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DETERMINATION OF HYDRAULIC PARAMETERS FOR GEOTHERMAL HEAT EXCHANGER

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ВИЗНАЧЕННЯ ГІДРАВЛІЧНИХ ПАРАМЕТРІВ ГЕОТЕРМАЛЬНОГО ТЕПЛООБМІННИКА

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ОПРЕДЕЛЕНИЕ ГИДРАВЛИЧЕСКИХ ПАРАМЕТРОВ ГЕОТЕРМАЛЬНОГО ТЕПЛООБМЕННИКА

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Annotation. Mineral mining by open cast is inevitably accompanied by anthropogenic transformation of fertile earths and hampers their practical use. The idea of the proposed method consists in creation of a treating object – a bioplateau - in the goaf of quarry. In the bioplateau, higher water plants will clean the quarry waters by way of absorbing mineral substances from water via roots, stems and leaves. Root, underwater and surface cellular mass will grow up and, in the process of the cell dying off and decomposition, will form humus part of fertile layer. Due to technical difficulties and high costs of water pumping into the borehole, it is necessary to determine basic hydraulic parameters of bioplateau for arranging its gravity flow. Purpose of the work was to determine basic hydraulic parameters for geothermal heat exchanger on the basis of determining of conditions for water gravity flowing through the tubular system of the given sizes. It is established that for arranging water feed into the geothermal borehole of biotreating object in the mode of gravity flow, it is necessary to arrange bottom of the «Morskaya Balka» Quarry with slope at angel no less 4°. One of the basic parameters, substantially impacting on the rate of hydraulic resistances, and, consequently, on the angle of quarry bottom slope, is diameters of external and internal pipe: the more is difference between diameters of external and internal pipe, the more is sum of hydraulic resistances. In order to diminish hydraulic resistances inside the geothermal borehole at diameter of external pipe 300 mm, diameter of internal pipe must make 0,25…0,3 of diameter of external pipe. Further increase of this relation does not give substantial decrease of pressure losses in geothermal heat exchanger. At diameter of external pipe of 200 mm, optimum diameter of internal pipe makes 0,35…0,4 of diameter of external pipe.

Keywords: goaf, geothermal energy, geothermal heat exchanger, higher water plants.

Introduction. Opencast minerals extraction is inevitably accompanied by anthropogenic transformation of fertile land and formation of anthropogenic landscapes representing broken relief with active erosion and other unfavorable and dangerous geomorphologic processes that complicate their practical use.

On the territory of Ukraine the total area of the transformed landscape comprises about 800,000 ha including over 122,000 ha of quarries [1]. In accordance with national legislation, opencast workings after their extraction termination shall be restored up to the condition that is suitable for their further use including agricultural one. Thus, nowadays the issue of restoration of worked-out quarries and degrade areas' return to their initial state is greatly urgent for mineral resource enterprises.

Analyses' results of recent studies and publications. In mineral resource sphere there are various possible types of areas utilization affected by mining operations requiring their preliminary assessment in order to choose their proper use direction [2].

