DETERMINING ADDITIONAL POWER LOSSES IN THE ELECTRICITY SUPPLY SYSTEMS DUE TO CURRENT’S HIGHER HARMONICS (p. 6-13)

Oleksandr Plakhtii
Limited Liability Company «VO OVENS», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-1535-8991

Volodymyr Nerubatskyi
Ukrainian State University of Railway Transport, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-4309-601X

Igor Ryslichenko
National Technical University «Kharkiv Polytechnic Institute», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0001-9839-4510

Olena Zhenchenko
Ukrainian State University of Railway Transport, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0003-2294-9527

Sergiy Tykhonravov
Ukrainian State University of Railway Transport, Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-5939-7749

Denys Hordiienko
Private JSC «ELAKS», Kharkiv, Ukraine
ORCID: http://orcid.org/0000-0002-0347-9536

The paper reports results of research into the influence of higher harmonics of the power source voltage and the load current on power losses in an electric network. The relevance of this study is predetermined by the ever-increasing number of the electric energy pulse consumers, which leads to an increase in the number of higher harmonics in power supply systems. In turn, higher harmonics cause deterioration not only in the qualitative indicators for electricity, but a significant reduction in energy efficiency as well. The study that we conducted has shown that existing analytical dependences of a network’s active resistance on the higher harmonics’ frequencies are mutually exclusive, contradictory, and inaccurate because they do not take into consideration the geometrical characteristics of the network conductors. Based on the first-order Bessel equations, we have obtained refined analytical dependences of a network’s active resistance on the higher harmonics’ frequencies, taking into consideration the geometrical properties of wires. It has been established that in addition to an increase in the active resistance value due to the influence of a skin effect, higher harmonics determine additional losses caused by an increase in the root-mean-square current value. We present the dependence of additional power losses and efficiency factor in the electric network as a function of values for the load current harmonic distortions coefficient and the coefficients for harmonic distortions in a power source voltage. It was established that the network current higher harmonics, caused by the pulse load, lead to the bigger losses in the network than the higher harmonics from the power source. The results obtained in this study could be used in the calculation of energy losses in electric networks due to higher harmonics and while estimating economic efficiency when introducing filter compensating devices.

Keywords: load current higher harmonics, power losses, harmonic distortions coefficient, skin effect.

References
1. Nerubatskyi, V. P., Plakhtiy, A. A., Gladka, A. V. (2018). EMC improvement research of three-phase active rectifiers with power factor correction in regenerative mode. Collected scientific works of Ukrainian State University of Railway Transport, 178, 21–28. doi: https://doi.org/10.18664/1994-7852.178.2018.138906
2. Plakhtiy, O. A., Nerubatskyi, V. P., Silantiev, A. S. (2017). Energy efficiency analyses of active rectifier with improved hysteretic control system. Informatychno-keriuchih systemy na zaliznychnomu transporti, 3, 10–16.
3. Plakhtii, O. A., Nerubatskyi, V. P., Kavun, A. V., Mashura, A. M. (2018). Compensation of input current harmonics in parallel multiple voltage source inverters. Electrical and computer systems, 27, 65–74. DOI: https://doi.org/10.15276/elcets.27.103.2018.07
4. Solsona, F. J. A., Carrera, A. P. (2014). Study of harmonics thermal effect in conductors produced by skin effect. IEEE Latin America Transactions, 12 (8), 1488–1495. doi: https://doi.org/10.1109/tla.2014.7014518
5. Tschemei, A., Onodera, H. (2011). Effect of Anomalous Skin Effect on Transmission-Line Loss. Leice Technical Report Microwaves, 111, 77–81.
6. Zhezheleiko, I. V. (2010). Vysishie garmoniki v sistemah elektronabzheniya promysshlennykh predpriyat. Moscow: Energoatomizdat, 373.
7. Zagirnyak, M., Mal’ka, M., Kalinov, A. (2015). Analysis of operation of power components compensation systems at harmonic distortions of mains supply voltage. 2015 Intl Aegean Conference on Electrical Machines & Power Electronics (ACEMP), 2015 Intl Conference on Optimization of Electrical & Electronic Equipment (OPTIM) & 2015 Intl Symposium on Advanced Electromechanical Motion Systems (ELECTROMOTION). doi: https://doi.org/10.1109/optim.2015.7426958
8. Shetinov, V. M., Baizul, I. M. (2013). The effect of higher harmonics in the power supply system electricity companies. Izvestiya Tul’skogo gosudarstvennogo universiteta. Tekhnicheskie nauki, 12, 27–31.
9. Lytarevich, A. G., Vyvrva, A. A., Dolinger, S. Yu., Ospirov, D. S., Chetverik, I. N. (2009). Estimation of additional power losses due to higher harmonics in elements of power system. Osnovyi nauchnyiVarost, 1, 109–113.
10. Borovikov, V. S., Harlov, N. N., Akinmanov, T. B. (2013). O neobhodimosti vklucheniya dobarovnych poter’ ot vyshih garmonik toka v tekhnikhicheskie poteri pri peredache elektricheskoy energii. Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursu, 322 (4), 91–93.
11. Akinmanov, T. B., Harlov, N. N., Borovikov, V. S., Usbakov, V. Y. (2014). Development of calculation methods for additional electrical power losses during transportation. 2014 9th International Forum on Strategic Technology (IFOST). doi: https://doi.org/10.1109/ifost.2014.6991138
12. Al-Mashakbeh, A. S., Zagirnyak, M., Mal’ka, M., Kalinov, A. (2017). Improvement of compensation method for non-active current components at mains supply voltage unbalance. Eastern-European Journal of Enterprise Technologies, 1 (8 (85)), 41–49. doi: https://doi.org/10.15587/1729-4061.2017.87316
13. Zhezheleiko, I. V. (2010). Elektronabzhenie poteri ot vyshih garmonik v sistemah elektronabzheniya. Elektrika, 4, 3–6.
Abstract and References. Energy-saving technologies and equipment

14. Beaty, H. W. (2000). Standard Handbook for Electrical Engineers. McGraw-Hill, 34–50.
15. Hayt, W. H., Buck, J. A. (2006). Engineering Electromagnetics. Graw Hill, 561.
16. Ben, C. J. (2012). The Practical Issues involved in Designing, Specifying and Installing Skin Effect Current Tracing Systems. IEEE Petroleum and Chemical Industry Conference Europe Conference Proceedings (PCIC EUROPE), 1–13.
17. Zaikin, D. I. (2015). Round and tubular wire skin effect modeling and usage SPICE as Maxwell’s equations solver. 2015 23rd Telecommunications Forum Telfor (TELFOR). doi: https://doi.org/10.1109/telfor.2015.7377551
18. Dias, R. A., Lira, G. R. S., Costa, E. G., Ferreira, R. S., Andrade, A. F. (2018). Skin effect comparative analysis in electric cables using computational simulations. 2018 Simposio Brasileiro de Sistemas Eletricos (SBSE). doi: https://doi.org/10.1109/sbse.2018.8395687
19. Czarnecki, L. S. (2004). On Some Misinterpretations of the Instantaneous Reactive Power p-q Theory. IEEE Transactions on Power Electronics, 19 (3), 828–836. doi: https://doi.org/10.1109/tpele.2004.826500
20. Kim, H., Blaabjerg, F., Bak-Jensen, B., Choi, J. (2002). Instantaneous power compensation in three-phase systems by using p-q-r theory. IEEE Transactions on Power Electronics, 17 (3), 701–710. doi: https://doi.org/10.1109/tpele.2002.802185
21. Jimm T, Wenn J, Smelleyr K (2005). Control and topologies for three-phase three-level active power filters, Twentieth Annual IEEE Applied Power Electronics Conference and Exposition, 2005. APEC 2005. doi: https://doi.org/10.1109/apec.2005.1433017
22. Malakova, M., Kalinov, A. (2017). APF control with the use of the direction of the energy flow determination method in the electric circuit with a nonlinear load. 2017 International Conference on Modern Electrical and Energy Systems (MEES). doi: https://doi.org/10.1109/mees.2017.8248894

