IMPROVING THE METHOD OF OPEN-PIT LIGNITE DEPOSITS DEVELOPMENT IN UKRAINE

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Abstract. *Subject of the research* is open-pit mining concerning a full-field industrial development of a number of lignite deposits; feasibility study has been performed for them as for the efficient environmental friendly processing of coal and associated minerals.

Objective of the research is to develop both methodology and conceptual approaches to high-productive, economically viable, and environmental friendly methods for open-pit lignite mining in the context of suprasalt depressive basins.

Task of the research is to analyze the current state of lignite mining in Ukraine; to characterize a new genetic Ukrainian coal type from geological and industrial viewpoint; to substantiate parameters of lignite open-pit mining on the basis of Novo-Dmytrivka mining and industrial district; to expand the capacities of lignite mining on the basis of Novo-Dmytrivka, Bantysh, Stepkivka, and Bereka deposits; to substantiate the integrated use of diverse rock masses in the context of the national economy; to use lignite in terms of its power; to produce montan wax; to apply sodium humite in the context of agriculture; to use overburden rocks for the construction of bordering dams of powerful water storages; and to develop recommendations concerning the design of Novo-Dmytrivka mining and industrial system with the integrated development of lignite and associated minerals.

Methods of the research are: analytical estimation of resources of lignite deposits; geological and engineering-technical analysis; and integrated and feasibility studies of indices of mining and opening operations. Optimization of the process solutions relies upon the analysis of changes in rock mass coefficient use within the open-pit area in the context of complete

land reclamation of the disturbed land and the development of new productive land instead of the littered territories. The updated research method is to determine the basic technological parameters of equipment taking into consideration significant water inflow in terms of working areas as well as the inflows effect on the output of the lignite open pit depending upon changes in the depth of mine workings.

The carried out research helped study more thoroughly the geological and engineering-technical features of lignite deposits in Ukraine. Their geological structures, coal-bearing capacity and the coal grades, total reserves, and their commercial significance have been determined. Parameters of benches and working sites have been substantiated. The parameters make it possible to decrease the current volume of overburden rock mining and to transfer their maximum values to the final stage of the open pit operation. Rational systems of mining and transportation equipment for the development of the open-pit field in terms of criteria of capacity, efficiency, and power consumption have been substantiated involving different traffic flows of rock mass movement in open pits and at the surface. There were issued recommendations to design the development of Novo-Dmytrivka lignite deposit. Relying upon the analyzed deposits of north-west Donbas, it is expedient to develop the unified coal-mining complex for the processing of lignite and associated minerals to be used by plants of building materials and structures as well as chemical and metallurgical plants as the basic raw material. There has been substantiated a possibility of commercial development of a number of lignite deposits in Ukraine to develop mining and preproduction complex with coal output at the level of 9-10 mln t/y and 23-24 mln t/y of coaly mass as well as their processing by thermal power station which capacity is 1800-2400 MW; a plant to produce 15 thousand tons of montan wax a year; briquetting factory which capacity is 2 mln t/y; and a concrete product plant to manufacture building structures with a capacity of 1 mln of m^2/y.

Introduction. Industrial development of new coal deposits is one of the key problems of strategic advance of fuel and energy complex of Ukraine. If coal share is 67%, and oil and gas shares are 18% and 15% among the world reserves of raw hydrocarbons, in Ukraine their volumes are distributed differently: coal is 954%, oil is 2%, and gas is 2.6%. In this context, only coal, owing to its reserves which have already been prospected, is able to decrease energy dependence of Ukraine upon foreign raw material in future. According to expert estimations, as for the heat power industry and raw processing, the role of coal will become more important both in Ukraine and in the whole world.

Bereka, Stepkivka, Biliaievka and Bantysh diapir structures are coal-bearing potentially. However, only the first stage of prospecting activities has been implemented within the deposits. The obtained data make it possible to evaluate the deposits in general to be insufficient for their complete commercial economic evaluation.

Up to now, Novo-Dmytrivka structure has already been studied in more detail; as for its scale and conditions of formation of a complex of various minerals and coal reserves it is among the unique ones. It is possible to build open pit with annual 9-10 mln t output of high-grade lignite on the basis of Novo-Dmytrivka deposit. In this context, opening coefficient will not be more than 4 m^3/t; it is 3 times less to compare with that achieved by open pits of *Oleksandriia* SHC.

There are no national practices concerning the development of such deposits. Thus, objective of the paper is to develop both a method and conceptual approaches to high-productive, efficient, and environmentally friendly techniques of open-pit lignite mining under the conditions of suprasalt depressive basins.

In this connection, scientific and practical tasks of the research are to analyze the current state of lignite mining in Ukraine; to substantiate parameters of open-pit lignite mining on the basis of Novo-Dmytrivka mining and industrial district; and to substantiate the integrated use of diverse rock mass for the national economy needs.

Zonation of Ukrainian deposits

Lignite is a natural type of solid sedimentary mineral as a transition form from peat to the rock varieties. Its deposits occur in the interior of the earth in the form of plate- and lens-shaped bodies with thickness being small to compare with its area. Lignite mining had obtained its wide significance since 1929 when *Ukrburvuhillia* Group was established. Dnipro lignite basin became a development centre. The basin is located within a central part of Ukraine; it stretches in the form of a wide belt from northwest to southeast passing through Zhytomyr Region, Kyiv Region, Cherkasy Region, Kirovohrad Region, Dnipropetrovsk Region, Zaporizhzhia Region and partially through Mykolaiv and Odesa Regions. Total extent of the basin is 650 km, and width is 70-175 km. Its area is almost 100.000 square kilometers.

