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АНАЛИЗ ЭФФЕКТИВНОСТИ ОЧИСТКИ ПОДЗЕМНЫХ ВОД ОТ ТЯЖЕЛЫХ МЕТАЛЛОВ

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Аннотация: Выполнены лабораторные исследования по определению рентабельного метода фильтрации подземных вод от тяжелых металлов в городе Москве. На первом этапе во время разработки котлована проводится осаждение большей части тяжелых металлов из подземных вод в грунте, который впоследствии вынимается из котлована, а оставшиеся тяжелые металлы в воде удаляются во время обработки для использования ее в питьевых целях. Также обсуждаются различные технологии повторного использования воды, включая механическую и сорбционную очистку, обратный осмос и очистку УФ-излучением. Эксперимент позволил сравнить эффективность использования теплового насоса и обратного осмоса для очистки воды. Система теплового насоса показала себя более эффективной при удалении металлов. Автором предложен модифицированный метод очистки воды для комплексного решения проблемы загрязнения грунта и подземных вод во время освоения подземного пространства, соответствующий стандартам, при котором система «вода–пар–вода» работает на возобновляемых источниках энергии. Оценена возможность использования предложенного метода при строительстве жилых комплексов и бизнес-центров с использованием солнечных батарей и легких вариантов ветрогенераторов. В целом эксперимент показал, что надежная система очистки воды может потребовать дополнительных затрат, и предварительный нагрев воды перед очисткой может снизить потребление энергии. Данный метод эффективно реализовывать в рамках комплексного способа по борьбе с загрязнением подземного пространства тяжелыми металлами. При разработке грунта можно будет изначально применять микроорганизмы для осаждения большей части металлов в грунте, который в дальнейшем будет использован для проведения фиторемидиации, а вода – для питьевых целей.

Ключевые слова: загрязнение подземного пространства, очистка от тяжелых металлов, комплексный метод совмещения строительства и экологии., фильтрация подземных вод, система «вода-пар-вода», обратный осмос, геоэкологический риск, возобновляемые источники энергии.

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Effectiveness of removing heavy metals from groundwater

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Abstract: The author is conducting laboratory studies to determine a cost-effective method for filtering groundwater from heavy metals in the city of Moscow, where in the first stage, during the development of a pit, most of the soil metals are precipitated, followed by excavation, and the remaining heavy metals will be purified during processing for use for drinking purposes. Various water reuse technologies are also discussed, including mechanical, sorption, reverse osmosis, and UV purification. The experiment allowed us to compare the effectiveness of using a heat pump and reverse osmosis for water purification. The heat pump system has proven to be effective in removing metals. The author proposed a modified method of water purification in a complex solution to soil and groundwater pollution during the development of underground space that meets the standards, where the "water-steam-water" system operated on renewable energy sources. The possibility of using the proposed method in the construction of residential complexes and business centers using solar panels and lightweight versions of wind generators has been assessed. Overall, the experiment showed that a reliable water purification system may require additional costs, and preheating the water before purification can reduce energy consumption. This method can be effectively implemented using a comprehensive method for combating the pollution of underground space with heavy metals, where the development of soil can initially use microorganisms to precipitate most of the metals in the soil, which will later be used for phytoremediation, and water – for drinking purposes.

Key words: pollution of underground space, removal of heavy metals, an integrated method of combining construction and ecology, groundwater filtration, water-steam-water system, reverse osmosis, geo-ecological risk, renewable energy sources.

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Introduction

Full-scale development of underground space requires expensive equipment, which, in turn, will prevent structural damage due to water-saturated soils. Cost-effective water purification is an annual challenge for the development of large cities. Since water pollution is growing intensively, conventional technologies are becoming outdated and cannot cope with increasingly hard and dirty water. Every year, many experts try to solve this problem by applying modern technologies and methods, but from the long-term perspective, they are unprofitable.

Every year, construction work is carried out in the city of Moscow, where new facilities are erected and old structures are reconstructed. When developing underground space at large city facilities, environmental monitoring of the environment was carried out. The work was carried out from the development of the pit to the construction of the foundation.