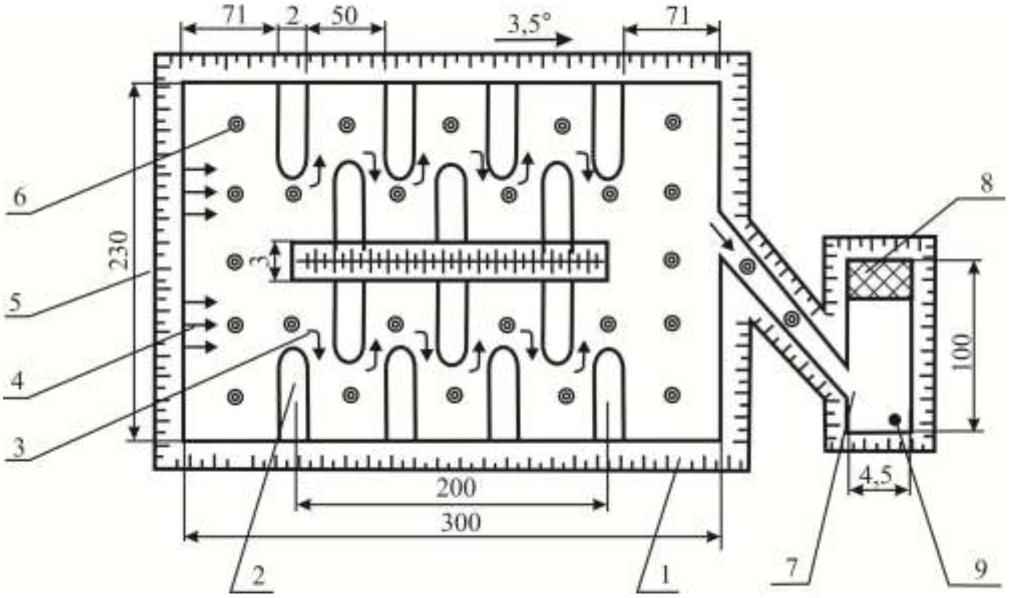
To restore territories with anthropogenic damages they use such methods as agricultural, forestry, sanitary and hygienic, building, landscape gardening, and hydro-economic.

The direction selection takes into account hydrological state, climatic zone, areal biological variety, economic expediency, purpose, and permitted use.

Worked-out quarries are divided into dry (non-watered), partially watered, and watered.

After their treatment partially watered and watered quarries are especially dangerous for people and ecosystems. Such quarries and adjacent damaged territories can be self-restored however the processes of the initial restorative succession are too slow. Besides, as a rule, quarry waters are polluted with suspended particles and characterized by the high mineralization thus requiring purification and desalination.

To solve the problem of intensive restoration of the territory damaged due to opencast mining operations with the simultaneous purification of quarry waters, the authors improved the methods of their biological treatment in bio-plateau system with thermal stabilization of geothermal energy (Fig. 1) [3].



1 – pit wall; 2 – auxiliary dams; 3 – bed; 4 – water inflow; 5 – main dam; 6 – vertical hole collector «pipe-in-pipe»; 7 – water collector; 8 – higher water plants; 9 – pump

Figure 1 – The scheme of quarry water biological treatment using geothermal energy

The idea of the proposed method includes a bio-plateau purification structure formation in the gob of the quarry where higher water like common reed grass, reed mace, etc. plants would be used for quarry water treatment. The plants absorb mineral substances from water with their roots, stems and leaves. At the same time the root, submersible and surface cell mass increases, and this, in the course of the cells' further dying-off and disintegration forms the humus part of the fertile layer.

The debatable question in the connection with the bio-plateau structure operation is the winter mode of work. To avoid the winter period decrease of water treatment one should maintain the water temperature on the treatment structure not lower than

10…12^{o}C. To provide such water temperature maintenance in winter within the specified range the thermal calculation was executed, and the basic parameters of the proposed technique were determined, and namely: number of holes, their diameter, and depth.

According to previous thermal calculations it was determined for Balka Mokraya Quarry in Donetsk Region [4] that for daily heating of 660 cu m of waters (the water quantity coming to the quarry from the water bearing layer during 24 hours) up to the temperature of 10^{o}C due to geothermal energy 24 geothermal holes shall be drilled with 200 mm diameter and 76 m depth. The latter need thermal insulation of 20 mm thick glass foam 25 m deep followed a by 4X13 steel casing installation with 20 mm wall thickness, and a coaxial plastic pipe of 50 mm diameter and 75 m length. The space between the casing and the rock mass between 25 and 75 m is to be filled with heat-conducting mix including up to 50% of graphite powder mass concentration [5].

In such case the daily water flow through the holes will be 396 cub m. The outlet water temperature equals to 12^{o}C. Mixing it with the rest volume of water would provide the quarry water temperature increase up to 10^{o}C.

Considering technical difficulties and high costs of water pumping to holes one should calculate the basic hydraulic parameters of the bio-plateau to provide its operation in gravity mode.

Problem statement. The aim of the work is to determine the basic hydraulic parameters of a geothermal heat exchanger on the ground of conditions discovery of gravity water passage through the tube system with target sizes.

