Gas hydrates technologies in the joint concept of geoenergy usage

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Abstract. The paper represents the analysis, which has helped to establish the usage of gas hydrate technologies in the methane conversion. This gas could be obtained in different ways. Possibilities and sources for the gas obtaining have been demonstrated. Use of other environmentally friendly sources to support operation in such systems in terms of joint energy complex has been considered. The necessary kinetic connections to provide operational sustainability of all the constituents have been given. The approach helps evaluate quantitatively the priority of its physicochemical transformations to obtain gas hydrates artificially. It is possible to transport methane at considerable distances when it is solidified. Actually, in this case there is no necessity to build costly compressor stations and pipelines for its transportation to consumers. The approach is extremely important for mining regions as it helps prolong the operating period and working out of the abandoned and off-balance coal reserves. In this case, it is proposed to apply special gasification technologies tending to maximum methane recovery. The proposed solutions give the possibility to define the trends of our further research. They will be highlighted in the following authors' studies.

1 Introduction

The improved social responsibility should change drastically the approaches of subsurface use as well as extraction of various minerals. The development of power sources, which will provide formation of hi-tech production, has to be environmentally friendly as much as possible [1-4]. Moreover, social aspects of functioning of the urbanized territories, within which minerals are mined, should also be involved [5, 6]. Practically any human activity results in the emission of greenhouse gases [7, 8], accumulation of wastes on the daily surface as result of mining activity [9-12]. Great attention is paid to the utilization of carbon dioxide [13-16].

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Newest research contains both theoretical studies and practical implementations of the proposed solutions basing on the environmental and economic component [17-20] along with the consideration of energy efficiency of the process maintenance [21-26].

The paper is aimed at analyzing the emission sources of methane, being another greenhouse gas, and identifying the possibilities of its further transformation into solid state for its further industrial use. These are gas hydrates technologies that make it possible to solve the stated problems [27-31].

CH_4 catching and transforming into another aggregate state makes it possible to solve the problem of its adsorption and transportation at long distances with further industrial use. Such an approach allows considering treatment of that energy gas in the innovative way with the formulation of a unified system of its obtaining from different sources of human activity. Final objective of the research is to develop a concept of joint system for extraction, adsorption, transformation, and transportation of methane with the help of gas hydrate technologies with its following industrial use.

2 Development of joint technologies for the geoenergy usage based on gas hydrates transformation

At all times, progress of human civilization has been followed by the increased production and consumption of power resources. According to the technological improvement, that makes us search for solution for all the mining-accompanied problems along with the solution of economic, ecological, and social issues [22, 32, 33].

Unfortunately, professional reorientation of miners is rather a complex and long-term process. It results in the increased social tension in mining regions [34, 35]. In increasing frequency, we face a problem of human consciousness manipulation with the help of modern Information Technology); moreover, instability and dissatisfaction of certain population layers may also be used to solve certain political problems. There are examples when miners have been involved in the sanctioned suppression of democratic expression of a social opinion. Disrupting manifestations in Romania at the time of the end socialist ideology in the Central and Eastern Europe with the help of miners is one of the latest and brightest examples.

The problem, being considered by the paper, involves both engineering aspects to form technical and technological provision of fuel and energy systems as well as political and social economic-ecological aspects able to model political situation and stability both in certain states and in regions on the whole. The research is aimed at reorienting the miners' activities taking into consideration the mentioned problems of creating new jobs by implementing gas hydrate technologies in mining and post-mining operations.

In our previous studies attention was paid to different cogeneration technologies conducted with the mining enterprises operation [24, 30, 36-39]. The specialized literature [37, 40-44] pays attention to the application of joint technological plants which means the usage of different renewable. Traditional energy sources with the consideration of the environmental management are fully described in the references [45-47]. This paper means the possibility of introduction the innovative technological issue of gas hydrates transforming with zero energy using.

2.1 Alternative coal power sector and other sectors for gas hydrates energy supplying

Development of such a production together with traditional coal power sector should be based upon wasteless methods helping solve both economic and social problems. First, it

concerns environmental protection. The fact is of principal importance while selecting a strategy to form complex production focusing the science on the development of engineering solutions aimed at the progress of business links, using the waste as a primary raw source, rather than on the decreased waste production within the isolated technological cycle. The production development will be of interbranch integration nature of a complex, combined (i.e. cogenerative), and wasteless mining energy-chemical manufacture with the use of raw materials in terms of maximum implementation of the produced waste for economic circulation.

