is within 0.5...1.0 mm.

The proposed technology will allow restoring the working surfaces of parts of machines and mechanisms in mechanical engineering, agriculture, car building.

**Keywords**: electric arc metallization, flux-cored rod, alloying, gas medium, spray jet.

**References**

1. Litovchenko, N. N., Logachev, V. N. (2013). Ways of improving equipment and technology of electric arc metallization. Tractors and agricultural machinery, 11, 52–54.
2. Vorobiev, P. A., Yusim, M. Y., Litovchenko, N. N., Denisov, V. I. (2008). Method of aerosol fluxing in electric arc metallization. Method of aerosol fluxing in electric arc metallization. Proceedings of GOSNITI, 101, 201–204.
3. Litovchenko, N. N., Petryakov, B. I., Tolkachev, A. A., Blokhin, S. A. (2013). Influence of the flow rate of heterophase flux on the physico-mechanical properties of the electrometallic flow. Welding production, 6, 43–47.
4. Solov'ev, R. Y., Vorob'ev, P. A., Litovchenko, N. N. (2013). Metal-carbothermal methods of reducing the degree of oxidation of dispersed metal in electric arc metallizing. Welding International, 27 (5), 423–427. doi: 10.1080/09507116.2012.715930
5. Denisov, V. I., Litovchenko, N. N., Logachev, V. N., Tolkachev, A. A. (2015). Activation of the process of electric arc metallization with liquid hydrocarbon fuel. Proceedings of GOSNITI, 12, 160–165.
6. Lo, K. H., Shek, C. H., Lai, J. K. L. (2009). Recent developments in stainless steels. Materials Science and Engineering: R: Reports, 65 (4-6), 39–104. doi: 10.1016/j.mser.2009.03.001
7. Olsson, J., Snis, M. (2007). Duplex – A new generation of stainless steels for desalination plants. Desalination, 205 (1-3), 104–113. doi: 10.1016/j.desal.2006.02.051
8. Charles, J. (2007). Duplex stainless steels – a review. In: Proceedings of 7th International conference on DSS, 35–42.
9. Voutchkov, I., Jaworski, B., Vitanov, V. I., Bedford, G. M. (2001). An integrated approach to friction surfacing process optimisation. Surface and Coatings Technology, 141 (1), 26–33. doi: 10.1016/s0257-8972(01)01127-6
10. Yamashita, Y., Fujita, K. (2001). Newly Developed Repairs on Welded Area of LWR Stainless Steel by Friction Surfacing. Journal of Nuclear Science and Technology, 38 (10), 896–900. doi: 10.1080/18811248.2001.9715112
11. Ivanov, V., Lavrova, E. (2014). Improving the Efficiency of Strip Cladding by the Control of Electrode Metal Transfer. Applied Mechanics and Materials, 682, 266–269. doi: 10.4028/www.scientific.net/amm.682.266
12. Royanov, V. A., Bovikov, V. I. (2015). Equipment for electric arc metallizing with pulsed discharge of the air-spraying jet. Welding International, 30 (4), 315–318. doi: 10.1080/01431161.2015.1058006

**DOI: 10.15587/1729-4061.2017.118943**

## INVESTIGATION OF THE EFFECT OF CHARACTERISTICS OF GASCONTAINING SUSPENSIONS ON THE PARAMETERS OF THE PROCESS OF ULTRASONIC WAVE PROPAGATION (p. 49-58)

**Vladimir Morkun**
Kryvyi Rih National University, Kryvyi Rih, Ukraine
**ORCID**: http://orcid.org/0000-0003-1506-9759

**Natalia Morkun**
Kryvyi Rih National University, Kryvyi Rih, Ukraine
**ORCID**: http://orcid.org/0000-0002-1261-1170

**Vitaliy Tron**
Kryvyi Rih National University, Kryvyi Rih, Ukraine
**ORCID**: http://orcid.org/0000-0002-6149-5794

**Svitlana Hryshchenko**
Kryvyi Rih National University, Kryvyi Rih, Ukraine
**ORCID**: http://orcid.org/0000-0003-4957-0904

In the course of present study, we have investigated patterns of connection between fluctuations in the number and size of particles, suspended in a fluid, and characteristics of the field of volumetric ultrasonic waves.