Ten geological and industrial districts are singled out at the territory of the basin (Fig. 1).

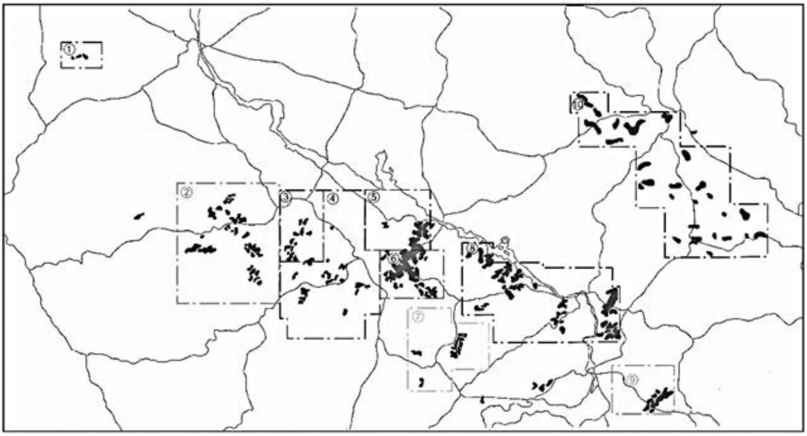

Fig. 1. Zoning of lignite districts in Ukraine

They stretch northwest to southeast as following [1]:

1. Korostyshiv – Korostyshiv deposit.

2. Zvenyhorodka – Yurkivka, Mokra Kalyhirka, Zelenkivka, Zalizniachkove, Oleksandrivka deposits and smaller ones.

3. Zlatopillia – Novo-Myrhorod, Zlatopillia, Zhurovka, Serdiukivka, Paleoloh (Kvytkovka and Mykhailivka deposits) formations.

4. Kirovohrad – Malo-Vyskivka, Zeleno-Haiska, Novo-Mykhailivka, Mamaika, Veselivka, Adzhamka, Balashivka and Zelenivka deposits.

5. Novo-Heorhiivka – Zolotarivka, Revivka, Taburyshche and Myronivka deposits.

6. Oleksandriia – Bandurovka, Morozivka (*Verbolozivska*, *Baidakivska*, *Semenivska* #4, *Semenivsko-Holovkivska* sites), Moshoryno-Svitlopil, Nova-Praha, Mykhailivka, Mariianivka and Balakhivka deposits.

7. Kryvyi Rih – Khrystoforivka, Hurievsk, Vesele-Ternivka,

Pychuhine and Kolomiitseve deposits.

8. Dnipropetrovsk – Hannivka, Fastiv, Novo-Aleksandrivka, Verhniodniprovsk, Sokolove, Saksahanske, Adalymivka, Pavlo-Hryhorivka, Shyroke, Barvinok and Kamiianske deposits, Karnaukhivka, Pavlivka, Synelnykove та Pervozvanivka deposits.

9. Horikhivka – Horikhivka deposit.

10. Northwest Donbas – Novo-Dmytrivka, Sula-Udai, Bantysh, Stepkivka and та Bereka deposits.

Almost 200 lignite deposits and occurrences are within the basin; however, not all of them have practical value and sufficient reserves to be mined. The Governmental balance of Ukraine has counted 27 deposits; 11 of them are suitable for open-pit mining. According to A+B+C1 categories, their reserves are 2409.3 mln tons; 215.7 mln tons belong to C2 category; and 393.1 mln tons are non-commercial reserves. Balance reserves, suitable for open-pit mining (according to A+B+C1 categories), are 510.9 mln tons; non-commercial reserves are 393.4 mln tons. They are mainly deposited in Kirovohrad Region (240.57 mln tons) and Dnipropetrovsk Region (106.62 mln tons); other their shares are in Cherkasy Region (187.4 mln tons), Zaporizhzhia Region (11.43 mln tons) and Vinnytsia Region (5.24 mln tons).

In terms of Dnipro basin, coal-bearing formation consists of one to three contiguous coal seams being, in actual fact, a common lignite layer divided by rock interlayers which thickness is 0.5 to 6 m and more. A bottom seam with up to 25 m thickness (when average value is 2-4 m) is the basic one. Upper seam is characterized by variable thickness (0.1 m to 3 m). Maximum thickness of all the seams is 29 m (Verkhniodniprovsk deposit). Configuration of the deposits is rather complicated; it duplicates borders of palaeovalleys within which they occur. The deposits are almost horizontal. Their depth from the surface varies from 10-30 m in the central part to 100-150 m within watersheds. Area of certain deposits is 50-60 km^2.