Ukrainian mining industry has several more alternatives of operation schedules concerning cogeneration of energy carriers. In addition to the mentioned well coal gasification, combined with steam and electricity generation and thermal energy accumulation, they are as follows: methane extraction and use in the process of gas-coal and shale deposit development; thermal energy generation in the process of geothermal deposit mining; use of low-potential heat of rocks of the Earth, water, and air; use of gas-turbine engines for traditional generating facilities; and use of thermal pumps to utilize low-potential heat of mine water, artesian water, ventilation emissions, thermal water during compressor cooling etc.

In addition to gas turbines, gas powered engines can also be used in cogeneration schemes for electric generator drive [48, 49]. Lower oxygen content in combustion products is the engine feature since air excess coefficient is not more than 2.0-2.2. Examples of the efficient application of cogeneration plants in the industrialized countries mean that up to now they are still among the most promising and resultative ways to improve the efficiency of fuel use in the context of power industry. Modern world cogeneration plants have expensive automatic process control systems (APCSs) making it possible to optimize processes of power generation as well as control the plants remotely. APCSs can also combine several plants into one power object which prolongs their operation period and reduces fuel consumption drastically.

Unfortunately, only several cogeneration plants operate in Ukraine. However, possibilities for their wide implementation are unique. In our country, a system of centralized heating, basing upon powerful TPPs and boiler houses, functions. Thousands of heating (water heating mainly) tanks, which capacity is from several to hundreds of megawatts (maximum capacity is 100-150 MW) are mounted in municipal boiler houses. They can be updated with simultaneous secondary structures and application of power generating thermal engines.

It is the most expedient idea to use heat pumps for objects with low thermodynamic potential. In this case, basic and time-constant area of underground low-potential heat extraction is formed with the help of different use of heat exchangers [50-54]. Definitely a special attention must be paid for chose the materials for pumps design [55-57].

Hence, the basic advantage of HP-plant to compare with heat generation with the use of traditional boilers is as follows: the heat pumps make it possible to produce similar heat amount just using 2/3 of extra low-temperature potential, and 1/3 of electric energy consumed by the HP plant compressor [58, 59].

Fig. 1 explains difference between heat supply by the heat pumps and the available energy sources. As it is seen, heat pump plants with the use of renewable energy sources are the most efficient ones. Taking into consideration the world tendency as for crude oil and gas price escalation, efficiency of the systems will experience constant increase. Hence, production of such heat pumps with different working capacities and corresponding energy characteristics is one of the topical tasks [23, 41, 60-62].

The carried out calculations show that extra capital charges for heat pump plants will be paid back during 4-8 years. In this context, annual electrical energy savings will be UAH 85 thousand, if HP plants are applied.

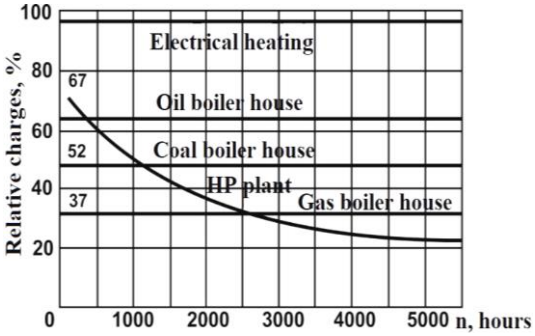

Fig. 1. Graph comparing heat supply systems when the available sources of thermal energy are substituted by heat pump plants (HP-plants).

Variable capacity of wind power plant as well as current and voltage oscillations follow from the fact. SWPPs are of significant material intensity since their strength should provide impulse impacts of wind flow. Moreover, they uglify landscape, make noise, and provoke electromagnetic interference for TV and radio channels.