DOI: 10.15587/1729-4061.2019.153663

DEVELOPMENT OF PLANAR MESOSCALE COMBUSTOR WITH DOUBLE NARROW SLIT FLAME HOLDER AND VARIOUS ASPECT RATIOS FOR MICROPOWER GENERATOR (p. 14-23)

Satworo Adiwidodo
Brawijaya University, Malang, Indonesia
State Polytechnic of Malang, Malang, Indonesia
ORCID: http://orcid.org/0000-0002-4774-6438

I Nyoman Gede Wardana
Brawijaya University, Malang, Indonesia
ORCID: http://orcid.org/0000-0003-3146-9517

Lilis Yuliati
Brawijaya University, Malang, Indonesia

Mega Nur Sasonkho
Brawijaya University, Malang, Indonesia

We have investigated the effects of the aspect ratio of the rectangular mesoscale combustor with a narrow slit flame holder on the flame stability limit, flame behavior and uniformity of combustor wall temperature. The combustor was made of copper with a cross-section area of 6 mm². The combustor aspect ratio (AR) was varied as 1, 1.5, 2.67, and 6. LPG and pure oxygen were premixed and the experiment was conducted at a limited flow rate. Pure oxygen is selected as an oxidizing agent with the intention of revealing in detail the range of flame stability within a very narrow quenching distance. All observed flames were inside the combustion chamber, not outside the channel. This research used a new type of flame holder namely double narrow slit flame holder as a flame stabilizer. The flame holder with double slit and a kind of bluff body in the center helps circulate the flow and prolong the residence time to make the flame more stable. The use of double narrow slit flame holder successfully extended the stability map to a very lean equivalence ratio (φ). However, there was a dead zone near stoichiometry condition due to very high flame propagation speed. Aspect ratio had an important role for the non-circular combustor. The aspect ratio gave a great effect to determine the limit of the stability map that can be achieved at the rich mixture. The combustor with AR=1.5 had the widest range of flammability limit, while AR=6 had the narrowest flame stability limits. However, the latter reached the most uniform wall temperature, which is important to obtain high efficiency thermal to electric energy conversion. The results of this study can be used to determine the right fuel mixture on the mesoscale combustor as a heat source on the micro power generator/thermal electric system.

Keywords: flame stability limit, wall temperature, aspect ratio, double narrow slit flame holder, planar mesoscale combustor.

References
1. Chou, S. K., Yang, W. M., Chou, K. J., Li, J., Zhang, K. L. (2011). Development of micro power generators – A review. Applied Energy, 88 (1), 1–16. doi: https://doi.org/10.1016/j.apenergy.2010.07.010
2. Ju, Y., Maruta, K. (2011). Microscale combustor: Technology development and fundamental research. Progress in Energy and Combustion Science, 37(6), 669–715. doi: https://doi.org/10.1016/j.pecs.2011.03.001
3. Li, J., Chou, S. K., Li, Z. W., Yang, W. M. (2009). A potential heat source for the micro-thermophotovoltaic (TPV) system. Chemical Engineering Science, 64 (14), 3282–3289. doi: https://doi.org/10.1016/j.ches.2009.04.005
4. Akram, M., Minaev, S., Kumar, S. (2013). Investigations on the Formation of Planar Flames in Mesoscale Divergent Channels and Prediction of Burning Velocity at High Temperatures. Combustion Science and Technology, 185 (4), 645–660. doi: https://doi.org/10.1080/00102205.2012.739224
5. Zhou, J., Wang, Y., Yang, W., Liu, J., Wang, Z., Cen, K. (2009). Improvement of micro-combustion stability through electrical heating. Applied Thermal Engineering, 29 (11-12), 2373–2378. doi: https://doi.org/10.1016/j.applthermleng.2008.12.005
6. Zhong, B.-J., Wang, J.-H. (2010). Experimental study on premixed CH₄/air mixture combustion in micro Swiss-roll combustors. Combustion and Flame, 157 (12), 2222–2229. doi: https://doi.org/10.1016/j.combustflame.2010.07.014
7. Li, J., Chou, S. K., Li, Z. W., Yang, W. M. (2010). Experimental investigation of porous media combustion in a planar micro-combustor. Fuel, 89 (3), 708–715. doi: https://doi.org/10.1016/j.fuel.2009.06.026
8. Li, J., Huang, J., Chen, X., Yan, M., Zhao, D., Wei, Z., Wang, N. (2017). Experimental Study on Flame Stability and Thermal Performance of an n-Heptane-Fueled Microscale Combustor. Combustion Science and Technology, 189 (7), 1198–1215. doi: https://doi.org/10.1080/00102202.2017.1279154
9. Wang, W.-C., Hung, C.-L., Chao, Y.-C. (2015). Numerical and Experimental Studies of Mixing Enhancement and Flame Stabilization in a Meso-Scale TPV Combustor With a Porous-Medium Injector and a Heat-Regeneration Reverse Tube. Heat Transfer Engineering, 35 (4), 336–337. doi: https://doi.org/10.1080/01457632.2013.810968
Finding thermal effectiveness of the collector, specifically, the influence of the components of thermal balance of the collector on the drop of temperatures in the heat carrier flow in the collector and the isolation level on heating efficiency.

We obtained analytical dependences for determining the components of thermal balance of the collector, distribution of the temperature field along the absorbing panel, which made it possible to improve the mathematical model of the heat exchange process in the developed air collector. The results of the research into the air collector allowed developing the program of numerical computer calculation of the temperature field of thermal flows.

It was established that application of the wavy absorbing surface of the absorber in the air heliocollector at the low level of insolation $E=377 \text{ W/m}^2$ allows increasing efficiency up to $\eta=58.3\%$, and at high energy lighting of $E=1,000 \text{ W/m}^2$, up to $\eta=63.9\%$. Performance of the collector was determined by the iterative calculation-quantitative method and made up more than 78–80 %. This is 10–20 % higher than that in flat collectors, and by 5–10 % higher than in cylindrical vacuumed collectors.

The obtained results can be used in the development and improvement of the technical facilities of fruit drying, for increasing the technological and energy effectiveness of the process.

