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Ecological-hydrogeological history of the development of the coal industry in the Western Donbas under the influence of a complex of technogenic factors

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Summary. The Western Donbas is a mining-manufacturing region of Ukraine with a potential for increasing coal extraction in the following years. The operation of mines is followed by intense water drainage of highly mineralized ground water which accumulates in tailing ponds, which were built in the ravines without barriers screening the water-containing rocks. The problem of rational usage and protection from contamination and ex-

haustion of all types of water sources available for practical usage is relevant for the studied region, and all around the world. The development of a fundamental scientific solution to this problem was started in 1986, when a constantly operating mathematical model (COMM) of the changes in hydrogeological conditions of the Western Donbas was developed. The authors were the Pavlohrad Geological-Survey Expedition (PGSE), the Dnipropetrovsk Affiliate of the Institute of Mineral Resources (DAIMR) and the Department of Geology and Hydrogeology of O. Honchar Dnipropetrovsk National University. It is a regional, multi-functional, constantly improved hydrogeological project limited in space but without a time limit. The COMM of the Western Donbas, along with the most obvious advantages, has one disadvantage. In spite of its small scale (1:100000), it provides only a general characteristic of technogenic changes in the ground water regime of the territory and cannot constitute a single scientific basis for developing nature-protection hydrogeologic measures. Therefore, it has been supplemented with mathematical models of the territories adjacent to the local objects of technogenic impact on the ground water. This includes tailing ponds, tailing dams, mining dumps and mine drainage. The first three types of technogenic objects have already been sufficiently studied and described in scientific publications (Eugrashkina, 2011; Eugrashkina, 2012; Eugrashkina, 2013; Eugrashkina, 2013). This paper focuses on the mathematical models, changes in hydrogeological conditions under the impact of the fourth factor mine drainage. The first three factors contaminate ground water, the fourth causes decreases in the operational reserves as a result of flow of the fresh water from the upper horizons to the productive dried-out layer.

Key words: mathematical model, theory of wells, regime observations, adequacy, cone of depression, ground water, nature-protection measures

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(Eugrashkina, 2011; Eugrashkina, 2012; Eugrashkina, 2013; Eugrashkina, 2013)].

Introduction. The objective of this research was creating and elaborating mathematical models of changes in the hydrogeological conditions of the territories in the zone of mine drainage impact. For scientific substantiation of nature-conservation hydrogeological procedures, we used the mathematical apparatus of the classic theory of single and connected

boreholes in random spatial arrangement. The adequacy was proven by comparing the results of calculations with real conditions of operation and regime observations in the zone of mine drainage impact. Material and methods. Chronologic sequence of the commissioning the mines and characteristic of their hydrogeological conditions is presented in Table 1.

Table 1. Hydrogeological character of mines in Western Donbas

	Name of mine	The year of commissioning	Depth of mining works from the ground surface, m	Size of the mine drainage, thou- sand m ³ mineralization, g/dm ³	Indexes of the drained horizons	weighted average water-conduc- tivity of the drained layer , m ² /day	weighted average elastic water separation of the drained layer μ^* , unit fraction.	weighted average gravitational water separation μ , fraction	piezoconductivity μ^* , m ² /day.	Level-conductability , m ² /day
1	Pershotravenska	1963	180-200	$\frac{12,33}{2,90}$	P ₂ , C _{IV}	132	0.009	0.1	14 666	1 400
2	Ternivska	1964	100	$\frac{6,74}{2,6}$	P ₂ , C _{IV}	70	0.008	0.09	8 750	778
3	Stepova	1965	145-250	$\frac{21,0}{3,5}$	P ₂ , C _{IV}	140	0.009	0.1	15 556	1 400
4	Pavlohradska	1968	105	$\frac{6,86}{6,3}$	P ₂ , C _{IV}	73	0.008	0.07	9 125	1 042
5	Yubilaina	1970	180-230	$\frac{24,39}{2,21}$	P ₂ , C _{IV}	161	0.009	0.11	17 888	1463.6
6	Blahodatna	1971	115	$\frac{7,78}{15,0}$	P ₂ , C _{IV}	86	0.008	0.09	10 750	955.6
7	Samarska	1973	160	$\frac{8,81}{7,5}$	P ₂ , C _{IV}	80	0.007	0.08	11 428	1 000
8	Dniprovska	1975	260	$\frac{5,34}{6,0}$	P ₂ , C _{IV}	42	0.006	0.09	7 000	466.7
9	Mine named after the Heroes of Space	1979	470	$\frac{1,0}{37,1}$	C _{IV}	25	0.001	0.04	2 000	625
10	Zahidno-Donbaska	1980	585	$\frac{1,13}{27,38}$	C _{IV}	2	0.001	0.07	2 000	285.7
11	Stashkov Mine	1982	140	$\frac{43,66}{2,66}$	P ₂ , C _{IV}	120	0.008	0.11	15 000	1 090.9