The authors believe that perspective progress of wind power sector may result from its use at mining enterprises. Arrangement of WPPs in mine workings of near wellbore area improves their operation conditions substantially. Mine ventilation flow involves significant reserve of constant kinetic energy; moreover, it is powerful source of rotation of underground wind power plants (UWPPs). Besides, velocity and direction are constant. Thus, wind wheels rotate regularly with no fluctuations and current or voltage oscillations. Hence, reliable high-efficient and cheap resource for electric power generation is obtained in mines transiting currently from their mining and other production processes to radically new functions. After their shutting down, they become enterprises of environmentally friendly wind power [63-65].

2.2 Thermal energy sector

To revive intrastratal pressure of geothermal deposit in summer, it is foreseen to add solar (helio) plants to operation. Systems with air-water heat pumps should be applied for hot water supply when the weather is grey. Solar collectors are mounted on the overhangs located at 3.5-4.2 m height over the ground. Photoelectric 1 kW transformers are planned for electric power supply of circulating pumps of the solar plant. Ventilation flow, leaving mines, subways, and other underground structures, contains much extra thermal energy as for the environment. In terms of large mines, such a potential is $9.1 \cdot 10^4$ MW·h/year. The energy is lost irrevocably when mine ventilation flow is discharged to the atmosphere.

Apart from that, mine atmosphere contains enough methane. Nowadays, it can be also a source of additional energy raw material. Gas hydrate technologies help solve quite successfully a problem of gas solidification with its further long-distance transportation [66]. As a result, a problem arises concerning the creation of a complex system for the methane formation and use in terms of the closed ecological, energy-saving, and hydrating complex.

3 Development and application of the energy-saving hydrating complex

The basis may help develop innovative industry, i.e. thermochemical energy, making it possible to reduce dependence upon the imported crude oil and natural gas. The industry will develop construction and operation of fuel and energy complex on the basis of gas

hydrate technologies which will involve use of methane from different sources including gasification of coal seams relying upon the progressive combined technology, and modern interbranch form of production management with complex processing of raw materials as well as complete waste utilization (Fig. 2).

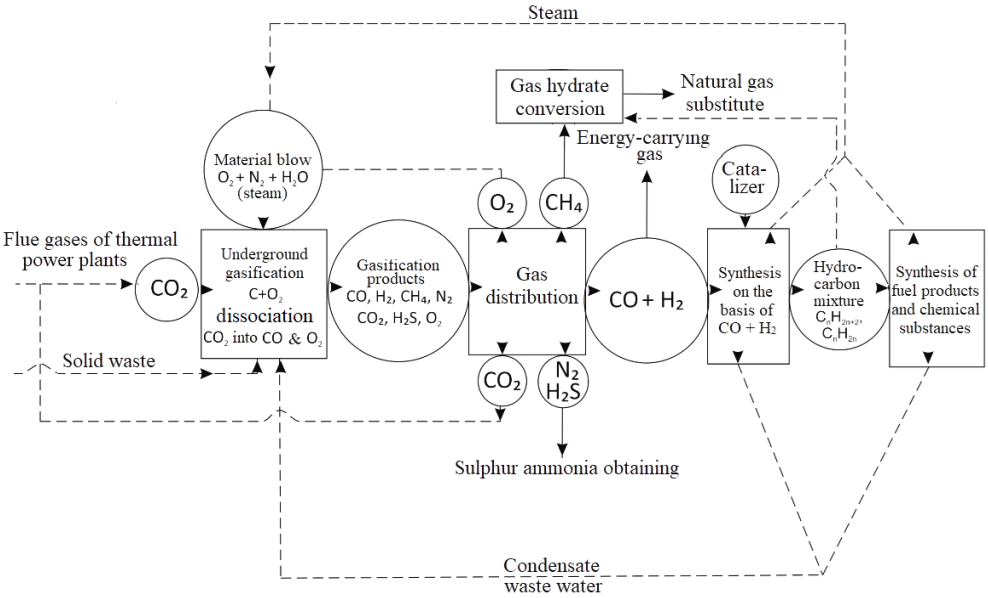

Fig. 2. Scheme of the environmentally friendly and wasteless production of synthetic hydrocarbons using coal and gas hydrate conversion.

The gas, discharged from gas turbine (CO_2), does not get to the atmosphere. It is directed to underground gas generator. While interacting with hot coal, the gas is decomposed into combustible gases $CO_2 + C = 2CO + O_2$. As it is understood, the waste (CO_2) may be profitable, if it is used to generate combustible gas applied by consumers.