**Keywords:** heliocollector, air heating system, absorber, heat flow, Rayleigh criterion, heating efficiency.

**References**

1. Aboghrara, A. M., Alghoul, M. A., Baharudin, B. T. H. T., Elbreki, A. M., Ammar, A. A., Sopian, K., Hairuddin, A. A. (2018). Parametric Study on the Thermal Performance and Optimal Design Elements of Solar Air Heater Enhanced with Jet Impingement on a Corrugated Absorber Plate. International Journal of Photoenergy, 2018, 1–21. doi: https://doi.org/10.1155/2018/1469385

2. Kou, K. B., Gbaha, P., Kolki, E. P. M., Fassinou, W. F., Touré, S. (2011). Modelling of thermal behaviour of a direct solar drier possessing a chimney. Application to the drying of cassava. Indian Journal of Science and Technology, 4 (12), 1609–1618.

3. Amankwah, E. A. Y., Dzisi, K. A., van Straten, G., van Willigenburg, L. G., van Boxtel, A. J. B. (2017). Distributed mathematical model supporting design and construction of solar collectors for drying. Drying Technology, 35 (14), 1675–1687. doi: https://doi.org/10.1080/07373937.2016.1269806

4. Çağlayan, N., Ertekin, C., Alta, Z. D. (2015). Experimental investigation of various type absorber plates for solar air heaters. Journal of Agricultural Sciences, 21 (4), 439–470.

5. Ondieki, H. O., Koech, R. K., Tomu, J. K., Rotich, S. K. (2014). Mathematical modeling of solar air collector with a trapezoidal corrugated absorber plate. International Journal of scientific & technological research, 3 (8), 51–56.

6. Liberty, J. T., Okonkwo, W. I., Ngabea, S. A. (2014). Solar crop drying – A viable tool for agricultural sustainability and food security. International Journal of Modern Engineering Research, 4 (6), 8–19.

7. Alta, Z. D., Çağlayan, N., Atmaca, I., Ertekin, C. (2014). Theoretical and experimental investigation of the performance of back-pass solar air heaters. Turkish Journal of Engineering and Environmental Sciences, 38, 293–307. doi: https://doi.org/10.3906/muh-1310-2

8. Burova, Z. A., Dekusha, L. V., Vorob’ev, L. I., Mazurenko, A. G. (2011). Determination of emission coefficient of energyeffective glasses by calorimetric method. Promyshlennaya teplotekhnika, 33 (6), 94–100.

9. Duffie, J. A., Beckman, W. A. (2013). Solar Engineering of Thermal Processes. John Wiley & Sons, 910. doi: https://doi.org/10.1002/9781118671693

10. Yuliati, L., Seo, T., Mikami, M. (2012). Liquid-fuel combustion in a narrow tube using an electrospray technique. Combustion and Flame, 159 (1), 462–464. doi: https://doi.org/10.1016/j.combustflame.2011.06.010

11. Mikami, M., Maeda, Y., Matsui, K., Seo, T., Yuliati, L. (2013). Combustion of gaseous and liquid fuels in meso-scale tubes with wire mesh. Proceedings of the Combustion Institute, 34 (2), 3387–3394. doi: https://doi.org/10.1016/j.proci.2012.05.064

12. Baignomhamadi, M., Tabajamaat, S., Farsiani, Y. (2015). Experimental study of the effects of geometrical parameters, Reynolds number, and equivalence ratio on methane–oxygen premixed flame dynamics in non-adiabatic cylindrical meso-scale reactors with the backward facing step. Chemical Engineering Science, 132, 215–233. doi: https://doi.org/10.1016/j.cej.2015.04.008

13. Faramarzpour, H., Mazzaheri, K., Alipoor, A. (2018). Effect of backward facing step on radiation efficiency in a micro combustor. International Journal of Thermal Sciences, 132, 129–136. doi: https://doi.org/10.1016/j.ijthermalsci.2018.06.002

14. Wan, J., Fan, A., Liu, Y., Yao, H., Liu, W., Gou, X., Zhao, D. (2015). Experimental investigation and numerical analysis on flame stabilization of CH4/air mixture in a mesoscope channel with wall cavities. Combustion and Flame, 162 (4), 1035–1045. doi: https://doi.org/10.1016/j.combustflame.2014.09.024

15. Evans, C. J., Kyritsis, D. C. (2011). Experimental Investigation of the Effects of Flame Phenomenology on the Wall Temperature Distribution of MesoScope Nonadiabatic Ducts. Combustion Science and Technology, 183 (9), 847–867. doi: https://doi.org/10.1080/00100022.2011.567109

16. Adiwidodo, S., Wardana, I. N. G., Yuliati, L., Sasonko, M. N. (2016). Flame Stability Measurement on Rectangular Slot Mesoscope Combustor. Applied Mechanics and Materials, 836, 271–276. doi: https://doi.org/10.4028/www.scientific.net/amm.836.271

17. Taamallah, S., Labry, Z. A., Shahbougue, S. J., Ghoniem, A. F. (2015). Thermo-acoustic instabilities in lean premixed swirl-stabilized combustion and their link to acoustically coupled and decoupled flame macrostructures. Proceedings of the Combustion Institute, 35 (3), 3273–3282. doi: https://doi.org/10.1016/j.proci.2014.07.002

**DOI:** 10.15587/1729-4061.2019.154550

**RESULTS OF RESEARCH INTO EFFICIENCY OF A FLAT SOLAR AIR HELICOLECTOR WITH A WAVY ABSORBING SURFACE (p. 24-36)**

Vitaliy Boyarchuk  
Lviv National Agrarian University, Dublyany, Ukraine  
**ORCID:** http://orcid.org/0000-0001-8294-8759

Sergiy Korobka  
Lviv National Agrarian University, Dublyany, Ukraine  
**ORCID:** http://orcid.org/0000-0002-4717-509X

Mykhailo Bahych  
Lviv National Agrarian University, Dublyany, Ukraine  
**ORCID:** http://orcid.org/0000-0003-1295-4162

Roman Krygul  
Lviv National Agrarian University, Dublyany, Ukraine  
**ORCID:** http://orcid.org/0000-0002-3061-9176

A new design of the air collector with the airtight and warmed casing and the absorber with the wavy surface that can be used as an additional heating element of the low-temperature heat source was developed. We established a series of generalizing dependences for finding thermal effectiveness of the collector, specifically, the influence of the components of thermal balance of the collector on the drop of temperatures in the heat carrier flow in the collector and the isolation level on heating efficiency.
The paper deals with the influence of the mean volumetric temperature of a thermo-element branch on the basic parameters, reliability indicators and the dynamics of operation of thermo-electric cooler under different temperature changes at the assigned heat load, geometry of branches of thermo-elements for specific current operation modes. It was shown that the mean temperature of the thermo-element, which is a reference point when calculating the energy performance of the thermoelectric cooler, can be used only for calculations in the stationary operation mode. Its use in the dynamic mode leads to significant errors. It was proven that the mean volumetric temperature of a thermo-electric branch can be such a reference point for a dynamic mode. The ratio for assessment of the mean volumetric temperature depending on the relative operating current was determined. The relationships between the mean volumetric temperature of a thermo-element, the time required to enter a stationary mode, the required number of thermo-elements, the differences between the mean volumetric and mean temperature, and a cooling coefficient, depending on the relative working current, were analyzed. It was shown that at an increase in the mean volumetric temperature at the assigned current operation mode and a temperature difference, exceeding 40K, the magnitude of operating current, the number of thermo-elements, consumption power, failure rate and time constant decrease and cooling factor increases. The time for entering a stationary mode during the transition from the mode of minimum failure rate to the mode of maximum cooling capacity decreases by 5%, while the failure rate increases by 16%.