The common feature of the basin coal is that, according to the degree of metamorphism, it belongs to lignite with the age varying for certain deposits and sites. As a rule, carbonaceous clays and sands occur in the upper part of the seams. Clay lenses, secondary kaolins, and sandstones are available among the sands. Fine sands and carbonaceous clays occurring more rarely are the floor of the coal deposits; within the areas where crystalline basement rises, primary kaolins are the floor. In the context of coal basins, kaolins and systems of sedimentary formations capping them occur on the rocks of the crystalline basement. As for the sedimentary formations, sandy varieties are groundwater reservoirs (aquifers), and clayed as well as carbonaceous poorly permeable layers are aquifuges. Within the basin, water-bearing levels of the Quaternary System, a system of Kyiv, Kharkiv, Poltava, and Buchak suites as well as underground water of fissured zones of crystalline floor rocks are singled out.

In the context of Verkhniodniprovsk deposit, reserves for open-pit mining are 159.2 mln tons. Mining and geological conditions are favourable: thickness of a coal seam is 10.6 m; industrial opening coefficient is 6.6 m^3/t; moisture is 51 %; ash content is 18.7 %; bitumen content is 8.3 %; and the heat of coal combustion is 2290 kkal/kg. There is a possibility to build open pit with annual capacity of 4.0 – 4.7 mln tons. However, the deposit is within a nature conservancy zone of the Dnieper River. Its allotment for mining in Dnipropetrovsk region being overloaded with mining enterprises is rather a problematic idea.

In the context of Synelnykovo lignite deposit, where total reserves are 350 mln tons, *Petrovska* site has been prospected for open-pit mining. Reserves of the site are 70 mln tons and opening coefficient is 9.1 m^3/t. The lignite contains 58% of moisture, 4.8% of sulphur, 20.8% of ash and 7.4% of bitumen; heat of the lignite combustion is 1810 kkal/kg. Mining and geological conditions are complicated. Other deposits of Verkhniodniprovsk lignite district have been explored preliminary; they are subject to underground mining.

Novo-Dmytrivka lignite deposit is in Barvenkovo District of Kharkiv Region. The deposit is confined to a deep basin above salt rod; it has trough-like occurrence form. Three lignite seams, which thickness varies from 2.0 m to 60 m, are of commercial interest. Balance reserves are 390 mln tons. Ash content of the lignite varies from 13.5% to 40%; moisture varies from 48.5% to 56 %; sulphur content varies from 1.5% to 3.8 %; heat of the lignite combustion varies from 1435 to 2930 kkal/kg. Depth of the lignite seams at the output to the surface is 50 to 60 m and in the central part of a trough is 300-400 m. Industrial opening coefficient is 4 m^3/t. The lignite is suitable for briquetting, production of montan wax, direct burning, as well as chemical and technological processing [2-5].

Sula-Udai deposit in Poltava Region consists of four sites: *Voronky* site, *Melikhivka* site, *Senchanka* site, and *Dubrovka* one. Total reserves of the sites are 504.5 mln tons. *Melikhivka* site was prospected preliminary; other sites are under prospecting. Lignite deposits of *Melikhivka* site is represented by two layers – upper layer and lower one. According to the preliminary data, thickness of the upper layer is 2.7 m; thickness of the lower layer is 3.8 m. Occurring depth of productive layers varies from 16 m to 112 m. Working moisture is 58.8% to 60.2%; sulphur content is 1.46% to 1.7%; heat of the fuel combustion is 2080 kkal/kg. A site, allocated previously for open-pit mining, has average opening coefficient at the level of 9.5 m^3/t; reserves are almost 100 mln tons. The lignite grade is understudied.

Analysis of practices concerning the development of lignite deposits

In the mid 1940s, economic research made it possible to find an opportunity for the construction of electrical and chemical integrated works on the basis of Ukrainian lignite. The integrated works was a part of thermal power plant with 222 thousand kW capacity, semi-coking plant with the output of 2 mln tons, and by-product processing facilities. According to data by [6], semi-coking would make it possible to generate the following from a kilogram of the lignite: 66 % of semicoke, 8.95 % of resin, 0.46 % of benzol, and 100 m^3/t of gas. On condition that 4.4 mln tons of lignite would be processed annually, there was proved the possibility to produce up to 2 mln tons of semicoke; it was planned to use the amount in such a way: 1.5 mln tons would be consumed by thermal power plant; 0.5 mln tons would be used for by-product. Moreover, following amount of chemicals was also involved: 21.5 thousand tons of benzol; 75 thousand tons of crude carbolic acid; 73 thousand tons of lubricants for impregnation of sleepers; 95 thousand tons of lignite tar pitch; 9 thousand tons of paraffin; and up to 32 thousand tons of sulphur.

Scientific and research as well as design and prospecting activities persisted during post-war period. They were focused on the substantiation of the expediency of open-pit lignite mining. Thus, in his early publications O.S. Fidelev [7-11] listed innovative for that time methods to determine possible depth of fully-mechanized open pits with the substantiation of expedient parameters of their development. There were considered conditions for possible use of German transport-and-dumping bridges in complex with multi-bucket excavators to mine opening rocks. There were analyzed parameters of selective mining with the use of lignite and enclosing interlayers of barren rock as the associated minerals. There were identified parameters of open-pit field opening as well as expedient use of continuous equipment depending upon rock hardness. There were formulated basic requirements for preliminary drainage of watered lignite deposits and use of internal dump within the worked-out areas. There was proposed a new design for a stable dump with the stepped cross section with the formation of pre-dump with the use of sandy opening rocks. There were substantiated recommendations concerning the arrangement of dump support and excavator support to arrange the transport-and-dumping bridges on the dump, lignite and within the intermediate area [12].