Production integration, being one of the key tendencies to organize thermochemical manufacturing of synthetic hydrocarbons, makes it possible to form certain wasteless enterprises on the basis of:

– complexes generating artificial gas, i.e. energy carrier and synthesis gas ($CO + H_2$) based upon UWCG with utilization of solid and smoke waste of power technological production;

– gas hydrate conversion for the natural gas substitute;

– complexes of organic synthesis of fuel products and chemical substances;

– gas and steam turbine plants generating electric energy and thermal energy;

– pilot plants to produce hydrogen, resin, carbon, polymers, fertilizers, feed proteins etc.

Thermochemical energetics may be qualified as environmentally friendly technologies (i.e. ecotechnologies) in terms of which production processes follow the principles of nature functioning: closeness, gradation, and complexity. In this context, all the interactions function jointly. It will help liquidate hard and dangerous work of miners, save nature from waste, level down morbidity rate, and improve wildlife health. The energetics is aimed at radical thinking alternations while solving environmental problems falling into the progress of geoenergetics: hazardous industries (i.e. mines, open casts, coal-preparation plants, thermal power stations, nuclear power stations etc.) should not be reconstructed with billions of expenses; it is more expedient to develop environmentally friendly activities on the basis of underground coal gasification which will provide stability and health of the environment [30, 67, 68].

Coal seam gasification is aimed at harmonious interaction between community and nature, human and environment as well as environmental improvement. A concept of waste control has also varied: waste prevention or utilization as raw material rather than its neutralization. Use of gas hydrate technologies in this cycle makes it possible to widen considerably the application range of methane from different energy sources.

4 Conclusions

National economy should rely upon the available proper sources (i.e. thermal energetics and nuclear energetics) as well as upon broad development of alternative energy sources. Moreover, it is important thing to combine them into cogeneration systems to provide their stable operation. Specific attention should be paid to the progress of radical methods of coal processing right in site (i.e. underground gasification and surface gasification). Use of gas hydrate technologies, in terms of which methane obtained from different sources is solidified, proposes new approaches to the formation of innovative possibilities while creating energy sources.

The paper represents the analysis aimed at determining the use of gas hydrate technologies during transformation of methane obtained by different methods. That approach helps prolong the operating period of mines with depleted residuals or the ones being under closure. The proposed technologies of generator gas extraction by anaerobic digesting of organic substances in methane-tanks as well as other approaches to the combined formation of new energy systems allow reorienting the mine operation. That approach is of prime importance for rather depressed mining regions as it helps solve the problem of social strain. Formation of joint energy and chemical production makes it possible both to improve economic expediency and prevent negative environmental impacts on the surface and underground mine environment. The proposed tendencies allow outlining related problems to be highlighted in further studies carried out by the authors.

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References

1. Von Thaden Ugalde, H.A., Robles, C., & Fuente Carrasco, M.E. (2020). Mining activity in the 20th century in the oaxaca valley: Today's public health risks. *Revista Internacional de Contaminacion Ambiental*, *36*(1), 165-175.
2. Hilson, G., & Murck, B. (2000). Sustainable development in the mining industry: Clarifying the corporate perspective. *Resources Policy*, *26*(4), 227-238. https://doi.org/10.1016/S0301-4207(00)00041-6
3. Lei, Y., Cui, N., & Pan, D. (2013). Economic and social effects analysis of mineral development in China and policy implications. *Resources Policy*, *38*(4), 448-457. https://doi.org/10.1016/j.resourpol.2013.06.005
4. Wellmer, F.W., & Hennig, W. (2003). Aspects for formulating mineral resources management policies. *Erzmetall: Journal for Exploration, Mining and Metallurgy*, *56*(1), 3-10.
5. Jønsson, J.B., & Bryceson, D.F. (2017). Beyond the artisanal mining site: migration, housing capital accumulation and indirect urbanization in East Africa. *Journal of Eastern African Studies*, *11*(1), 3-23. https://doi.org/10.1080/17531055.2017.1287245
6. Kasmaee, S., & Tinti, F. (2018). A method to evaluate the impact of urbanization on ground temperature evolution at a regional scale. *Rudarsko Geolosko Naftni Zbornik*, *33*(5), 1-12. https://doi.org/10.17794/rgn.2018.5.1