The practical significance of the conducted research is both to improve the quality of design of coolers and to select the necessary modes of thermo-electric system for ensuring thermal modes of electronic equipment depending on the importance of dynamic or reliability criteria of control.

Keywords: thermo-element branch, mean volumetric temperature, reliability indicators, dynamics of cooler.

References
1. Zaykov, V. P., Kinshova, L. A., Moiseev, V. F. (2009). Prediction of reliability indicators, thermoelectric cooling devices. Book 1. One-stage devices. Odessa: Polytechnical, 120.
2. Apratsev, O. R. (2017). Thermoelectric coolers and thermal processes in terms of SPICE modeling. Electronics and electrical engineering, 2, 1–12. doi: https://doi.org/10.7256/2453-8884.2017.2.21379
3. Belova, O. V., Chernyshev, A. V. (2004). Mathematical Modeling of Heat Sources in Peltier Thermoelectric Elements. Scientific Instrument Making, 14 (1), 51–57.
4. Ordin, S. V. (2018). Experimental and Theoretical Expansion of the Phenomenology of Thermoelectricity. Global Journal of Science Frontier Research: A Physics and Space Science, 18 (1), 1–8.
5. Bochegov, V. I., Grabov, V. M. (2017). On the thermal conductivity of the gradient-inhomogeneous branches of thermoelements at a difference in the operating temperature. Semiconductors, 51 (7), 874–875. doi: https://doi.org/10.1134/s106378261707003x
6. Poudel, B., Hao, Q., Ma, Y., Lan, Y., Minnic, A., Yu, B. et. al. (2008). High-Thermoelectric Performance of Nanostructured Bismuth Antimony Telluride Bulk Alloys. Science, 320 (5876), 634–638. doi: https://doi.org/10.1126/science.1156446
7. Zhang, L., Wu, Z., Xu, X., Xu, H., Wu, Y., Li, P., Yang, P. (2010). Approach on thermoelectricity reliability of board-level backplane based on the orthogonal experiment design. International Journal of Materials and Structural Integrity, 4 (2/3/4), 170. doi: https://doi.org/10.1504/ijmsi.2010.035205
8. Choi, H.-S., Seo, W.-S., Choi, D.-K. (2011). Prediction of reliability on thermoelectric module through accelerated life test and Physics-of-failure. Electronic Materials Letters, 7 (3), 271–275. doi: https://doi.org/10.1007/s13391-011-0917-x
9. Zaykov, V., Mescheryakov, V., Zhuravlov, Y. (2018). Analysis of relationship between the dynamics of a thermoelectric cooler and its design and modes of operation. Eastern-European Journal of Enterprise Technologies, 1 (8 (91)), 12–24. doi: https://doi.org/10.15587/1729-4061.2018.123891
10. Egorov, V. I. (2006). Exact methods for solving heat conduction problem. Saint Petersburg, St. Petersburg State University ITMO, 48.

DOI: 10.15587/1729-4061.2019.156129
SYNTHESIS OF THE INTEGRATIVE TRIGENERATION SYSTEM FOR A «SOLAR HOUSE» IN THE MIDDLE EAST REGION (p. 43–50)

Larisa Morozuk
Odessa National Academy of Food Technologies, Odessa, Ukraine
ORCID: http://orcid.org/0000-0003-1433-1984

Alla Denysyova
Odessa National Polytechnic University, Odessa, Ukraine
ORCID: http://orcid.org/0000-0002-3906-3960

Alhemiri Saad Aldin
Odessa National Polytechnic University, Odessa, Ukraine
ORCID: http://orcid.org/0000-0002-4860-7923

This research aims to synthesize a trigeneration system for a “solar house” based on an autonomous small solar photovoltaic plant,
which could meet the year-round private consumers' needs for heat and cold supply.

The climatic data on the Middle East countries, such as Iran, Saudi Arabia, the United Arab Emirates, Turkey, Syria, and Iraq, were used. Day and night air temperatures in different regions of these countries throughout the year and the total daily radiation, which comes onto a horizontal surface area, were determined. The obtained results revealed that the entire territory of the Middle East is suitable for the development of solar power supply. Seasonal and daily temperature fluctuations require the year-round use of artificial cold for air conditioning and heating of premises. As a result of the analysis, the generalized circuit solution of the small integrated trigeneration system, based on the photovoltaic solar station, was synthesized. Additional solar collectors with a water heater-accumulator provide hot water supply. Air conditioning and heating are provided by a refrigerating machine. The time of modes change is determined by ambient temperature, which does not correspond to comfortable temperature in particular premises. The temperature mode in premises is maintained by the fresh air flow from the active ventilation system, cooled or heated in heat-exchanger of a machine. To harmonize the operation of all elements of the system, the toolkit for determining thermal loads and temperatures modes on premises and elements of the trigeneration system were developed. The study makes it possible to argue that “solar houses” can solve energy, environmental problems of regions, satisfy the social needs of the population in the Middle East countries.

**Keywords:** solar house, photovoltaic station, trigeneration, compressor refrigerating machine, active ventilation.

**References**

1. Klyuev, P. G. (2010). Solnechnaya energetika: 2010. Available at: http://www.nanometer.ru/2010/08/23/12825909129704_216802.html
2. Ghafour, A., Munir, A. (2015). Worldwide overview of solar thermal cooling technologies. Renewable and Sustainable Energy Reviews, 43, 763–774. doi: 10.1016/j.rser.2014.11.073
3. Strany OPEK delayut stavku na solnechnuyu generaciyu (2017). Available at: https://eadaily.com/ru/news/2017/04/06/strany-oppek-delayut-stavku-na-solnechnuyu-generaciyu
4. Amerhanov, R. A., Draganov, B. H. (2006). Teplotekhnika. Moscow, 432.
5. Proektirovanie solnechnogo doma. Available at: http://www.mensh.ru/articles/proektirovanie-solnechnogo-doma
6. Lazzarin, R. M. (2014). Solar cooling: PV or thermal? A thermodynamic and economical analysis. International Journal of Refrigeration, 39, 38–47. doi: https://doi.org/10.1016/j.ijrefrig.2013.05.012
7. Princip raboty avtomonnoy fotoelektricheskoy stanitsy. Available at: http://www.vorobiov.com/archive/domikpro/detail-princip-raboty-avtomonnoy-fotoelektricheskoy-stanitsy.html
8. Xu, Y., Li, M., Luo, X., Ma, X., Wang, Y., Li, G., Hassanien, R. H. E. (2018). Experimental investigation of solar photovoltaic operated ice thermal storage air-conditioning system. International Journal of Refrigeration, 86, 258–272. doi: https://doi.org/10.1016/j.ijrefrig.2017.11.035
9. Infante Ferreira, C., Kim, D.-S. (2014). Techno-economic review of solar cooling technologies based on location-specific data. International Journal of Refrigeration, 39, 23–37. doi: https://doi.org/10.1016/j.ijrefrig.2013.09.033
10. Opoku, R., Anane, S., Edwin, I. A., Adaramola, M. S., Seidu, R. (2016). Comparative techno-economic assessment of a converted DC refrigerator and a conventional AC refrigerator both powered by solar PV. International Journal of Refrigeration, 72, 1–11. doi: https://doi.org/10.1016/j.ijrefrig.2016.08.014