Findings of investigation. To arrange the work of the bio-plateau in the gravity mode one should provide the velocity head on the input of the pipe system's annular clearance to allow negotiation of friction and form losses by water with its further going out of the inside pipe to the surface (Fig. 2).

The water velocity at the accepted flow rate of Q =0,001 m^3/s:

– in the annular channel:

$$V_1 = \frac{Q}{\frac{\pi}{4}\cdot(D^2 - d^2)}, \tag{1}$$

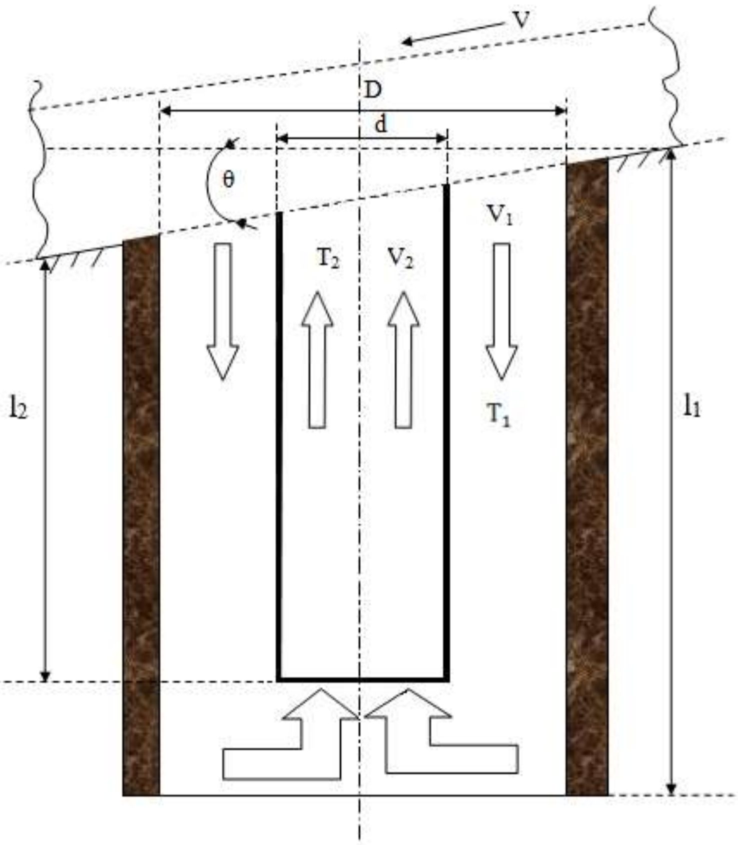
– in the inside pipe:

$$V_2 = \frac{4Q}{\pi d^2}, \tag{2}$$

Reynolds number, correspondingly:

$$\mathrm{Re}_1 = \frac{V_1(D-d)}{\nu_1}, \quad \mathrm{Re}_2 = \frac{V_2 d}{\nu_2}. \tag{3}$$

where *D* – diameter of the outside steel pipe, *D* =100 mm = 0.1 m; *d* – diameter of the inside pipe, *d* =50 mm = 0.05 m;



T₁, T₂ – corresponding temperatures of cold water, coming into the hole, and heated one going out of the hole; *V, V₁,V₂* – flow rates in the bed of the bio-plateau in the out- and inside pipes correspondingly; *D, d* – out- and inside pipes diameters; *l₁, l₂* – out- and inside pipes lengths, *Θ* – inclination of the bed of the bio-plateau

Figure 2 – The scheme of water flows in the geothermal heat exchanger

The water flow character and calculated dependencies selection is determined from Re value (when Re≤2320 is laminar, and Re<2320 is turbulent).

The total head losses include form losses, friction losses along the inside pipe as well as friction losses in the annular channel along the inside wall of the outside pipe and the outside wall of the inside pipe.

$$\Delta P = \sum_{i=1}^{n} h^{LR} + h_{1-2}^{FR} + h_{3-4}^{FR}, \tag{4}$$

where $\sum_{i=1}^{n} h^{LR}$ – the sum of form losses due to the flow turn at the inlet to and outlet from the heat exchanger, and the 180^{o} turn at the transition from the annular channel to the inside pipe; h_{1-2}^{FR} – friction losses along the annular channel; h_{3-4}^{FR} – friction losses along the inside pipe.