7. Zhou, A., Hu, J., & Wang, K. (2020). Carbon emission assessment and control measures for coal mining in China. *Environmental Earth Sciences*, *79*(19), 461. https://doi.org/10.1007/s12665-020-09189-8
8. Sahu, H.B., & Tibrewal, K. (2018). Greenhouse gas inventory for mines: An urge to develop clean technology. *Journal of Mines, Metals and Fuels*, *66*(8), 526-530.
9. Kalybekov, T., Rysbekov, K., Sandibekov, M., Bi, Y.L., & Toktarov, A. (2020). Substantiation of the intensified dump reclamation in the process of field development. *Mining of Mineral Deposits*, *14*(2), 59-65. https://doi.org/10.33271/mining14.02.059
10. Bosak, P., Popovych, V., Stepova, K., & Dudyn, R. Environmental impact and toxicological properties of mine dumps of the Lviv-Volyn Coal basin. *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences*, *2*(440), 48-54.
11. Malanchuk, Z., Moshynskyi, V., Malanchuk, V., Korniienko, Y., & Koziar, M. (2020). Results of research into the content of rare earth materials in man-made phosphogypsum deposits. *Key Engineering Materials*, (844), 77-87. https://doi.org/10.4028/www.scientific.net/kem.844.77
12. Moshynskyi, V., Malanchuk, Z., Tsymbaliuk, V., Malanchuk, L., Zhomyruk, R., & Vasylchuk, O. (2020). Research into the process of storage and recycling technogenic phosphogypsum placers. *Mining of Mineral Deposits*, *14*(2), 95-102. https://doi.org/10.33271/mining14.02.095
13. Fan, L., & Xu, J. (2020). Authority – enterprise equilibrium based mixed subsidy mechanism for carbon reduction and energy utilization in the coalbed methane industry. *Energy Policy*, (147), 111828. https://doi.org/10.1016/j.enpol.2020.111828
14. Li, S., Zheng, H., Su, Y., Zhao, Y., & He, T. (2020). Effect of fluid field on the eco-friendly utilization and recycling of CO_2 and dyes in the waterless dyeing. *Journal of CO_2 Utilization*, (42), 101311. https://doi.org/10.1016/j.jcou.2020.101311
15. Song, C. (2006). Global challenges and strategies for control, conversion and utilization of CO_2 for sustainable development involving energy, catalysis, adsorption and chemical processing. *Catalysis Today*, *115*(1-4), 2-32. https://doi.org/10.1016/j.cattod.2006.02.029
16. Hunt, A.J., Sin, E.H.K., Marriott, R., & Clark, J.H. (2010). Generation, capture, and utilization of industrial carbon dioxide. *ChemSusChem*, *3*(3), 306-322. https://doi.org/10.1002/cssc.200900169
17. Sobolev, V., Cabana, E.C., Howaniec, N., Dychkovskyi, R., Jura, B., Bąk, A., & Smoliński, A. (2020). Estimation of dense plasma temperature formed under shock wave cumulation. *Materials*, *13*(21), 4923. https://doi.org/10.3390/ma13214923
18. Medunić, G., Mondol, D., Rađenović, A., & Nazir, S. (2018) Review of the latest research on coal, environment, and clean technologies. *Rudarsko Geolosko Naftni Zbornik*, *33*(3), 13-21. https://doi.org/10.17794/rgn.2018.3.2
19. Bondarenko, V., Lozynskyi, V., Sai, K., & Anikushyna, K. (2015). An overview and prospectives of practical application of the biomass gasification technology in Ukraine. *New Developments in Mining Engineering 2015: Theoretical and Practical Solutions of Mineral Resources Mining*, 27-32. https://doi.org/10.1201/b19901-6
20. Sobczyk, E.J., Kaczmarek, J., Fijorek, K., & Kopacz, M. (2020) Efficiency and financial standing of coal mining enterprises in Poland in terms of restructuring course and effects. *Gospodarka Surowcami Mineralnymi*, *36*(2), 127-152 https://doi.org/10.24425/gsm.2020.132565
21. Smil, V. (2015). A new world of energy. *The Cambridge World History*, *7*(1), 164-184.
22. Buzylo, V., Pavlychenko, A., Savelieva, T., & Borysovska, O. (2018). Ecological aspects of managing the stressed-deformed state of the mountain massif during the development of multiple coal layers. *E3S Web of Conferences*, (60), 00013. https://doi.org/10.1051/e3sconf/20186000013
23. Dychkovskyi, R., Shavarskyi, Ia., Saik, P., Lozynskyi, V., Falshtynskyi, V., & Cabana, E. (2020). Research into stress-strain state of the rock mass condition in the process of the operation of double-unit longwalls. *Mining of Mineral Deposits*, *14*(2), 85-94. https://doi.org/10.33271/mining14.02.085
24. Falshtynskyi, V., Lozynskyi, V., Saik, P., Dychkovskyi, R., & Tabachenko, M. (2016). Substantiating parameters of stratification cavities formation in the roof rocks during underground coal gasification. *Mining of Mineral Deposits*, *10*(1), 16-24. https://doi.org/10.15407/mining10.01.016