**DOI:** 10.15587/1729-4061.2019.149217

**EFFECT OF BACKWARD FACING STEP ON COMBUSTION STABILITY IN A CONSTANT CONTACT AREA CYLINDRICAL MESOSCALE COMBUSTOR** (p. 51-59)

**Andi Sanata**
Brawijaya University, Malang, Indonesia
**ORCID:** https://orcid.org/0000-0001-5508-8642

**Nyoman Gede Wardana**
Brawijaya University, Malang, Indonesia
**ORCID:** https://orcid.org/0000-0003-3146-9517

**Lilis Yuliati**
Brawijaya University, Malang, Indonesia

**Mega Nur Sasongko**
Brawijaya University, Malang, Indonesia

This experiment investigates the effect of backward facing step size variation on combustion stability in the cylindrical meso-scale combustor with the constant contact area. The backward facing step was varied by changing the combustor inlet diameter while the combustor diameter at the combustion zone was kept constant, i.e. has a constant contact area. Butane gas (C4H10) was used as fuel with air as an oxidizing agent. The result shows that the backward facing step has an important role in the combustion stabilization mechanism. Stable flame could be stabilized inside the meso-scale combustor with the backward facing step. Without the backward facing step, the flame blows out, then stable at the combustor rim. Recirculation flow occurs in the area behind the backward facing step. The increasing backward facing step size leads to an increase in reactant inlet velocity, recirculation flow size and shear stress in the area near the backward facing step. At large backward facing step size, the high reactant inlet velocity together with the large shear stress quenches the flame while the heat recovered by recirculation flow is less sufficient to stabilize
flame so that the flame drifts to the downstream position. Hence bigger backward facing step size causes narrower flame stability limit area. The smaller the backward facing step size the wider the flame stability limit which shifts more toward lower equivalence ratio and high reactant velocity regions. Decreasing the backward facing step size decreases the reactant velocity into the combustion reaction zone as well as decreases the recirculation flow and the shear stress, so that the quenching effect decreases. The smaller recirculation flow has a better function for the flame holder to increase flame stability inside the meso-scale combustor. Therefore, small backward facing step size has a very important role in recovering heat energy stabilizing the flame in the meso-scale combustor.

**Keywords:** backward facing step, cylindrical meso-scale combustor, constant contact area, flame holder, flame stability limit.

**References**

1. Mikami, M., Maeda, Y., Matsui, K., Seo, T., Yuliati, L. (2013). Combustion of gaseous and liquid fuels in meso-scale tubes with wire mesh. Proceedings of the Combustion Institute, 34 (2), 3387–3394. doi: https://doi.org/10.1016/j.proci.2012.05.064

2. Yang, W. M., Chou, S. K., Shu, C., Li, Z. W., Xue, H. (2002). Combustion in micro-cylindrical combustors with and without a backward facing step. Applied Thermal Engineering, 22 (16), 1777–1787. doi: https://doi.org/10.1016/s1359-4311(02)00113-8

3. Xue, H., Yang, W., Chou, S. K., Shu, C., Li, Z. (2005). Microthermophotovoltaics Power System for Portable MEMS Devices: Microscale Thermophysical Engineering, 9 (1), 85–97. doi: https://doi.org/10.1080/10893950590913431

4. Chou, S. K., Yang, W. M., Chua, K. J., Li, J., Zhang, K. L. (2011). Development of micro power generators – A review. Applied Energy, 88 (1), 1–16. doi: https://doi.org/10.1016/j.apenergy.2010.07.010

5. Maruta, K. (2011). Micro and mesoscale combustion. Proceedings of the Combustion Institute, 33 (1), 125–130. doi: https://doi.org/10.1016/j.proci.2010.09.005

6. Ju, Y., Maruta, K. (2011). Microscale combustion: Technology development and fundamental research. Progress in Energy and Combustion Science, 37 (6), 609–715. doi: https://doi.org/10.1016/j.pecs.2011.03.001

7. Wan, J., Fan, A., Liu, Y., Yao, H., Liu, W., Gou, X., Zhao, D. (2015). Experimental investigation and numerical analysis on flame stabilization of CH4/air mixture in a mesoscale channel with wall cavities. Combustion and Flame, 162 (4), 1035–1045. doi: https://doi.org/10.1016/j.combustflame.2014.09.024

8. Yuliati, L., Seo, T., Mikami, M. (2012). Liquid-fuel combustion in a narrow tube using an electrospray technique. Combustion and Flame, 159 (1), 462–464. doi: https://doi.org/10.1016/j.combustflame.2011.06.010

9. Li, Z. W., Chou, S. K., Shu, C., Xue, H., Yang, W. M. (2005). Characteristics of premixed flame in microcombustors with different diameters. Applied Thermal Engineering, 25 (2–3), 271–281. doi: https://doi.org/10.1016/j.applthermaleng.2004.06.007

10. Pan, J., Zhang, R., Lu, Q., Zha, Z., Bani, S. (2017). Experimental study on premixed methane-air catalytic combustion in rectangular microchannel. Applied Thermal Engineering, 117, 1–7. doi: https://doi.org/10.1016/j.applthermaleng.2017.02.008

11. Chou, S. K., Yang, W. M., Li, J., Li, Z. W. (2010). Porous media combustion for micro thermophotovoltaic system applications. Applied Energy, 87 (9), 2862–2867. doi: https://doi.org/10.1016/j.apenergy.2009.06.039

12. Pan, J. F., Wu, D., Liu, Y. X., Zhang, H. F., Tang, A. K., Xue, H. (2015). Hydrogen/oxygen premixed combustion characteristics in micro porous media combustor. Applied Energy, 160, 802–807. doi: https://doi.org/10.1016/j.apenergy.2014.12.049

13. Di Stazio, A., Chauveau, C., Dayma, G., Dagaut, P. (2016). Combustion in micro-channels with a controlled temperature gradient. Experimental Thermal and Fluid Science, 73, 79–86. doi: https://doi.org/10.1016/j.expthermflusci.2015.09.020

14. Taywade, U. W., Deshpande, A. A., Kumar, S. (2013). Thermal performance of a micro combustor with heat recirculation. Fuel Processing Technology, 109, 179–188. doi: https://doi.org/10.1016/j.fuproc.2012.11.002

15. Altay, H. M., Speth, R. L., Hudgins, D. E., Ghoniem, A. F. (2009). Flame–vortex interaction driven combustion dynamics in a backward-facing step combustor. Combustion and Flame, 156 (5), 1111–1125. doi: https://doi.org/10.1016/j.combustflame.2009.02.003

16. Baigomhammadi, M., Tabejamaat, S., Farsiani, Y. (2015). Experimental study of the effects of geometrical parameters, Reynolds number, and equivalence ratio on methane–oxygen premixed flame dynamics in non-adiabatic cylindrical meso-scale reactors with the backward facing step. Chemical Engineering Science, 132, 215–233. doi: https://doi.org/10.1016/j.ces.2015.04.008

17. Roy, V., Majumder, S., Sanjaly, D. (2010). Analysis of The Turbulent Fluid Flow in an Axisymmetric Sudden Expansion. International Journal of Engineering Science and Technology, 2 (6), 1569–1574.