The friction losses of the flow along the annular channel include those along the inside wall of the annular channel, and along the outside wall of the inside pipe.

$$h_{1-2}^{FR} = h_S^{FR} + h_B^{FR}, \tag{5}$$

where h_B^{FR} – friction losses along the inside wall of the annular channel; h_S^{FR} – friction losses along the outside wall of the inside pipe.

The friction losses along the inside wall of the annular channel are calculated using Darcy-Weisbach formula [Bashta, T. M., 1982]:

$$h_B^{FR} = \lambda_{FR}^{(1)} \frac{l_1}{D} \frac{\rho_1 V_1^2}{2}, \tag{6}$$

where $l_1 = 76$ – the length of the annular channel (the hole depth), m; $\lambda_{FR}^{(1)}$ – friction coefficient.

The friction coefficient for the annular channel is determined by Altschul formula [Steinberg, M. O., 1992]:

$$\lambda_{FR}^{(1)} = 0{,}11\left(\frac{\Delta_{eq}^{(1)}}{D} + \frac{68}{\mathrm{Re}_1}\right)^{0.25}, \tag{7}$$

where $\Delta_{eq}^{(1)}$ – equivalent roughness of the annular channel, mm.

The friction losses along the outside wall of the inside pipe are determined using the formula:

$$h_S^{FR} = \lambda_{FR}^{2} \frac{l_2}{d} \frac{\rho_1 V_1^2}{2}, \tag{8}$$

where $\lambda_{FR}^{(2)}$ – friction coefficient for the inside pipe walls, m;

$$\lambda_{FR}^{(2)} = 0{,}11 \cdot \left(\frac{\Delta_{eq}^{(2)}}{d} + \frac{68}{\mathrm{Re}_2}\right)^{0{,}25}, \tag{9}$$

l_2 – the length of the inside pipe, $l_2 = 75$ m; $\Delta_{eq}^{(2)}$ – equivalent roughness of the inner tube surface, mm.

We assume that the equivalent roughness of the in- and outside walls' surface of the inside pipe is equal.

The friction losses along the inside pipe h_{3-4}^{FR} are determined by the formula:

$$h_{3-4}^{FR} = \lambda_{FR}^{2} \frac{l_2}{d} \frac{\rho_2 V_2^2}{2}, \tag{10}$$

The form losses are determined by Weisbach formula [Altschul, A. D., 1976]:

$$h^{LR} = \sum_{i=1}^{n} \xi_i^{LR} \frac{\rho V^2}{2}, \tag{11}$$

where ξ_i^{LR} – coefficient of the i-th form loss.

The form losses include as follows: the 180° flow turn, the inlet to and the outlet from the pipe.

On the ground of reference values [Steinberg, M. O., 1992]: ξ_{turn}= 3.6 (180° turn); ξ_{inlet}= 1.0 (inlet to the pipe); ξ_{outlet}= 1.0 (outlet from the pipe to the basin).

Physical parameters of water are accepted from reference values [Mikheev, M. A., 1977]:

– at T=T_1: density ρ_1, kg/m^3, kinematic viscosity ν_1, m^2/s;

– at T=T_2: correspondingly, ρ_2 and ν_2.

The mean water temperature in the annular space is accepted:

$$T = \frac{T_1 + T_2}{2}\ , \tag{12}$$

where T_1 и T_2 – corresponding temperatures of cold water coming into the hole, and heated one going out of the hole, C;

Calculation:

$$T = \frac{7+12}{2} = 9{,}5^{\circ} C$$

ρ_1 = 1000 kg/m^3; ν_1 = 1,33·10^{-6} m^{2}s.