25. Pivnyak, G., Razumny, Y., & Zaika, V. (2009). The problems of power supply and power saving in the mining industry of Ukraine. *Archives of Mining Sciences*, (54), 5-12.
26. Małkowski, P., Niedbalski, Z., & Hydzik-Wiśniewska, J. (2013). The change of structural and thermal properties of rocks exposed to high temperatures in the vicinity of designed geo-reactor. *Archives of Mining Sciences*, *58*(2), 465-480. https://doi:10.2478/amsc-2013-0031
27. Bondarenko, V., Tabachenko, M., & Wachowicz, J. (2010). Possibility of production complex of sufficient gasses in Ukraine. *New Techniques and Technologies in Mining*, 113-119. https://doi.org/10.1201/b11329-19
28. Nikolsky, V. (2020). A study of heat exchange processes within the channels of disk pulse devices. *Energies*, *13*(13), 3492. https://doi.org/10.3390/en13133492
29. Bondarenko, V., Svietkina, O., & Sai, K. (2017). Study of the formation mechanism of gas hydrates of methane in the presence of surface-active substances. *Eastern-European Journal of Enterprise Technologies*, *5*(6(89)), 48-55. https://doi.org/10.15587/1729-4061.2017.112313
30. Dychkovskyi, R., Shavarskyi, J., Cabana, E.C., & Smoliński, A. (2019). Characteristic of possible obtained products during the well underground coal gasification. *Solid State Phenomena*, (291), 52-62. https://doi.org/10.4028/www.scientific.net/ssp.291.52
31. Ovchynnikov, M., Ganushevych, K., & Sai, K. (2013). Methodology of gas hydrates formation from gaseous mixtures of various compositions. *Annual Scientific-Technical Collection – Mining of Mineral Deposits*, 203-205. https://doi.org/10.1201/b16354-37
32. Małkowski, P., Niedbalski, Z., Majcherczyk, T., & Bednarek, Ł. (2020). Underground monitoring as the best way of roadways support design validation in a long time period. *Mining of Mineral Deposits*, *14*(3), 1-14. https://doi.org/10.33271/mining14.03.001
33. Maldynova, A., Osmanov, Z., & Galiyev, D. (2018). Formation of marketing strategy for promoting an innovative product. *Journal of Applied Economic Sciences*, *13*(7), 1951-1958.
34. Sribna, Y., Trokhymets, O., Nosatov, I., & Kriukova, I. (2019). The globalization of the world coal market – contradictions and trends. *E3S Web of Conferences*, (123), 01044. https://doi.org/10.1051/e3sconf/201912301044
35. Mustakhimov, A., & Zeynullin, A. (2020). Scaled-up laboratory research into dry magnetic separation of the Zhezdinsky concentrating mill tailings. *Mining of Mineral Deposits*, *14*(3), 71-77. https://doi.org/10.33271/mining14.03.071
36. Dychkovskyi, R.O. (2015). Forming the bilayer artificially created shell of georeactor in underground coal well gasification. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 37-42.
37. Caceres, E., & Alca, J.J. (2016). Rural electrification using gasification technology: Experiences and perspectives. *IEEE Latin America Transactions*, *14*(7), 3322-3328. https://doi.org/10.1109/tla.2016.7587637
38. Caceres, E., & Alca, J.J. (2016). Potential for energy recovery from a wastewater treatment plant. *IEEE Latin America Transactions*, *14*(7), 3316-3321. https://doi.org/10.1109/tla.2016.7587636
39. Bondarenko, V., & Dychkovskiy, R. (2006). Methods of extraction of thin and rather thin coal seams in the works of the scientists of the underground mining faculty (National Mining Uuniversity). *New Technological Solutions in Underground Mining International Mining Forum*, 21-25. https://doi.org/10.1201/noe0415401173.ch3
40. Sobolev, V. (2020). Reasons for breaking of chemical bonds of gas molecules during movement of explosion products in cracks formed in rock mass. *International Journal of Mining Science and Technology*, *30*(2), 265-269. https://doi.org/10.1016/j.ijmst.2020.01.002
41. Falshtyns'kyy, V., Dychkovs'kyy, R., Lozyns'kyy, V., & Saik, P. (2013). Justification of the gasification channel length in underground gas generator. *Annual Scientific-Technical Collection – Mining of Mineral Deposits*, 125-132. https://doi.org/10.1201/b16354-22
42. Dychkovskyi, R.O. (2015). Determination of the rock subsidence spacing in the well underground coal gasification. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 30-36.