Analytical models are presented in Figs. 1-4. Development of the mathematical model of the eastern groups of mines (Fig. 1) was finished due to the decision to close the “Pershotravneva” mine. The model was published in an article co-written by the scientific supervisor (Eugrashkina and Marchenko, 2016). All epignostic [epignosis is a characteristic of hydrogeological process in the past – *Translator’s note*] and predicting tasks were solved using the method of gradual changes in the steady states. The current studies were conducted independently for the group of mines in the Western Donbas. The basis of the mathematical models were the 2 methods – the abovementioned method of changes in the steady

states conditions and the Theis fundamental solution modified for solution of this task.

The mathematical model for the group of mines – Pavlohradaska, Blahodatna, Heroes of Space (Fig. 2) was developed after of the Pavlohradaska Mine was put into operation in 1968. It worked as a “single well” to 1971, then the Blahodatna Mine was put into operation, making a mathematical series of first single, and then associated “wells”. In 1979, the Mine named after Heroes of Space joined this group. Since then, all the mines created a model of three randomly located wells.

The mathematical models for the rest of the mines are in the stage of development (Fig. 3-4).

Fig. 1. Model of locations of the eastern group of mines, scale: 1:100 000, $r_{3-5} = 4\ 100\text{ m}$; $r_{1-3} = 2\ 200\text{ m}$; $r_{1-5} = 4\ 200\text{ m}$.

Fig. 2. The model of locations of the Mine named after Heroes of Space, the Blahodatna Mine, the Pavlohradaska Mine, scale: 1:100 000, $r_{9-4} = 4\ 600\text{ m}$; $r_{6-4} = 2\ 500\text{ m}$; $r_{9-6} = 2\ 800\text{ m}$.

Fig. 3. The model of locations of the mines of the Zahidno-Donbaska, Pavlohradskaa, Ternivska, scale: 1:100 000, $r_{2-4} = 6\,300\text{ m}$; $r_{2-10} = 2\,600\text{ m}$; $r_{4-10} = 7\,750\text{ m}$. The Pavlohradskaa Mine is included in two models (Fig. 2, 3).

Fig. 4. The model of locations of the Samarska Mine, the Dniprovskaa Mine, the Mine named after Stashkov, scale: 1:100 000, $r_{7-8} = 8\,000\text{ m}$; $r_{8-11} = 2\,000\text{ m}$; $r_{7-11} = 8\,100\text{ m}$.

The model in Fig.2 chronologically characterizes in detail the change in hydrogeological conditions to 2020 inclusive.

The examples of solving the task of prediction and analysis of the results. According to the selected methods, for three associated “wells”, the mathematical description of the water drainage processes at the end of 2020 looks as follows:

1. Method of gradual change in the steady states, Pavlohradskaa Mine, 4

$$\sum S_4 = S_4 + S_{4-6} + S_{4-9} = \frac{Q_4}{2\pi T_4} \ln \frac{R_4}{r_4} + \frac{Q_6}{2\pi T_6} \ln \frac{R_6}{r_6} + \frac{Q_9}{2\pi T_9} \ln \frac{R_9}{r_9} \quad (1)$$

$$\sum S_4 = \frac{6860}{2 \cdot 3,14 \cdot 73} \ln \frac{6670,73}{3,0} + \frac{7780}{2 \cdot 3,14 \cdot 86} \ln \frac{6201,17}{25,00} + \frac{1000}{2 \cdot 3,14 \cdot 25} \ln \frac{5297}{4600} = 126$$

$$R_4 = 1,5\sqrt{a_4 t_4} = 6670,73 \text{ м};$$

$$R_6 = 1,5\sqrt{a_6 t_6} = 6201,17 \text{ м};$$

$$R_9 = 1,5\sqrt{a_9 t_9} = 5297 \text{ м}.$$

2. Theis fundamental solution:

$$\sum S_4 = \frac{Q_4}{4\pi T_4} \ln \frac{2,25 a_4 t_4}{r_4^2} + \frac{Q_6}{4\pi T_6} \ln \frac{2,25 a_6 t_6}{r_{4-6}^2} + \frac{Q_9}{4\pi T_9} \ln \frac{2,25 a_9 t_9}{r_{4-9}^2} \quad (2)$$

$$\sum S_4 = \frac{6860}{4 \cdot 3,14 \cdot 73} \ln \frac{2,25 \cdot 1042 \cdot 52 \cdot 365}{9} + \frac{7780}{4 \cdot 3,14 \cdot 86} \ln \frac{2,25 \cdot 955 \cdot 49 \cdot 365}{6250000} + \frac{1000}{4 \cdot 3,14 \cdot 2} \ln \frac{2,25 \cdot 285,7 \cdot 41 \cdot 365}{2116000} = 125$$