**DOI: 10.15587/1729-4061.2019.156121**

**IMPROVING ENERGY EFFICIENCY OF COAL TRANSPORTATION BY ADJUSTING THE SPEEDS OF A COMBINE AND A MINE FACE CONVEYOR (p. 60-70)**

Mykola Stadnik
Vinnytsia National Agricultural University, Vinnytsia, Ukraine
ORCID: http://orcid.org/0000-0003-2109-6219

Dnytro Semenchenko
Donetsk National Technical University, Pokrovsk, Ukraine
ORCID: http://orcid.org/0000-0002-2674-9453

Anatoly Semenchenko
Donetsk National Technical University, Pokrovsk, Ukraine
ORCID: http://orcid.org/0000-0001-5706-7386

Pavlo Belytsky
Donetsk National Technical University, Pokrovsk, Ukraine
ORCID: http://orcid.org/0000-0003-0982-7103

Svitlana Virych
Donetsk National Technical University, Pokrovsk, Ukraine
ORCID: http://orcid.org/0000-0003-4734-345X

Viktor Tkachov
National Technical University “Dnipro Polytechnic”, Dnipro, Ukraine
ORCID: http://orcid.org/0000-0002-2079-4923

The object of this research is the process that forms the weighted specific energy consumption for the transportation of rock mass by a coal face scraper conveyor at intensive coal mining under conditions of the non-uniform movement of a cleaning combine. The subject of this study is the regularities in the influence of uneven feed speed of a cleaning combine on energy indicators for the transportation of breakage face by a scraper conveyor under conditions of intensive coal mining. The aim of this work is to substantiate a technique to improve energy efficiency in the operation of the system “Cleaning combine – mine face conveyor” under intensive coal mining conditions. We have statistically processed the results of experimental research into feed...
speed of the cleaning combine KDK500 at the eastern coal face No. 23 of deposit c11 at the mine “Yuzhnodonbasskaya” (Ugledar, Ukraine) of GP “Donetskugol”, undertaken by the Institute “Dongiprouglemash” (Ukraine). We have constructed the structural and mathematical models of the process that enables the output cargo flow of breakage face and forms specific energy consumption for the transportation of rock mass by a coal face scraper conveyor. A mathematical model of the operating process takes into consideration the impact of the magnitude and non-uniformity of the feed speed of a cleaning combine on energy consumption at cargo transportation. We have established significant non-uniformity in the speed modes, in the productivity of a cleaning combine, caused by the mining-geological conditions and the nature of the technological process, by existing procedures for harmonizing the operational modes of mining and transporting equipment at breakage faces. The influence has been established of speed modes and efficiency of the combine on specific energy consumption for the transportation of cargo by a coal face scraper conveyor. The result is the high irregularity of a cargo flow both along a coal face and along further transport chain, which leads to a significant increase in energy consumption for cargo transportation. We have examined the effect of speed modes during operation of a combine, consequently its efficiency, on energy indicators for the process of coal transportation and the distribution of a cargo flow. It was established that increasing the feed speed of a cleaning combine and decreasing the speed of a scraper conveyor bring down specific energy costs for the transportation of discharged rock mass along a coal face.

Keywords: coal combines, specific energy consumption, mine face scraper conveyors, cargo flow characteristic, direction of combine’s motion.

References

1. Krutov, G. V., Savickiy, A. I. (2015). Ekonomicheskaya ocenka efektivnosti investitsiy v energoberegayuschei reguliernoye elektroprivody konveyerov gorno-obogatitel’nykh kombinatov. Politeknicheskii zhurnal. Available at: http://www.metajournal.com.ua/Economic-evaluation-of-the-effectiveness-of-investments-in-energy-saving-electric-adjustable-conveyors-mining-and-processing/

2. Ruhlov, A. V., German, E. D. Energeticheskie karakteristiki magistral’nogo konveyeroprovoda ugol’nykh shafot. Available at: http://www.nbnu.gov.ua/old_jrn/natural/Geta/2010_84/7.pdf

3. Semenchenko, A., Stadnik, M., Belitsky, P., Semenchenko, D., Stepansenko, O. (2016). The impact of an uneven loading of a belt conveyor on the loading of drive motors and energy consumption in transportation. Eastern-European Journal of Enterprise Technologies, 4 (1 (82)), 42–51. doi: https://doi.org/10.15567/1729-4061.2016.73936

4. Semenchenko, A. K., Stadnik, N. I., Belitsky, P. V., Semenchenko, D. A. (2017). Mathematical model of target function for optimizing modes of the belt-conveyor drive operation. Steklo i keramika, 134, 163–178.

5. Adadurov, V. V., Azenkin, V. V., Voyush, F. S. et. al.; Budilovski, V. A.; Sulima, A. A. (Eds.) (1999). Teoreticheskie osnovy i raschetny transporta energoemkikh proizvodstv Doneck. RIA DonNTU, 217.

6. Ponomarenko, V. A., Makarova, E. V., Kreymer, E. L. et. al. (1977). Tekhnologiya, organizatsiya i ekonomika podzemnogo transporta. Moscow: Nedra, 221.

7. Wang, N., Wen, Z., Liu, M., Guo, J. (2016). Constructing an energy efficiency benchmarking system for coal production. Applied Energy, 169, 301–308. doi: https://doi.org/10.1016/j.apenergy.2016.02.030

8. Wang, X., Li, B., Yang, Z. (2018). Analysis of the Bulk Coal Transport State of a Scraper Conveyor Using the Discrete Element Method. Strojnoi vestnіk – Journal of Mechanical Engineering, 64 (1), 37–46. doi: https://doi.org/10.5545/sv-jme.2017.4790

9. Stadnik N. I. (2013). Mekhanotronnyi podhod pri analize dvizushchishestry gornyh kompleksov. Naftogazova energetika, 1 (19), 91–98.

10. Fedotov, G. S., Zhuravlev, E. I. (2016). Determination of optimal energy parameters of winning assembly under different ground conditions based on cutter-loader simulation model. Gornyi informatsionno-analiticheskii byulleten’, 12, 356–361.

11. Gusarov, A., Gusarov, O., Kovalev, Ye. (2007). Approaches to the power increase of economy-type conveyor induction motors in coal-mining industry. Naukovyi pratsi DonNTU: Elektrotekhnik ta enerhetyka, 7 (128), 164–165.

12. Tkachenko, A. A., Osichev, A. V. (2013). Snižhenie tokovyh i dinamicheskikh nagruzok v reguliernom asinhronnom elektroprivode shaltnogo skrebkovo konveyera pri zaklinavanii cepi. Visnyk NTU «KhPI», 17, 157–162.