At T_2 = 12°C: ρ_2 = 999,7 kg/m^3; ν_2 = 1,246·10$^{-6,}$ m^{2}s *c*.

$$V_1 = \frac{0{,}001}{\frac{3{,}14}{4}\cdot(0{,}1^2 - 0{,}05^2)} = 0{,}17 \text{ m/s;}$$

$$V_2 = \frac{4\cdot 0{,}001}{3{,}14\cdot 0{,}05^2} = 0{,}5 \text{ m/s}$$

$$\mathrm{Re}_1 = \frac{0{,}17\cdot(0{,}1 - 0{,}05)}{1{,}33\cdot 10^{-6}} = 6390 > 2300;$$

$$\mathrm{Re}_2 = \frac{0{,}5\cdot 0{,}05}{1{,}246\cdot 10^{-6}} = 20064 > 2300.$$

On the ground of reference values [Chugaev, R. R., 1975]: $\Delta_{eq}^{(1)}$ = 0,07, mm; $\Delta_{eq}^{(2)}$ = 0,0058, mm.

Calculation:

$$\lambda_{FR}^{(1)} = 0{,}11\cdot\left(\frac{0{,}07}{100} + \frac{68}{6390}\right)^{0{,}25} = 0{,}035$$

$$\lambda_{FR}^{(2)} = 0{,}11\cdot\left(\frac{0{,}0058}{50} + \frac{68}{20064}\right)^{0{,}25} = 0{,}027$$

$$h_B^{FR} = 0{,}035\cdot\frac{76}{0{,}1}\cdot\frac{1000\cdot 0{,}17^2}{2} = 384{,}37$$

$$h_S^{FR} = 0{,}027 \cdot \frac{75}{0{,}05} \cdot \frac{1000 \cdot 0{,}17^2}{2} = 585{,}23$$

$$h_{1-2}^{FR} = 384{,}37 + 585{,}23 = 969{,}6$$

$$h_{3-4}^{FR} = 0{,}027 \cdot \frac{75}{0{,}05} \cdot \frac{959{,}7 \cdot 0{,}5^2}{2} = 4858{,}48$$

As compared to other components the value of the head losses in the h_{3-4}^{FR} inside pipe is almost five times higher than the sum losses in the annular space.

$$h^{LR} = 3{,}6 \cdot \frac{1000 \cdot 0{,}17^2}{2} + 1 \cdot \frac{1000 \cdot 0{,}17^2}{2} + 1 \cdot \frac{959{,}7 \cdot 0{,}5^2}{2} = 186{,}43$$

$$\Delta P = 969{,}6 + 4858{,}48 + 186{,}43 = 6014{,}51 \ PA$$

Thus, the ΔP = 6014.51 Pa backwater is required at the inlet to the hole.

The flow rate at the inlet to the hole mouth shall equal to:

$$V = \sqrt{\frac{2 \cdot \Delta P}{\rho}} = \sqrt{\frac{2 \cdot 6014{,}51}{1000}} = 3{,}5 \text{ m/s.}$$

In accordance with Chézy equation:

$$V = C \cdot \sqrt{R \cdot i_p}, \qquad (13)$$

where C = $\sqrt{\frac{8g}{\lambda}}$ – Chézy coefficient; g = 9.81 m/s^2 – acceleration of gravity; λ – coefficient of the bed roughness, λ = 0.35 – for the channel of irregular profile contaminated with stones and water plants; i_p – piezometric bed inclination (quarry bottom), $i_p = sin\theta$; R – hydraulic radius, m.

$$R = \frac{W}{\lambda}, \qquad (14)$$

where W – water section of flow, m^2; λ – wetted perimeter, m.

The water section of the flow is determined using the formula:

$$W = B \cdot H, \qquad (15)$$

where B – river bed width, m; B = 10 m; H – bed depth, m; H = 1 m.