The calculated decrease corresponds to the depth of the working area of the Pavlohradskaya Mine. This correspondence is a direct justification of the model's adequacy to real conditions. Analogical calculations of decreases were made for the Blahodatna Mine and the Mine of Heroes of Space with calculation of the numbers 6 and 9 respectively. The expressions 1 and 2 contain the following symbols:

S_4 – total water decrease in the mining shaft of Pavlohradskaya Mine (conventional number 4) m;

S_{4-6} – decrease caused by water drainage from the Blahodatna Mine, m;

S_{4-9} – decrease caused by water drainage from the Mine of Heroes of Space, m;

Q_4, Q_6, Q_9 – water drainage of the corresponding mines, thousands m³/day;

r_4 – radius of the Pavlohradskaya Mine shaft, m;

r_{4-6}, r_{4-9} – distance from the Pavlohradskaya to the Blahodatna Mine and the Mine of Heroes of Space, m;

a_4, a_6, a_9 – weighted average values of hydraulic conductivity of the water-bearing horizons of the drained layer in the mine sections, m²/day;

t_4, t_6, t_9 – the duration of operation at the end of late 2020, years.

For the Blahodatna Mine and the Mine of Heroes of Space, the following results were obtained:

1. Method of gradual change in the stationary conditions:

$$S_6 = 112,0 \text{ м}; \quad S_9 = 450 \text{ м}.$$

2. Theis fundamental solution:

$$S_9 = 111,0 \text{ м}; \quad S_9 = 437 \text{ м}.$$

The difference between the factual and assessed depth of mining working areas is 1 m for the Blahodatna Mine, and 13m for the Mine of Heroes of Space. The accuracy is high and indicates the correctness of the parameters and the selection of the methods. This difference in time should decrease, for classic hydrogeological processes always converge. Conclusions and recommendations on the problem investigated.

1. Four main factors of the negative impact on the regime, capacity and the quality of the ground water for drinking and technical supply are as follows: tailing ponds of the mine waste water, tailing dam of the central concentrating mill (CCM), mining dumps and the mine water drainage.

2. The first three factors contaminate the ground water, the fourth decreases its operational capacity by flowing down to the productive water-bearing horizons which have dried-out during the period of exploitation.

3. This factor is impossible to eliminate, for it is caused by natural geologic-hydrogeological conditions of the deposits.

4. The first and the second factors could be eliminated as follows: instead of the first pond and tailing dam, in each ravine, a cascade of three water reservoirs could be built. The discharge of low-mineralized water is made to the first one. It is used for irrigation with provision of substances for improving

soil properties. The amount of these substances was calculated in accordance with the method of the Ukrainian Research Institute of Hydraulic Engineering and Land Development. The second and the third water reservoirs are covered by a colloid-saline screen barrier. This is an invention of the Sokolovsky Ukrainian Research Institute of soil science and agrochemistry. The properties of such screen barrier to absorb salt and provide clean water to the water-bearing horizons. In the experimental variant, the screen barrier was successfully working for 5 years. This development can be improved in order to extend the term of operation of the required water filtration. After expiry of the control term, the water is released into the third pond, in the second pond the screen barrier is renewed. Thus, due to cleaning, the loss of water flow to the dried productive horizons is compensated.

5. For the third factor – mining dumps, efficient methods of recultivation have been developed and proposed by Oles Honchar DNU and Dnipro State Agrarian University.

Conclusions on the developed mathematical models of changes in the hydrogeological conditions in the zone of mine water drainage impact.

1. Classical theory of wells is a fundamental basis for developing mathematical models of mine water drainage.

2. The adequacy of the results of modeling to the real changes in the hydrogeological conditions is proved by comparing with the results of modeling, regime observations, made by the Prydniprovya Geological Survey Expedition.

3. Mathematical models allow highly accurate solving of the following tasks:

- a) direct problems which characterize changes in the hydrodynamic pressures under the impact of the mine drainage in time and space;
- b) inverse tasks of determining and concretization of the hydrogeological parameters;
- c) inductive tasks for substantiating the selection of an equation which describes the studied process and method of solving tasks.

4. The final goal of all types of studies is scientific substantiation of the complex of nature-protecting hydrogeological measures.

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