Fundamental work by M.H. Novozhylov titled as “Open-pit mining” was published in 1950. The book has substantiated a tendency for the development of a complex of scientific and research activities not only for the national practices of open-pit mineral mining but also for the whole world community [13]. Along with the substantiation of engineering solutions concerning the provision of open-pit sides and protection against landslide phenomena, the book gives information on the methods of deposit dewatering, and consideration of the mineral reserves for the operation period of the enterprise. Moreover, it considers thoroughly the problems of mechanization of opening and mining activities with the use of various excavator facilities and hydraulic transport means; corrects the classification of opening schemes and systems of mineral mining; calculates and plans extraction volumes in terms of overburden and mineral in the context of different possibilities.

The methods of opening and further development of lignite deposits depend significantly on geological conditions of their occurrence. For instance, coal industries in Germany and the USA are characterized by the uniformity of deposits within the countries;

alternatively, in the context of Russia, Kazakhstan, and Ukraine occurrence conditions of deposits are rather various. It should be noted that the USA applies open-pit mining mainly for horizontal or flat seams which average thickness is 1.6 m, and maximum value is 4 to 6 m; Germany applies open-pit mining for horizontal seams which thickness is 10 to 30 m and more, occurring under overburden with 20 to 80 m thickness. Alternatively, at the territory of former USSR no less than ten types of coal deposits can be singled out. The deposits differ in their seam thickness, mode of occurrence (from horizontal to steep), hardness of coal and enclosing rocks, dilution of productive layers, water intake, climatic conditions etc. The above has become the foundations to apply various methods to open deposits; various extraction and transportation equipment as well as various mining parameters contrasting open-pit mining method applied in Germany and the USA.

Substantial volume of mining operations in the context of the national enterprises results from the following which took place while opening the deposits:

– flows of coal and rock are divided into zones which either unite several benches or separate them according to flanks;

– mobile machinery moves along the separated opening mine workings of freightless direction or freight-hauling; and

– transportation flows are organized according to flexible schedule and interchange points are transferred closer to excavator.

It should be noted that Ukrainian lignite industry was developed in a post-war period on the basis of specific deliveries of heavy mining equipment from Germany. Its task was to provide fuel (i.e. lignite briquettes) for rural areas mainly. Production of the briquettes involved a significant consumption of heat and electric energy. Hence, thermal power plants (TPPs) became a part of coal processing complexes. Neighbouring miner towns and settlements consumed a certain share of the produced heat and electric energy. Worsening of mining and geological conditions in mines and open pits, depreciation and physical wear of equipment, elimination of subsidies for the briquettes purchase by people and decreased level of their paying capacity as well as gasification of villages resulted in sharp drop of mining within the basin.

Currently, lignite is not mined in Ukraine; the product is processed while using imported raw material only. Mining operations in Vatutino, Novomyrhorod, and Korostyshiv districts have been ceased due to low technical-and-economic indices. It is not expedient now to build new coal-mining enterprises on the account of the limited reserves, relatively high opening coefficients, and remoteness from processing plants in the context of the districts [14].

According to the data by the Ministry of Coal Industry, only *Kostyantynivsky* open pit with *Protopopivska* site and *Morozivski* open pit operated in 2005. They mined 313.4 thousand tons of lignite; 311 thousand tons were mined in 2006; 211 thousand tons were mined in 2007; and 40.7 thousand tons were mined in 2008. Then, the mining operations were suspended due to tear and wear of extraction facilities and underfinancing of the holding company.

It follows from the performed geological and industrial review that depending upon the occurrence mode of lignite deposits, their grade and amount of the commercial reserves it is expedient to restart inactive mining operations in *Kostyantynivsky* and *Morozivski* open pits. However, their commercial reserves and operational performance are not sufficient to meet energy requirements of the region. Thus, Novo-Dmytrivka deposit should be noted among the new top-priority lignite-mining objects to be built since it can be used as the basis for the development of a powerful fuel and energy complex. It should also be noted that several analogous basin-like lignite deposits (i.e. Bantysh deposit, Stepivka deposit, Bereka deposit, Biliaevka deposits and others) have been prospected in the neighbourhood of Novo-Dmytrivka deposit. They are ten salt-dome lignite deposits with gigantic reserves above salt rods. The lignite is characterized by high output of resin (up to 18.5%) and bitumen (up to 10 – 15 %) [15].

Relying upon the world practices and previous studies, the State Scientific and Research Design Institute of Coal Industry, *Ukrenergoprom* Institute, and LAUBAG Company [16] have proved it is expedient to use lignite for heat and electric energy generation while building fuel and energy complexes in the place of its extraction (on the basis of Novo-Dmytrivka deposit). Production of synthetic liquid fuel and lignite-based gas is both possible and useful owing to the number of the available engineering solutions [17-26].

Moreover, the deposit may be used as the basis to produce montan wax, humic fertilizers, sorbents, coal-alkali reagents, and building materials [27-34].