The wetted perimeter is determined using the formula:

$$\lambda = 2H + B, \qquad (16)$$

$$W = 10 \cdot 1 = 10 \text{ m} \qquad \lambda = 2 + 10 = 12 \text{ m}$$

$$R=\frac{10}{12}=0{,}83\ \text{m}$$

Calculation:

$$C=\sqrt{\frac{8\cdot 9{,}81}{0{,}35}}=14{,}97\ \text{m}^{0,5}\cdot\text{s}^{-1}$$

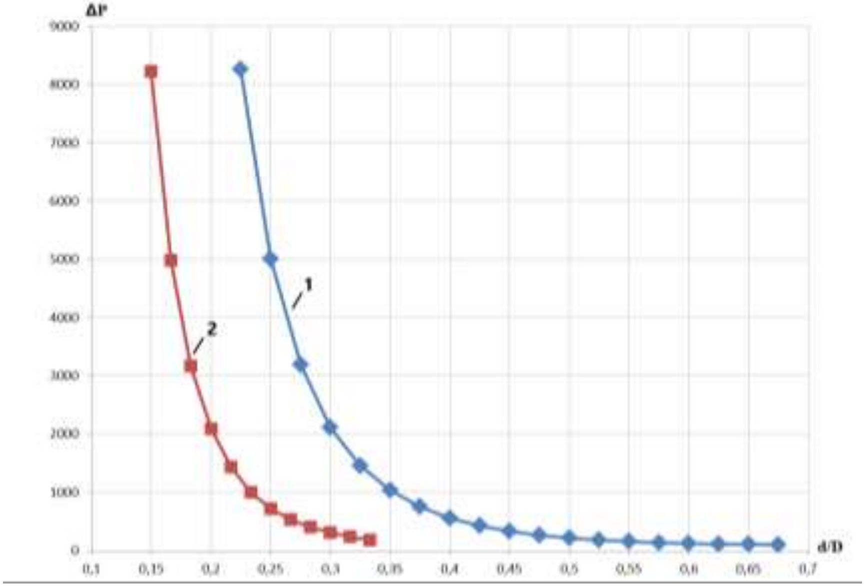
$$i_p=\frac{V^2}{C^2R}=\frac{3{,}5^2}{14{,}97^2\cdot 0{,}83}=0{,}065;$$

$$\theta=\arcsin(ip)=\arcsin 0{,}065=3{,}7°=4°$$

Thus, to provide water supply to the hole in gravity mode for Balka Mokraya Quarry conditions its bottom shall be designed with at least 4^{o} inclination.

The findings obtained are true exclusively for the target parameters of Balka Mokraya Quarry. In real conditions outside parameters of purification structures may differ including water consumption, pipes roughness, and bed's width and depth having influence upon the values of hydraulic resistances.

Due to the analysis it was determined that one of the main factors influencing the value of hydraulic resistance and, consequently, the angle of the quarry bottom inclination is the diameter of inside and outside pipe. So, it would be expedient to determine the ratio of pipes' diameters for minimal sum of hydraulic resistances. For that the assumption was accepted that the hydraulic resistance in the inside pipe should be approximately equal to the sum of hydraulic resistances in the annular space. The prevailing dimension is the hole diameter, so calculations were based on 200 and 300 mm diameters of the outside pipe. The corresponding results are represented in the Fig. 3.



ΔP – head losses, Pa; d/D – ratio of diameters of the in- and outside pipes;
1 – D = 200 mm, 2 – D = 300 mm

Figure 3 – Dynamics of head loss changes due to the diameters ratio of the in- and outside pipes

On the ground of the graph the conclusion could be made that the larger difference between the diameters of the inside and outside pipe the greater the sum of hydraulic resistances. So, to decrease hydraulic resistances within the geothermal hole with the 300 mm outside pipe diameter the diameter of the inside pipe shall be 0.25… 0.3 of the outside pipe diameter. The further growth of the d/D ratio cannot provide any substantial decrease of the head losses in the geothermal heat exchanger. For 200 mm outside pipe diameter the optimal diameter of the inside pipe shall be 0.35…0.4 of the outside pipe diameter.

Conclusion. Based on the calculations it was established that to provide water supply to the geothermal hole of the biological treatment structure in gravity mode the bottom of Balka Mokraya Quarry shall be constructed with at least 4^o inclination.

To reduce hydraulic resistances within the geothermal hole with the 300 mm outside pipe diameter the diameter of the inside pipe shall be 0.25…0.3 of the outside pipe diameter. When the diameter of the outside pipe is 200 mm the diameter of the inside pipe shall be 0.35…0.4 of the diameter of the outside pipe.