13. Makaryan, L. V., Sel’nicyna, M. V. (2016). Analiz i modelirovanie sluchaynogo shaltnogo gruzopotoka na magistral’nom sbornom konveyere. Gornyi informatsionno-analiticheskii byulleten’, 5, 67–74.

14. Kondrakhin, V., Stadnik, N., Belitsky, P. (2013). Statistical Analysis of Mine Belt Conveyor Operating Parameters. Naukovyi pratsi DonNTU. Seriya elektromekhanichnichnia, 2, 140–150.

15. Korneev, S. V. (2005). Koncepciya adaptacii zaboynyh skrebkovyh kompleksov k podzemnym usloviyam. Avtomaticheskaya sistem priprovod konveyerov. Naukovi pratsi DonNTU. Seriya elektromekhanichnichnia, 7 (128), 164–165.

16. Leng, S., Chung, I.-Y., Edrington, C. S., Cartes, D. A. (2011). Coordination of multiple adjustable speed drives for power quality improvement. Electric Power Systems Research, 81 (6), 1227–1237. doi: https://doi.org/10.1016/j.epsr.2011.01.012

17. Zhang, S., Xia, X. (2011). Modeling and energy efficiency optimization of belt conveyors. Applied Energy, 88 (9), 3061–3071. doi: https://doi.org/10.1016/j.apenergy.2011.03.015

18. Ventcel’, E. S. (1999). Teoriya veroyatnostey. Moscow: Vysshaya shkola, 383.

19. Ventcel’, E. S., Ovecharov, L. A. (2000). Teoriya sluchaynyh proizvodstev. Moscow: Vysshaya shkola, 383.

20. Braslavskiy, I. Ya., Ishmatov, Z. Sh., Polyakov, V. H. (2004). Energosbergayushchey asinhronnyh elektroprivodov. Moscow, 202. Available at: http://en-res.ru/wp-content/uploads/2012/12/asinhr_electroprivod_brasil.pdf

21. Tchakhov, V., Bublikov, A., Isakova, M. (2013). Control automation of shearer transporting belts in terms of auger gumming criterion. Energy Efficiency Improvement of Geotechnical Systems, 137–144. doi: https://doi.org/10.1201/b16355-19

22. Tchakhov, V., Bublikov, A., Gruler, G. (2015). Automated stabilization of loading capacity of coal shearer screw with controlled cutting drive. New Developments in Mining Engineering 2015, 465–477. doi: https://doi.org/10.1201/b19901-82

DOI: 10.15587/1729-4061.2019.154840

DEVELOPMENT AND INVESTIGATION OF THE REDUCED MATHEMATICAL MODEL OF THE PROCESS OF BAKING CARBON PRODUCTS (p. 70-78)

Oleksii Zhuchenko
National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0001-5611-6529

Anton Korotynskyi
National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0002-6309-5970
The development of optimal control of the process of baking carbon products involves consideration of the influence of characteristic zones of the furnace and uniformity of the temperature field of workpieces. This statement suggests the development of a distributed-parameter mathematical model of the furnace. It is known that the calculation time of such models is quite large, and their application in real time is impossible. According to the above, for further development of the optimal control system of the baking process, there is a need to reduce the full mathematical model providing the necessary calculation time.

The reduced mathematical model of the baking process, which differs from the known models in shorter calculation time was developed and investigated in compliance with accuracy requirements. It is found that for cases of using \( n > 15 \) first basis vectors, the restriction on the permissible error of approximation of the values of Fourier coefficients is fulfilled. The possibility of choosing the optimal structure of identification models determines the possibility of obtaining temperature images of the reduced mathematical model with the necessary accuracy.

The results obtained allow flexible selection of the reduced mathematical model in accordance with the technical capabilities of computing equipment.

Given that in the process of baking carbon products, the defining temperatures are workpiece temperatures, only control points of workpieces were selected for the quality study of reduced models.

Since the process of baking carbon products consists of three main stages, three reduced mathematical models of these stages were implemented for adequate modeling of such a process.

The study of the accuracy of reduced models included comparisons of temperature values calculated by the reduced model with temperatures calculated by the initial model, which in this case was considered as a generator of experimental data.

**Keywords:** baking process, temperature fields, variable separation method, carbon products.

**References**

1. Butkovskiy, A. G. (1965). Teoriya optimal’noy upravleniya sistemy s raspredelenymi parametrami. Moscow: Nauka, 474.
2. Carlberg, K., Choi, Y., Sargsyan, S. (2018). Conservative model reduction for finite-volume models. *Journal of Computational Physics*, 371, 280–314. doi: https://doi.org/10.1016/j.jcp.2018.05.019
3. Bampton, M. C. C., Craig Jr. R. R. (1968). Coupling of substructures for dynamic analyses. *AIAA Journal*, 6 (7), 1313–1319. doi: https://doi.org/10.2514/3.4741
4. Friswell, M. I., Garvey, S. D., Penny, J. E. T. (1995). Model reduction using dynamic and iterated IRS techniques. *Journal of Sound and Vibration*, 186 (2), 311–323. doi: https://doi.org/10.1006/jsvi.1995.0451
5. Chaturantabut, S., Sorensen, D. C. (2010). Nonlinear Model Reduction via Discrete Empirical Interpolation. *SIAM Journal on Scientific Computing*, 32 (5), 2737–2764. doi: https://doi.org/10.1137/090766498
6. Xiao, D., Fang, F., Busman, A. G., Pain, C. C., Navon, I. M., Du, J., Hu, G. (2014). Non-linear model reduction for the Navier–Stokes equations using residual DEIM method. *Journal of Computational Physics*, 263, 1–18. doi: https://doi.org/10.1016/j.jcp.2014.01.011
7. Willcox, K., Peraire, J. (2002). Balanced Model Reduction via the Proper Orthogonal Decomposition. *AIAA Journal*, 40 (11), 2323–2330. doi: https://doi.org/10.2514/2.1570
8. Gorban, A. (2018). Model reduction in chemical dynamics: slow invariant manifolds, singular perturbations, thermodynamic estimates, and analysis of reaction graph. *Current Opinion in Chemical Engineering*, 21, 48–59. doi: https://doi.org/10.1016/j.coche.2018.01.009
9. Antoulas, A. C., Sorensen, D. C., Gugercin, S. (2001). A survey of model reduction methods for large-scale systems. *Contemporary Mathematics*, 193–219. doi: https://doi.org/10.1090/conm/280/04630
10. Rapoport, E. Ya. (2003). Strukturnoe modelirovanie ob’ektov i sistem upravleniya s raspredelennymi parametrami. Moscow: Vysshaya shkola, 239.
11. Karvatskyi, A. Ya., Pulinets, I. V., Shylovych, I. L. (2012). Mathematical model of heat-hydrodynamic state of the multichamber furnace during the baking of electrode blanks. *Eastern-European Journal of Enterprise Technologies*, 1 (4 (55)), 33–37. Available at: http://journals.uran.ua/cejet/article/view/3316/3117
12. Zhuchenko, O. A. (2015). Metod sproshchennia matematychnykh modelei obiektiv keruvannia iz rozpodilennymy parametramy. Avtomatyatsiya tekhnonolohichnykh i biznes-prosesiv, 7 (1), 15–25.
13. Yaroshchuk, L. D., Zhuchenko, O. A. (2015). Formation of control criteria system of multistage extrusion process. Visnyk Vinnyts’kogo politekhnichnogo instytutu, 2, 101–105.