The presence of particles of the solid phase and gas bubbles introduces certain features to the process of attenuation and scattering of ultrasonic wave energy. The scattering of waves on the solid phase particles becomes considerable when the wavelength is commensurate with the size of the particles themselves.

In order to characterize the absorption and scattering of acoustic oscillations by oscillating gas bubbles, we applied the concepts of effective cross-sections of damping, absorption and scattering. The dependence is presented of the magnitude of cross-section of ultrasound damping by air bubbles on frequency of the sound wave.

It was established that the magnitude of attenuation of volumetric ultrasonic oscillations of high frequency (≥5 MHz) in an actual pulp depends almost only on the concentration of the solid phase and particle size of the crushed material.

The frequency of volumetric ultrasonic waves, at which the components of their absorption and scattering by particles of the solid phase in suspension are equal, characterizes the average particle size. A given frequency does not depend on the particle concentration and can be applied to estimate their mean size.

**Keywords**: gas bubbles, ore enrichment, volumetric ultrasound waves, particle distribution, characteristics of pulp.

**References**

1. Rzhevskiy, V. V., Yamshchikov, V. S. (1968). Ul'trazvukovoy kontrol' i issledovaniya v gornom dele. Moscow: Nedra, 120.
2. Morkun, V., Tron, V. (2014). Automation of iron ore raw materials beneficiation with the operational recognition of its varieties in process streams. Metallurgical and Mining Industry, 6, 4–7.