German Company LAUBAG made a forecast concerning the restart of lignite industry in Ukraine; according to the forecast, the use of reserves, having been out of operation lately, is interesting from the commercial viewpoint. First of all, it is planned to restart mining operations in the *Kostyantynivsky* and *Morozivski* open pits which have already been opened and equipped; their reserves are 48.6 and 20.1 mln tons respectively; their projected annual outputs are 2.3 and 1.5 mln tons respectively. In future, the additional development of Verkhniodniprovsk deposit is planned with 146.4 mln tons of reserves, Novo-Dmytrivka deposit with 390 mln tons of reserves, and Sula-Udai deposit with 130 mln tons of reserves and annual productivity of 4.7; 8 – 10; and 2 – 4.6 mln tons respectively [16].

Geological and industrial description of Novo-Dmytrivka deposit

Currently, Novo-Dmytrivka suprasalt depressive basin (Fig. 2) has been investigated thoroughly and estimated industrially; genetic type of lignite deposits, being new for Ukraine, is connected with it. According to the conditions of the mineral complex origination and the lignite reserves, the deposit is among the unique ones. Its industrial coal-bearing properties depend on Oligocene deposits (Bereka series) and Miocene deposits (Poltava series). Structurally, they form syndepositional trough where amplitude along the floor of the basic coal lens is 330 to 360 m. In terms of three productive levels, commercial reserves of lignite are 394 mln tons, including 50.8% of A category, 21.8% of B category, and 27.4% of C1 category. Moreover, beyond the boundaries of original walls of the depression, non-commercial reserves have been estimated at a level of 52.5 mln tons (south-east part of the deposit). Hence, lignite reserves within the basic productive levels (i.e., 3^{rd}-4^{th}) are 446.5 mln tons; and total geological reserves are more than 600 mln tons. Basic coal-bearing capacity belongs to a central part of the depression where coal lenses are of maximum thickness (74 and 37 m) and coal-bearing coefficient is 34% [35-38].

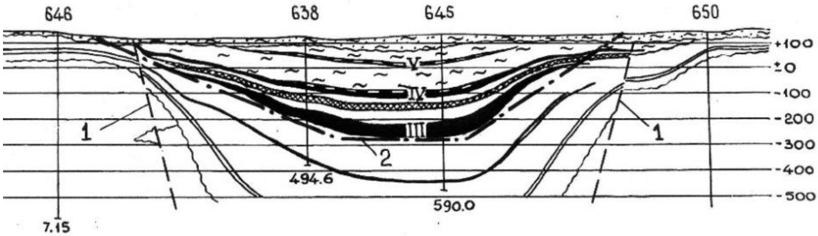

Fig. 2. Geological section of Novo-Dmytrivka deposit:
1 – a boundary of a salt rod; 2 – boundaries of open-pit field;
III, IV, V – commercially important coal levels

Coal levels one and two are of minor thickness (to compare with other levels) in terms of their deeper occurrence depth; thus, they have not any industrial importance and cannot be considered as non-commercial reserves.

Level three of the deposit is of simple structure (i.e. it has no rock interlayers); it occupies 7.8 square kilometers within 2.0 m thickness forming genetically a syndepositional basin. Its thickness decreases gradually towards boundary walls; at the angle of 8 to 12^0 it thins away completely. The lignite grade is rather high: ash content is 5.6 to 15.8%; sulphur content is 2.0 to 3.2%; and combustion heat is 6700 to 6900 kkal/kg. Wax content is 56 to 62%; output of humic acids is 47.0 to 65.5 g/m^3; and technological grade Б is 1.2. The commercial lignite reserves are 296.1 mln tons; ash content of 290.7 mln tons of them is less than 20%.

Level four is characterized by complicated structure (2-3 members) and maximum thickness of 37 m. Technological lignite grade is Б – 1; ash content is 8.1 to 29.2%; sulphur content is 2.6 to 4.1%; and combustion heat is 6350 kkal/kg. Bitumen output is up to 13%; output of humic acids is 47.7 to 76.0 g/m^3. Commercial reserves are 98 mln tons.

Level five consists of two coal members with 2.5 and 5.4 m; total value is 8.2 m. It is characterized by high ash content (15 to 45%) and non-commercial reserves (58.3 mln tons). Modern techniques make it possible to apply such coal as low-grade fuel. At the same time, two above-mentioned levels may become a fuel source for thermal power stations, a material to produce coal briquettes, and a raw material for chemical and technological processing to generate petroleum products, montan wax, and humic acids. Total lignite reserves of the three productive levels are more than 452 mln tons.

Carbonaceous clays, diatomites, native sulphur, fireproof and ceramic clays, glass sands and building sands as well as lead-zinc ores and mercury ores within original walls of the depressive basin are among the associated minerals.

Reserves of the carbonaceous clays with 35 to 45% of organic material are 480 mln cubic meters or almost 1 billion tons; sulphur reserves (if concentration is more than 7% to be minimum commercial content) are more than billion tons, and diatomite reserves are up to 160 mln cubic meters. Since 2001, Donetsk State Regional Geological Enterprise (town of Bakhmut) has been engaged in prospecting and evaluating activities within the walls of Novo-Dmytrivka depression to survey zink-lead ores.

Thus, Novo-Dmytrivka deposit should be considered as a complex one taking into account the availability of mineral being important for Ukraine. The minerals are 85 to 90% of the productive thickness overburden.