**DOI:** 10.15587/1729-4061.2019.154527

**ASSESSMENT OF EFFICIENCY OF DRYING GRAIN MATERIALS USING MICROWAVE HEATING (p. 78-85)**

Irina Boshkova
V. S. Martynovsky Institute of Refrigeration, Cryotechnologies and Ecoenergetics Odessa National Academy of Food Technologies, Odessa, Ukraine
[ORCID: http://orcid.org/0000-0001-3089-9223]

Natayla Volgusheva
V. S. Martynovsky Institute of Refrigeration, Cryotechnologies and Ecoenergetics Odessa National Academy of Food Technologies, Odessa, Ukraine
[ORCID: http://orcid.org/0000-0002-9984-6502]

Alexandr Titov
Odessa National Polytechnic University, Odessa, Ukraine
[ORCID: http://orcid.org/0000-0003-1908-5713]

Sergii Titar
Odessa National Academy of Food Technologies, Odessa, Ukraine
[ORCID: http://orcid.org/0000-0001-7584-7114]

Leonid Boshkov
V. S. Martynovsky Institute of Refrigeration, Cryotechnologies and Ecoenergetics Odessa National Academy of Food Technologies, Odessa, Ukraine
[ORCID: http://orcid.org/0000-0002-2196-1519]

We present results of experimental work on studying the drying of a dense layer of grain using microwave heating. We investigated a series of techniques to supply heat to grain to assess energy efficiency of a microwave field. We studied the following ways of drying: a microwave method, a pulsating microwave method, a microwave-convective cyclic method with blow of a layer with heated air flow and air without preheating, simultaneous microwave-convective drying method.

Studying the kinetics of drying in a microwave field showed that we can divide the process into heating periods (zero drying rate), constant (first drying rate) and falling (second drying rate). These periods are characteristic for drying of colloidal capillary-porous
bodies at other methods of heat supply. We obtained empirical relationships for the drying rate and the average temperature of grain in the first period based on the generalization of experimental data on the study on drying of grain of buckwheat, barley, oats, and wheat. We presented kinetic dependences in a dimensionless form. They summarize data on the studied grains. The aim of comprehensive studies of various methods of heat supply during drying was determination of the optimal method and rational operational parameters, which ensure high intensity of the process and the required quality of the finished product with minimal energy consumption.

All studies took place under identical conditions and for the same grain (oats) to ensure the accuracy of the comparison. We determined that the most preferable method is a simultaneous microwave-convective energy supply without air preheating, which minimizes specific energy consumption. Experimental studies on drying using a microwave field made possible to select the required process parameters: power, heating rate, mass, and form of loading. We plan to develop a technology for drying of grain using microwave energy based on the study data.

**Keywords:** microwave heating, microwave-convective, moisture content, temperature, drying rate, optimal method.

**References**

1. Therdthai, N., Zhou, W. (2009). Characterization of microwave vacuum drying and hot air drying of mint leaves (Mentha cordifolia Opiz ex Fresen). Journal of Food Engineering, 91 (3), 482–489. doi: https://doi.org/10.1016/j.jfoodeng.2008.09.031
2. Abbasi Souraki, B., Mowla, D. (2008). Experimental and theoretical investigation of drying behaviour of garlic in an inert medium fluidized bed assisted by microwave. Journal of Food Engineering, 88 (4), 438–449. doi: https://doi.org/10.1016/j.jfoodeng.2007.12.034
3. El-Naggar, S. M., Mikhaiel, A. A. (2011). Disinfection of stored wheat grain and flour using gamma rays and microwave heating. Journal of Stored Products Research, 47 (3), 191–196. doi: https://doi.org/10.1016/j.jspr.2010.11.004
4. Acierno, D., Barba, A. A., d’Amore, M. (2003). Heat transfer phenomena during processing materials with microwave energy. Heat and Mass Transfer, 40 (5), 413–420. doi: https://doi.org/10.1007/s00231-003-0482-4
5. Okeke, C., Abioye, A. E., Omosun, Y. (2014). Microwave Heating Applications in Food Processing. IOSR Journal of Electrical and Electronics Engineering, 9 (4), 29–34. doi: https://doi.org/10.9790/1676-09422934
6. Feng, H., Yin, Y., Tang, J. (2012). Microwave Drying of Food and Agricultural Materials: Basics and Heat and Mass Transfer Modeling. Food Engineering Reviews, 4 (2), 89–106. doi: https://doi.org/10.1007/s12393-012-9048-x
7. Gursoy, S., Choudhary, R., Watson, D. G. (2013). Microwave drying kinetics and quality characteristics of corn. International Journal of Agricultural and Biological Engineering, 6 (1), 90–99.
8. Alibus, I. (2010). Determination of drying parameters, ascorbic acid contents and color characteristics of nettle leaves during microwave-, air- and combined microwave-air-drying. Journal of Food Process Engineering, 33 (2), 213–233. doi: https://doi.org/10.1111/j.1745-4530.2008.00268.x
9. Taib, M. R., Muhamed, I. I., Ngo, C. L., Ng, P. S. (2013). Drying Kinetics, Rehydration Characteristics and Sensory Evaluation of Microwave Vacuum and Convective Hot Air Dehydrated Jackfruit Bulbs. Journal of Food Engineering, 65 (1), 51–57. doi: https://doi.org/10.10113/jt.v65.1129
10. Hemis, M., Choudhary, R., Gariépy, Y., Raghavan, V. G. S. (2015). Experiments and modelling of the microwave assisted convective drying of canola seeds. Biosystems Engineering, 139, 121–127. doi: https://doi.org/10.1016/j.biosystemseng.2015.08.010
11. Yang, H., Tang, J. (Eds.) (2002). Advances in Agricultural Science and Technology. Vol. 1. Advances in Bioprocessing Engineering. World Scientific, 184. doi: https://doi.org/10.1142/9789812706584
12. Cha-um, W., Rattanadecho, P., Pakdee, W. (2009). Experimental analysis of microwave heating of dielectric materials using a rectangular wave guide (MODE: TE10) (Case study: Water layer and saturated porous medium). Experimental Thermal and Fluid Science, 33 (3), 472–481. doi: https://doi.org/10.1016/j.expthermflusci.2008.11.008
13. Aukornsri, T., Tang, J., Tang, Z., Lin, H., Songsermpong, S. (2018). Dielectric properties of rice model food systems relevant to microwave sterilization process. Innovative Food Science & Emerging Technologies, 45, 98–105. doi: https://doi.org/10.1016/j.ifset.2017.09.002
14. Sakai, N. (2010). Dielectric properties of food and microwave heating Japan Journal of Food Engineering, 11 (1), 19–30. doi: http://doi.org/10.11301/jsfe.11.19
15. Volgusheva, N., Altman, E., Boshkova, I., Titlov, A., Boshkov, L. (2017). Study into effects of a microwave field on the plant tissue. Eastern-European Journal of Enterprise Technologies, 6 (8 (90)), 47–54. doi: https://doi.org/10.15387/1729-4061.2017.115118