43. Saik, P.B., Dychkovskyi, R.O., Lozynskyi, V.H., Malanchuk, Z.R., & Malanchuk, Ye.Z. (2016). Revisiting the underground gasification of coal reserves from contiguous seams. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 60-66.
44. Falshtynskyi, V.S. (2013). Determination of the technological parameters of borehole underground coal gasification for thin coal seams. *Journal of Sustainable Mining*, *12*(3), 8-16. https://doi:10.7424/jsm130302
45. Gorova, A., Pavlychenko, A., & Borysovs'ka, O. (2013). The study of ecological state of waste disposal areas of energy and mining companies. *Annual Scientific-Technical Collection – Mining of Mineral Deposits*, 169-172. https://doi.org/10.1201/b16354-29
46. Dryzhenko, A., Moldabayev, S., Shustov, A., Adamchuk, A., & Sarybayev, N. (2017). Open pit mining technology of steeply dipping mineral occurences by steeply inclined sublayers. *SGEM*, *17*(13), 599-606. https://doi.org/10.5593/sgem2017/13/s03.076
47. Malanchuk, Z., Malanchuk, Y., Korniyenko, V., & Ignatyuk, I. (2017). Examining features of the process of heavy metals distribution in technogenic placers at hydraulic mining. *Eastern-European Journal of Enterprise Technologies*, *1*(10(85)), 45-51. https://doi.org/10.15587/1729-4061.2017.92638
48. Pivnyak, G., Dychkovskyi, R., Bobyliov, O., Cabana, E.C., & Smoliński, A. (2018). Mathematical and geomechanical model in physical and chemical processes of underground coal gasification. *Solid State Phenomena*, (277), 1-16. https://doi.org/10.4028/www.scientific.net/ssp.277.1
49. Griadushchiy, Y., Korz, P., Koval, O., & Bondarenko, V. (2007). Advanced experience and direction of mining of thin coal seams in ukraine. *International Mining Forum*, 2-7. https://doi:10.1201/noe0415436700.ch1
50. Golovchenko, A., Dychkovskyi, R., Pazynich, Y., Edgar, C.C., Howaniec, N., Jura, B., & Smolinski, A. (2020). Some aspects of the control for the radial distribution of burden material and gas flow in the blast furnace. *Energies*, *13*(4), 923. https://doi.org/10.3390/en13040923
51. Kolb, A., Pazynich, Y., Mirek, A., & Petinova, O. (2020). Influence of voltage reserve on the parameters of parallel power active compensators in mining. *E3S Web of Conferences*, (201), 01024. https://doi.org/10.1051/e3sconf/202020101024
52. Pivnyak, G. (2020). Conditions of suitability of coal seams for underground coal gasification. *Key Engineering Materials*, (844), 38-48. https://doi.org/10.4028/www.scientific.net/kem.844.38
53. Sarycheva, L. (2003). Using GMDH in ecological and socio-economical monitoring problems. *Systems Analysis Modelling Simulation 2003*, *43*(10), 1409-1414. https://doi.org/10.1080/02329290290024925
54. Falshtynskyi, V., Saik, P., Lozynskyi, V., Dychkovskyi, R., & Petlovanyi, M. (2018). Innovative aspects of underground coal gasification technology in mine conditions. *Mining of Mineral Deposits*, *12*(2), 68-75. https://doi.org/10.15407/mining12.02.068
55. Krupnik, L., Yelemessov, K., Beisenov, B., & Baskanbayeva, D. (2020). Substantiation and process design to manufacture polymer-concrete transfer cases for mining machines. *Mining of Mineral Deposits*, *14*(2), 103-109. https://doi.org/10.33271/mining14.02.103
56. Baskanbayeva, D. (2018). Studying fiber-reinforced concrete for casting housing parts of pumps. *Eastern-European Journal of Enterprise Technologies*, *6*(12(96)), 22-27. https://doi.org/10.15587/1729-4061.2018.151038
57. Yelemessov, K., Krupnik, L., Bortebayev, S., Beisenov, B., Baskanbayeva, D., & Igbayeva, A. (2020). Polymer concrete and fibre concrete as efficient materials for manufacture of gear cases and pumps. *E3S Web of Conferences*, (168), 00018. https://doi.org/10.1051/e3sconf/202016800018
58. Beshta, O.S. (2012). Electric drives adjustment for improvement of energy efficiency of technological processes. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (4), 98-107.
59. Falshtynskyi, V.S., Dychkovskyi, R.O., Saik, P.B., Lozynskyi, V.H., & Cabana, E.C. (2017). Formation of thermal fields by the energy-chemical complex of coal gasification. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 36-42.
60. Gornostayev, S.S., Crocket, J.H., Mochalov, A.G., & Laajoki, K.V.O. (1999). The platinum-group minerals of the Baimka placer deposits, Aluchin horst, Russian Far East. *Canadian Mineralogist*, *37*(5), 1117-1129.