The current state of Ukrainian power industry and permanent deficit of energy carriers need immediate development of the deposit as a raw material base for active thermal power station. The detailed analysis of both grade and technological properties of the lignite demonstrates their complete applicability to be used as power fuel [2]. The performed calculations mean that Novo-Dmytrivka deposit can be used as the basis to build thermal power station with 2400 MW capacity and provide it with fuel for the period of 60 to 70 years.

Substantiating the prospects of Novo-Dmytrivka open-pit building

As of 2018, Ukraine has extremely limited possibilities of coal mining to be independent in the progress of its heavy industry. It is particularly important for lignite. Oleksandriia lignite district has no long-term perspectives to support its productivity. Other promising deposits are not developed, and some deposits are under prospecting and detailed exploration. At the same time, Novo-Dmytrivka deposit has been explored thoroughly; its reserves are considerable. Thus, the deposit may be taken as an example to restart the operations of coal industry in the near future [39].

Novo-Dmytrivka lignite deposit differs from Oleksandriia deposits not only in significant reserves of various minerals but also in the complicated occurrence conditions due to considerable depth and water intakes which may affect the economic expediency of raw material extraction [40]. Hence, its development should involve pre-estimation concerning the economic feasibility to build mining enterprise. In such a case, it makes sense to analyze the available mining systems used during many years to extract manganese ores and lignite in Ukraine along with the considered mining techniques involving water pressure [41]. Minimum value of the reduced costs to mine basic mineral (i.e. a ton of the raw material) is applied as the efficiency criterion of the considered systems. Thus, substantiation of economic expediency to develop Novo-Dmytrivka deposit with further construction is quite topical scientific and practical issue.

Basing upon the practice of opening activities, open-pit field can be opened with the help of the two high-productive rotary and conveyor systems: system 1 consists of a rotary excavator CPC-2000 which theoretical efficiency is 4900 m^3/h, conveyor transport, interbench loader and a stacker of ARs-B 5000.60 type. The system operates starting from the initial construction stage moving gradually to lower working levels of the open pit; system 2 is as follows: opening operations are planned to be performed with the use of more powerful rotary excavator SRs-6300 which theoretical efficiency is 14000 m^3/h and where rock is loaded on a belt conveyor with the interbench loader and stacker [42].

It is wise to perform mining by means of mechanical shovel, where capacity of a bucket is not less than 12 cubic meters, completed with dumping trucks. Such a composition corresponds to the increased strength of lignite within the rock mass; moreover, the method has been widely piloted in open pits having similar mining and geological conditions.

Preliminary estimation of capital investment to purchase and mount the mining equipment is USD 680.7 mln (Table 1). Operational costs for the lignite extraction were determined relying upon the recommendations of German “Master plan of lignite industry development in Ukraine”. According to the technique, the estimated extraction costs differ from classical prime cost by the level of depreciation charges and involve the discounted equipment cost.

Operational costs are determined on the basis of the applied equipment. Workforce requirements depend upon the mounted technical facilities of the open pit and its operational mode (i.e., one-shift control and maintenance of the equipment, and three-shift production process).

A value of other categories of staff relations has been calculated according to Ukrainian standards. Workforce requirements to perform auxiliary and intermediate operations were estimated using the practices of Eastern European coal enterprises. For the selected types of costs, following prerequisites of their estimation have been calculated:

– depletion period is 36 years; and

– lignite mining is expected after 6 years of the point when equipment started to be mounted and auxiliary works concerning the open pit construction and lignite seam opening began.

Table 1

The expected investment for the purchase of mining equipment to be used while Novo-Dmytrivka open pit operating

Capital equipment	**Quantity, units**	**Cost, USD thousands**	**Cost including VAT, USD thousands**
Excavator with no less than 12 m^3 bucket	1	3 754	4 505
Rotary excavator SRs-2000	1	36 993	44 392
Rotary excavator SRs-6300	2	177 878	213 454
Stacker of ARs-B 5000.60 type	1	16 614	19 937
Stacker of Spreader ARs- (K) 8800.195 type	3	144 078	172 894
Reloader of BRs (K) 1800.65 type	1	4 543	5 452
Reloader of BRs 1600.47/72 type	2	23 364	28 037
Face conveyor	2	23 665	28 398
Frontal conveyor	1	14 732	17 678
Main conveyor	2	29 446	35 335
Stacking conveyor	2	36 265	43 518
Dumping trucks	5	4 358	5 230
Unaccounted mining equipment (10 %)		51 569	61 883
Total		567 260	680 712

Maintenance cost depends upon the annual investment total:

– infrastructural devices – 2 %;

– chain and rotary excavators – 3 %;

– belt stackers– 3-3.5 %;

– dragline excavators, face shovels – 4 %;

– auto dumpers – 6 %;

– auxiliary facilities – 3 %;

– electric energy – USD80/MW excluding VAT; forecast of retail tariff for electric energy consumption for industry is prescribed at the level of class one;

– average expenditures connected with a salary of a worker are USD 850/month;

– payroll tax is 22%;

– annual administrative cost and total production cost are USD 3 mln; and

– land tax, rent payments, and other expenses connected with unaccounted cost.

Extra operational expenses of a mining enterprise have been calculated for a period of the projected capacity attainment (9 mln tons a year); they are USD 4.71/t.