3. Morkun, V., Morkun, N., Tron, V. (2015). Identification of control systems for ore-processing industry aggregates based on nonparametric kernel estimators. Metallurgical and Mining Industry, 1, 14–17.
4. Golik, V., Komashchenko, V., Morkun, V., Burdzieva, O. (2015). Metal deposits combined development experience. Metallurgical and Mining Industry, 6, 591–594.
5. Morkun, V., Morkun, N., Tron, V. (2015). Formalization and frequency analysis of robust control of ore beneficiation technological processes under parametric uncertainty. Metallurgical and Mining Industry, 5, 7–11.
6. Morkun, V., Morkun, N., Tron, V. (2015). Distributed closed-loop control formation for technological line of iron ore raw materials beneficiation. Metallurgical and Mining Industry, 7, 16–19.
7. Golik, V., Komashchenko, V., Morkun, V. (2015). Feasibility of using the mill tailings for preparation of self-hardening mixtures. Metallurgical and Mining Industry, 3, 38–41.
8. Morkun, V., Tron, V. (2014). Ore preparation multi-criteria energy-efficient automated control with considering the ecological and economic factors. Metallurgical and Mining Industry, 5, 4–7.
9. Cao, Q., Cheng, J., Feng, Q., Wen, S., Luo, B. (2017). Surface cleaning and oxidative effects of ultrasonication on the flotation of oxidized pyrite. Powder Technology, 311, 390–397. doi: 10.1016/j.powtec.2017.01.069
10. Morkun, V., Morkun, N., Pikilnyak, A. (2014). Simulation of the Lamb waves propagation on the plate which contacts with gas containing iron ore pulp in Waveform Revealer toolbox. Metallurgical and Mining Industry, 5, 16–19.
11. Golik, V., Komashchenko, V., Morkun, V. (2015). Innovative technologies of metal extraction from the ore processing mill tailings and their integrated use. Metallurgical and Mining Industry, 3, 49–52.
12. Brazhnikov, N. I. (1965). Ul'trazvukovye metody. Leningrad; Moscow: Energiya, 248.
13. Viktorov, I. A. (1981). Zvukovye poverhnostnye volny v tverdyh telah. Moscow: Nauka, 286.
14. Kundu, S., Kumari, A., Pandit, D. K., Gupta, S. (2017). Love wave propagation in heterogeneous micropolar media. Mechanics Research Communications, 83, 6–11. doi: 10.1016/j.mechrescom.2017.02.003
15. Brazhnikov, N. I., Shavykina, N. S., Gordeev, A. P., Skripalev, V. S. (1975). Ispol'zovanie voln Lemba dlya signalizatsii urovnya zhidkih sred. Pribory i sistemy upravleniya, 9, 31–32.
16. Goncharov, S. A. (2009). Povyshenie effektivnosti obogatitel'nyh tekhnologiy putem vozdeystviya vysokoenergeticheskogo ul'trazvuka na pererabatyvaemoe syr'e. Visnyk Kryvorizkoho tekhnichnoho universytetu, 23, 236–239.
17. Podgorodetskiy, N. S. (2007). Avtomaticheskoe upravlenie protsessom raskrytiya poleznogo komponenta pri izmel'chenii rudy. Visnyk Kryvorizkoho tekhnichnoho universytetu, 19, 120–124.
18. Louisnard, O. (2012). A simple model of ultrasound propagation in a cavitating liquid. Part I: Theory, nonlinear attenuation and traveling wave generation. Ultrasonics Sonochemistry, 19 (1), 56–65. doi: 10.1016/j.ultsonch.2011.06.007
19. Louisnard, O. (2012). A simple model of ultrasound propagation in a cavitating liquid. Part II: Primary Bjerknes force and bubble structures. Ultrasonics Sonochemistry, 19 (1), 66–76. doi: 10.1016/j.ultsonch.2011.06.008
20. Jamshidi, R., Brenner, G. (2013). Dissipation of ultrasonic wave propagation in bubbly liquids considering the effect of compressibility to the first order of acoustical Mach number. Ultrasonics, 53 (4), 842–848. doi: 10.1016/j.ultras.2012.12.004
21. Zhang, Y., Du, X. (2015). Influences of non-uniform pressure field outside bubbles on the propagation of acoustic waves in dilute bubbly liquids. Ultrasonics Sonochemistry, 26, 119–127. doi: 10.1016/j.ultsonch.2015.02.016
22. Tejedor Sastre, M. T., Vanhille, C. (2017). A numerical model for the study of the difference frequency generated from nonlinear mixing of standing ultrasonic waves in bubbly liquids. Ultrasonics Sonochemistry, 34, 881–888. doi: 10.1016/j.ultsonch.2016.07.020
23. Vanhille, C., Campos-Pozuelo, C. (2009). Nonlinear ultrasonic waves in bubbly liquids with nonhomogeneous bubble distribution: Numerical experiments. Ultrasonics Sonochemistry, 16 (5), 669–685. doi: 10.1016/j.ultsonch.2008.11.013
24. Merouani, S., Ferkous, H., Hamdaoui, O., Rezgui, Y., Guemini, M. (2015). A method for predicting the number of active bubbles in sonochemical reactors. Ultrasonics Sonochemistry, 22, 51–58. doi: 10.1016/j.ultsonch.2014.07.015
25. Vanhille, C., Campos-Pozuelo, C. (2014). Numerical simulations of the primary Bjerknes force experienced by bubbles in a standing ultrasonic field: Nonlinear vs. linear. Wave Motion, 51 (7), 1127–1137. doi: 10.1016/j.wavemoti.2014.06.001
26. Xu, Z., Yasuda, K., Koda, S. (2013). Numerical simulation of liquid velocity distribution in a sonochemical reactor. Ultrasonics Sonochemistry, 20 (1), 452–459. doi: 10.1016/j.ultsonch.2012.04.011
27. Tudela, I., Sáez, V., Esclapez, M. D., Díez-García, M. I., Bonete, P., González-García, J. (2014). Simulation of the spatial distribution of the acoustic pressure in sonochemical reactors with numerical methods: A review. Ultrasonics Sonochemistry, 21 (3), 909–919. doi: 10.1016/j.ultsonch.2013.11.012
28. Vanhille, C., Campos-Pozuelo, C., Sinha, D. N. (2014). Nonlinear frequency mixing in a resonant cavity: Numerical simulations in a bubbly liquid. Ultrasonics, 54 (8), 2051–2054. doi: 10.1016/j.ultras.2014.07.004
29. Xu, Y., Guan, Z., Jin, Y., Tian, Y., Liu, Y., Xu, C., Shi, Y. (2017). Study of the ultrasonic propagation law in the gas–liquid two-phase flow of deepwater riser through numerical simulation. Journal of Petroleum Science and Engineering, 159, 419–432. doi: 10.1016/j.petrol.2017.09.051
30. Gubaidullin, D. A., Fedorov, Y. V. (2013). Sound waves in two-fraction polydispersed bubbly media. Journal of Applied Mathematics and Mechanics, 77 (5), 532–540. doi: 10.1016/j.jappmathmech.2013.12.008