61. Dychkovskyi, R.O., Avdiushchenko, A.S., Falshtynskyi, V.S., & Saik, P.B. (2013). On the issue of estimation of the coal mine extraction area economic efficiency. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (4), 107-114.
62. Gorova, A., Pavlychenko, A., Kulyna, S., & Shkremetko, O. (2012). Ecological problems of post-industrial mining areas. *Geomechanical Processes During Underground Mining*, 35-40. https://doi:10.1201/b13157-7
63. Vlasova, E., Kovalenko, V., Kotok, V., & Vlasov, S. (2016). Research of the mechanism of formation and properties of tripolyphosphate coating on the steel basis. *Eastern-European Journal of Enterprise Technologies*, *5*(5(83)), 33-39. https://doi.org/10.15587/1729-4061.2016.79559
64. Dychkovskyi, R., Vladyko, O., Maltsev, D., & Cabana, E.C. (2018). Some aspects of the compatibility of mineral mining technologies. *Rudarsko-Geološko-Naftni Zbornik*, *33*(4), 73-82. https://doi.org/10.17794/rgn.2018.4.7
65. Su, C., & Hu, Z. (2017). Reliability assessment for Chinese domestic wind turbines based on data mining techniques. *Wind Energy*, *21*(3), 198-209. https://doi:10.1002/we.2155
66. Sai, K., Malanchuk, Z., Petlovanyi, M., Saik, P., & Lozynskyi, V. (2019). Research of Thermodynamic Conditions for Gas Hydrates Formation from Methane in the Coal Mines. *Solid State Phenomena*, (291), 155-172. https://doi.org/10.4028/www.scientific.net/SSP.291.155
67. Golovchenko, A., Pazynich, Y., & Potempa, M. (2018). Automated monitoring of physical processes of formation of burden material surface and gas flow in blast furnace. *Solid State Phenomena*, (277), 54-65. https://doi.org/10.4028/www.scientific.net/ssp.277.54
68. Lozynskyi, V.G., Dychkovskyi, R.O., Falshtynskyi, V.S., Saik, P.B., & Malanchuk, Ye.Z. (2016). Experimental study of the influence of crossing the disjunctive geological faults on thermal regime of underground gasifier. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 21-29.