The data, concerning the capital investment and operational cost, show that despite significant expenses connected with the purchase of mining equipment, operational cost to extract a ton of lignite are expected to be USD 4.7 when the open pit has attained its projected capacity. If combustion heat of lignite is 2527 kkal/kg, then extraction cost of a ton of a fuel equivalent is USD 13.1 excluding VAT.

However, such statistical data as CAPEX and OPEX prevent from judging about the operational efficiency on one or another deposit on the whole. It is usual to make the evaluations basing upon the cash flow forecast.

Hence, to have the opportunity to substantiate the expedient development of certain open-pit sites, it was decided to adopt a method turned out to be reliable while developing the calculation of lignite industry and power industry applied in Germany and represented in the “Master Plan of Lignite Industry Development in Ukraine” formed by German lignite and energy groups of companies. According to the Plan, alternatives of the development of the projects are estimated by means of general internationally recognized methods of the dynamic business calculations. In this context, annual expenses and revenues are determined either for the whole period of a deposit operation or for the period of extraction planning.

Expenses and revenues have been mutually compared in terms of financial and mathematical averaged expenses and then determined with the help of the indices:

- actual cost in terms of different calculation types of interest rates;
- financial and mathematical averaged costs (FMACs); and
- a level of internal interest rate.

Prerequisite to apply methods of dynamic business calculations is as follows: each investment cost and current production cost is recorded on operating years of the whole period being the analysis in the form of a payment line. Neither depreciation deductions nor interests are involved. Possible interest rate on the loan or the invested capital value is involved in shares while cash flows forecasting. Unreported income is processed similarly. Annual excess of the income above expenses as well as excess of the income above expenses for the whole operational period of the deposit is also involved in the calculation process. Thus, operation of the enterprise should provide positive net cash flow (NCF). In this context, following ratio should be met:

$$NCF \geq 0 \qquad (1)$$

As a rule, the payments are different at certain dates and certain years. To make them comparable, they should be estimated for a certain date of operation with the help of imputed interest rate. As a result, it is guaranteed that the payments which should be made later are insignificant to compare with those to be made earlier. The applied imputed interest rate depends upon the interest rate for long- and medium-term credit and the accepted amount of the charged interest. If the forecasts for future potential interest and expected investment risk are dangerous, then higher interest rates are usually involved. As a rule, starting point of the whole operational period or starting point of a production process is considered. Total payments of the date are indicated as net assets value.

Implementation of the projects is rational from the viewpoint of production and economy if in terms of the stated imputed interest rate (discount interest rate) difference between the net assets value and investment is at least equal to zero; positive difference is much better. As a rule, in the context of firmly stated imputed interest rate, such an interest rate is fixed when net assets value tends to zero. The interest rate is called internal one.

Application of the methods means that along with production costs, the expected prices for the end product are also known; moreover, income for the whole project period is earned. It often happens that prices for commercial output are unknown, unapproved, and unstudied. If so, then the averaged financial and mathematical expenses are set; the expenses may be considered as specific forms of capital cost representation. The calculated cost of the enterprise corresponds to the financial and mathematical value of a product unit which should be identified for the whole operation period. In other words, net assets value of the income excess above expenses will tend to zero. In this context, following ratio should be met:

$$NPV = 0 = -(CAPEX_i + CAPEX_{(i+1)} + CAPEX_{(i+n)}) + NCF_{(i+n+1)}/(1 + IRR) + \\ + NCF_{(i+n+2)}/(1 + IRR)^2 + NCF_{(i+n+3)}/(1 + IRR)^3 + NCF_{(i+n+4)}/(1 + IRR)^4 + \\ + \mathrm{NCF}_{(i+n+5)}/(1 + \mathrm{IRR})\text{^}5 + (NCF_{(i+n+6)}/IRR)/((1 + IRR)^5) \quad (2)$$

If so, income excess above expenses is set basing upon the expenses and expected earnings from the end product sales; besides, its value is set as that one at the level of FMAC.

To consider and evaluate a new deposit in comparison with other ones, it is required to determine cost values as well as financial and mathematical expenses for the enterprises separately. As a result of the FMAC calculations, following values concerning the operation of an enterprise on the basis of Novo-Dmytrivka open pit have been obtained (Table 2).

Table 2

Financial estimation of Novo-Dmytrivka open pit operations

Index	Measurement unit	Cost connected with extraction of a ton of raw coal	Cost connected with generation of a ton of fuel equivalent
Capital cost	USD/ton	10.5	29.0
Operational cost	USD/ton	7.0	19.4
Total cost	USD/ton	17.5	48.3

Data from Table 2 indicate that in the context of implementation of the 10% interest of the rate of return on invested capital, the price for raw lignite extraction should not be less than USD 17.5 per ton excluding VAT or USD 48.3 per ton in the context of fuel equivalent.

The calculated price for fuel is quite comparable with the price for black coal extraction. Since the calculations involved certain share of assumptions, to determine stability of the FMAC-based price it is required to analyze its sensitivity according to the parameters: change in interest rate on capital is ± 25 %; change in operating cost is ± 25 %; and change in capital investment is ± 25 %. Fig. 3 represents modeling of the fuel prices.