**DOI: 10.15587/1729-4061.2017.118159**

**ANALYSIS OF THE ELECTROMAGNETIC FIELD OF MULTILAYERED BIOLOGICAL OBJECTS FOR THEIR IRRADIATION IN A WAVEGUIDE SYSTEM (p. 58-65)**

**Vadym Popriadukhin**
Tavria state agrotechnological university, Melitopol, Ukraine
**ORCID**: http://orcid.org/0000-0001-9845-6177

**Iryna Popova**
Tavria state agrotechnological university, Melitopol, Ukraine
**ORCID**: http://orcid.org/0000-0001-5429-8269

**Natalia Kosulina**
Kharkiv Petro Vasylenko National Technical University of Agriculture, Kharkiv, Ukraine
**ORCID**: http://orcid.org/0000-0003-4055-8087

**Aleksandr Cherenkov**
Kharkiv Petro Vasylenko National Technical University of Agriculture, Kharkiv, Ukraine
**ORCID**: http://orcid.org/0000-0003-1244-8104

**Mariya Chorna**
Kharkiv Petro Vasylenko National Technical University of Agriculture, Kharkiv, Ukraine
**ORCID**: http://orcid.org/0000-0002-7011-1457

We report theoretical study on the distribution of electromagnetic field in biological objects. To perform the analysis, we selected multilayer bio-objects the size less than a wavelength of the irradiating field. In order to investigate diffraction of electromagnetic wave on the biological objects of a given type, we used integral Maxwell equations in combination with boundary conditions both at the border of the object's layers and at the border of a guiding electrodynamic structure.

A theoretical research into creation of a waveguide system was conducted for the irradiation of biological objects with dimensions less than a wavelength of the irradiating field. The waveguide system employed two diffusers: a biological object and a metallic sphere. Location of the bio-object was permanent while the sphere could move along a section of the waveguide. The result of research is the obtained dependence of reflectance coefficient on the distance between diffusers. Reflectance coefficient was obtained for frequency 58.6 GHz, waveguide dimensions d=10.668 mm, h=4.318 mm, radius of the metallic sphere 4 mm, dielectric permittivity of biological objects from 2 to 14 units the size $\frac{a}{\lambda} << 1$. Calculations showed that by selecting the distance between a bio-object and a metallic sphere, it is possible to achieve that the bio-object is located in the antinode of the electromagnetic field.

**Keywords**: electromagnetic field, multi-layered biological objects, waveguide system, irradiation of biological objects.