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Анотація. Видобуток корисних копалин відкритим способом неминуче супроводжується антропогенною трансформацією родючих земель, що утруднює їх практичне використовування. Ідея запропонованого способу полягає у створенні у виробленому просторі кар'єру очисної споруди – біоплато, в якому для очищення кар'єрних вод використовуватимуться вищі водні рослини, що через коріння, стебла і листя всмоктуватимуть мінеральні речовини з води. При цьому наростає коренева, підводна і поверхнева клітинна маса, яка в процесі подальшого відмирання і розкладання кліток утворює гумусну частину родючого шару. У зв'язку з технічними труднощами і великими витратами при організації подачі води до свердловини насосом, необхідно визначити основні гідравлічні параметри біоплато, які дозволять організувати його роботу у режимі самопливу. Мета роботи полягає у визначенні основних гідравлічних параметрів геотермального теплообмінника на основі розкриття умов самотечного проходження води через трубчасту систему заданих розмірів. Встановлено, що для організації подачі води до геотермальної свердловини біоочисної споруди у режимі самопливу, дно кар'єру «Балка Мокра» необхідно спорудити під кутом не менше 4°. Одним з основних параметрів, що істотно впливають на величину гідравлічних опорів, отже, і на кут нахилу дна кар'єру, є діаметри зовнішньої і внутрішньої труби. Чим більше різниця в їх діаметрах, тим сума гідравлічних опорів більше. Для зменшення гідравлічних опорів усередині геотермальної свердловини при діаметрі зовнішньої труби 300 мм діаметр внутрішньої труби повинен бути рівний 0,25…0,3 від діаметру зовнішньої. Подальше збільшення цього відношення не забезпечує істотного зниження втрат напору у геотермальному теплообміннику. Для зовнішньої труби діаметром 200 мм, оптимальний діаметр внутрішньої труби складатиме 0,35…0,4 від діаметру зовнішньої.

Ключові слова: вироблений простір, геотермальна енергія, геотермальний теплообмінник, вищі водні рослини.

Аннотация. Добыча полезных ископаемых открытым способом неизбежно сопровождается антропогенной трансформацией плодородных земель, затрудняющей их практическое использование. Идея предложенного способа заключается в создании в выработанном пространстве карьера очистного сооружения – биоплато, в котором для очистки карьерных вод, будут использоваться высшие водные растения, через корни, стебли и листья впитывающие минеральные вещества из воды. При этом нарастает корневая, подводная и поверхностная клеточная масса, которая в процессе дальнейшего отмирания и разложения клеток образует гумусовую часть плодородного слоя. В связи с техническими трудностями и большими затратами при организации подачи воды в скважину насосом необходимо определить основные гидравлические параметры биоплато, которые позволят организовать его работу в режиме самотека. Цель работы заключается в определении основных гидравлических параметров геотермального теплообменника на основе раскрытия условий самотечного прохождения воды через трубчатую систему заданных размеров. Установлено, что для организации подачи воды в геотермальную скважину биоочистного сооружения в режиме самотека дно карьера «Балка Мокрая» необходимо соорудить под углом не менее 4°. Одним из основных параметров, существенно влияющих на величину гидравлических сопротивлений, а значит - и на угол наклона дна карьера, являются диаметры внешней и внутренней трубы. Чем больше разница в диаметре внешней и внутренней трубы, тем сумма гидравлических сопротивлений больше. Для уменьшения гидравлических сопротивлений внутри геотермальной скважины при диаметре внешней трубы 300 мм диаметр внутренней трубы должен быть равен 0,25…0,3 от диаметра внешней. Дальнейшее увеличение этого отношения не обеспечивает существенного снижения потерь напора в геотермальном теплообменнике. Для внешней трубы диаметром 200 мм, оптимальный диаметр внутренней трубы составляет 0,35…0,4 от диаметра внешней.

Ключевые слова: выработанное пространство, геотермальная энергия, геотермальный теплообменник, высшие водные растения.

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