Data in Fig. 3 explain that the project to develop Novo-Dmytrivka deposit is mostly sensible to capital cost; the least sensibility is in production cost. It means that the improvement of financial stability of Novo-Dmytrivka-based mining enterprise should involve: the required capital raising with the lowest percent interest rate and downward capital investment optimizing. Reduction of operational cost is only possible at the expense of the electricity generation (construction of own technological thermal station) and income increase resulting from marketing of products.

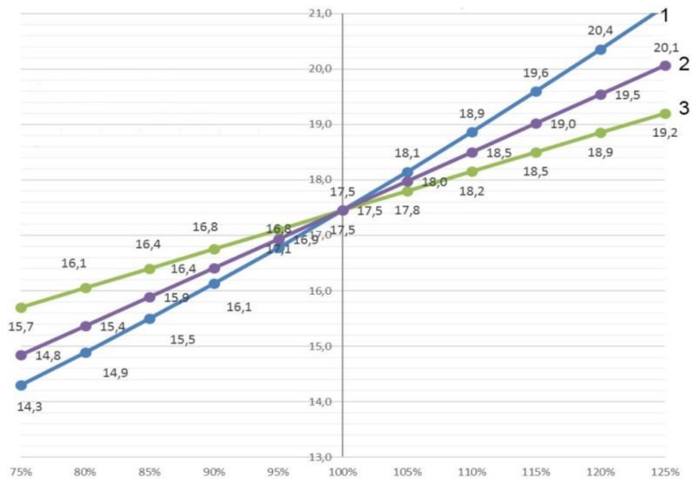

Fig. 3. Analysis of sensitivity of fuel price FMAC, USD/t: 1 is interest rate change; 2 is change in the amount to be invested; 3 is change in production operational cost.

Reserves of Novo-Dmytrivka deposits involve carbonaceous clays referring to the Lower Pliocene (above coal deposit 5) and to Poltava Miocene formation (between coal deposits 4 and 5); the clays occupy the area of more than 6 square kilometers.

Average thickness of the carbonaceous clays is 75 meters and their previous reserves are more than 450 mln cubic meters; in terms of specific weight being 1.35 t/ $м^3$ they are more than 600 mln tons. Carbonaceous clays have never been studied before as energy raw material. On the analogy of Dnipro lignite basin, their ash content and combustion heat with a view to combustible mass and as-received fuel are 4500-5600 and 700-900 kkal/kg respectively. Typical ash content varies within 55-65%.

The research helped understand that the carbonaceous clays overlap both *Verkhni* and *Skladny* coal levels. Taking into consideration their high ash content and low combustion heat their use as a certain associated raw material is not possible. However, in a mixture with rough lignite, the rock mass (rough coal + carbonaceous clay) is energy raw material suitable for its further use. For a comparison: lower combustion heat of rock mass with a value of 1825.5 kkal/kg corresponds to so-called power generating coal used to be burnt at lignite thermal stations 1 and 3 in the town of Oleksandriia. Co-extraction of the rough lignite and carbonaceous clays makes it possible to increase the mineral amount by more than 20 mln tons a year with high economic indices (Table 3).

Table 3

The data concerning calculations of lignite and carbonaceous clays extraction according to FMAC, USD/ton

Index	Rough lignite extraction, mln tons a year		Carbonaceous clay extraction, mln tons a year	
	value	t.r.f.	value	t.r.f.
Capital cost	10.5	29.0	4.7	18.0
Production cost	7.0	19.4	3.2	12.1
Total	17.5	48.3	7.9	30.1

The data from Table 3 explain that co-extraction of the rough lignite and carbonaceous clay makes it possible to reduce the calculated price for fuel by 60 %. Analysis of the indices sensitivity according to FMAC calculations has been carried out similarly as for the rough lignite extraction. Previous technical and economical modeling of Novo-Dmytrivka deposit mining demonstrates the feasibility of lignite complex use taking into consideration the extraction of carbonaceous clays. Despite the necessity in significant capital investment, integral financial and economic indices of the mining enterprise are high.

Conclusions. All known Ukrainian lignite deposits, occurred above salt rods, are complex ones; that is they involve other minerals in addition to lignite. Their list varies depending upon deposits: from diatomite and fireproof clays to building and glass sands. Aside from its basic use, lignite may be applied for briquettes and production of montan wax being valuable raw material for many industries.

Taking into account the form of Novo-Dmytrivka deposit and its borders, it is expedient to consider pivoting mining method with the opportunity of internal dump formation making it possible to use parameters of mining and loading equipment more effectively. The use of productive rotary and conveyor scheme to extract minerals regulates timing of mineral mining since processes of rotary and conveyor system production and maintenance may achieve three years.

To reduce introduction period of a mining enterprise and to accelerate its attainment of projected capacity it is wise to consider the use of cycle facilities as a part of hydraulic excavators and open-pit dumping trucks.

Innovative techniques and equipment were developed for selective mining of lignite and associated minerals, their transportation and transient dumping. Period of their reuse and supply to consumers help provide such related industries as building industry, metallurgical industry, chemical industry and agriculture with valuable mineral raw material. Its extraction from technogenic deposits will be performed with the use of the equipment systems applied while lignite deposits mining. Recommendations, being a result of the performed research, have been published. The recommendations concern the introduction of the obtained results while designing lignite open pits.

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