**References**

1. Konstantinov, I. S., Mamatov, A. V., Sapryka, V. A., Cherenkov, A. D., Sapryka, A. V., Kosulina, N. G. (2015). Theoretical Analysis of Electromagnetic Field Electric Tension Distribution in the Seeds of Cereals. Research journal of Pharmaceutical, Biological and Chemical Scinces, 6 (6), 1686–1694.
2. Kosulina, N., Cherenkov, A., Pirotti, E., Moroz, S., Chorna, M. (2017). Determining parameters of electromagnetic radiation for energoinformational disinfection of wool in its pretreatment. Eastern-European Journal of Enterprise Technologies, 2 (5 (86)), 52–58. doi: 10.15587/1729-4061.2017.96074
3. Chernaya, M. A., Kosulina, N. G. (2013). Biophysical analysis of the impact of information electromagnetic field on biological objects. Bulletin of Kharkiv national technical University of agriculture named of P. Vasilenko, 142, 86–87.
4. Kovacic, P., Somanathan, R. (2010). Electromagnetic fields: mechanism, cell signaling, other bioprocesses, toxicity, radicals, antioxidants and beneficial effects. Journal of Receptors and Signal Transduction, 30 (4), 214–226. doi: 10.3109/10799893.2010.488650
5. Kesari, K. K., Kumar, S., Behari, J. (2011). Pathophysiology of Microwave Radiation: Effect on Rat Brain. Applied Biochemistry and Biotechnology, 166 (2), 379–388. doi: 10.1007/s12010-011-9433-6
6. Feng, B., Wang, Z. (2017). Effect of an electromagnetic field on the spectra and elliptic flow of particles. Physical Review C, 95 (5). doi: 10.1103/physrevc.95.054912
7. Cichoń, N., Czarny, P., Bijak, M., Miller, E., Śliwiński, T., Szemraj, J., Saluk-Bijak, J. (2017). Benign Effect of Extremely Low-Frequency Electromagnetic Field on Brain Plasticity Assessed by Nitric Oxide Metabolism during Poststroke Rehabilitation. Oxidative Medicine and Cellular Longevity, 2017, 1–9. doi: 10.1155/2017/2181942
8. Grundler, W., Kaiser, F., Keilmann, F., Walleczek, J. (1992). Mechanisms of electromagnetic interaction with cellular systems. Naturwissenschaften, 79 (12), 551–559. doi: 10.1007/bf01131411
9. Watters, F. L. (1976). Microwave radiation for control of Tribolium confusum in wheat and flour. Journal of Stored Products Research, 12 (1), 19–25. doi: 10.1016/0022-474x(76)90018-7
10. Boyarskii, D. A., Tikhonov, V. V., Komarova, N. Y. (2002). Model of Dielectric Constant of Bound Water in Soil for Applications of Microwave Remote Sensing. Progress In Electromagnetics Research, 35, 251–269. doi: 10.2528/pier01042403
11. Van Lamsweerde-Gallez, D., Meessen, A. (1975). The role of proteins in a dipole model for steady-state ionic transport through biological membranes. The Journal of Membrane Biology, 23 (1), 103–137. doi: 10.1007/bf01870247
12. Webb, S. J. (1975). Genetic continuity and metabolic regulation as seen by the effects of various microwave and black light frequencies on these phenomena. Annals of the New York Academy of Sciences, 247 (1 Biologic Effe), 327–351. doi: 10.1111/j.1749-6632.1975.tb36009.x
13. Sher, L. D., Kresch, E. (2009). In the possibility of no thermal biological effects of pulsed electromagnetic radiation. Biophys. S., 18, 980–990.
14. Lin, J. C. (2005). Advances in Electromagnetic Fields in Living Systems. Springer, 227. doi: 10.1007/b104216
15. Nikol'skiy, V. V., Nikol'skaya, T. I. (2012). Electrodynamics and radio wave propagation. Moscow: Librocom, 544.
16. Pirotti, Ye. L., Kaplun, O. V. (2015). Mathematical models of electromagnetic fields in the middle of the cylindrical and spherical biological structures. Bulletin of Kharkiv national technical University of agriculture named of P. Vasilenko, 164, 166–168.