Monthly monitoring of soil and groundwater contamination revealed a high content of maximum permissible concentrations of heavy metals. After assessing groundwater pollution, it was decided to propose one of the options for combating pollution and subsequent water purification. As a result of processing statistical data, it was revealed that the metho. I proposed has a combined structure, where we initially precipitate most of the heavy metals in the ground for subsequent excavation from pits, and the groundwater will undergo additional filtration and will be used as drinking water.

Some scientists [1, 2] analyze an effective way to reuse wastewater. They believe that drinking water is obtained by reclaiming wastewater for portable reuse from contaminated sources. Another group of scientists [3] is considering various methods of water purification that are more effectively suitable for various megacities. Also, this problem is currently acute for the Republic of Tatarstan, where a study of the concentration of heavy metals in the region is being conducted. Based on the experiment, it was revealed that the "reverse osmosis" method is an inexpensive solution to the problem. In recent studies [4], the technology of saltwater purification based on membrane purification is being studied. Unlike their study, in our study, water purification by filtration is not intended to purify water from salt, but to extract heavy metals from water. A number of researchers [5] proposed filtering water from metaldehyde to convert it into drinking water. Experiments are being conducted to filter water for further drinking use. The study [6] is devoted to ultraviolet treatment for reverse osmosis, which at that time was considered an innovative method of water purification.

It is worth noting that the technologies are quite expensive. Cheaper and more efficient freezing and evaporation technologies have not found their application in our country. If we consider the freezing method, the experiments [7] have shown that this method is relevant only for the cold regions of our country and has not shown high efficiency.

But regarding evaporation. I can say that this method has a place to be, and it is worth introducing it as a pilot method for providing water to the Republic of Crimea and the city of Mariupol, water from the Azov and Black Seas can be used for evaporation. To understand how a modified method of water evaporation will fight the purification of water from a huge number of salts and harmful chemical elements, we will conduct our own experiment using water from several districts in the city of Moscow.

If we consider all of the above methods, they can only be used in a combined method. Thus, it is possible to carry out measures to protect the environment using only complementary methods, where the efficiency and economy of developing underground space for mass construction in the city of Moscow will not ignore environmental aspects.

In Moscow, redundancy in recent years, the development of the city has been aimed at transforming it into an efficient city, where transport routes in the form of subways, highways will be located underground [8, 9]. Thus, drinking water transportation from outside the city will be much more expensive [10]. Therefore, the best option for providing the city with drinking water consists of several stages of water treatment: analysis of the chemical composition of the well, selection of optimal types of filtrations, water treatment for city residents, and transportation [11, 12].

Materials & Methods

When developing underground space for water use, special attention must be paid to water treatment methods to ensure the safety and quality of the water. Some water purification methods that may be used in this context include:

1. Filtration: Using filters to remove particles, sediment and solids from water.
2. Disinfection: The use of disinfection methods such as ultraviolet treatment, chlorination or the use of ozonizers to eliminate germs and bacteria from water.
3. Osmosis: The use of reverse osmosis to remove microorganisms, viruses, salts, minerals and other contaminants from water.

4. Distillation: Using the distillation method to remove various contaminants such as salts, heavy metals and organic compounds by evaporation and then collecting clean water.

5. Flavofiltration: This is a method that combines filtration and biological treatment processes using plant filters to remove contaminants from water.

These methods can be used in combination or individually, depending on the characteristics of the underground water source, the level of contamination and the requirements for water purity. When using any underground water treatment method, it is also important to monitor water quality to ensure it meets safety standards. Thus, after the disinfection stage, we move on to filtration.

There are several technologies used to reuse water, depending on how pure it needs to be and for what it will be used.

The entire water purification system can be reduced to several purification methods:

- Mechanical [3];
- Sorption [13, 14];
- Reverse osmosis [15, 16];
- UV cleaning.

For the laboratory experiment, we chose two cleaning methods:

1. Using a heat pump.

In a reverse osmosis filter, water is filtered through a very thin membrane that allows only molecules to pass through. The output is, in fact, distilled water, and the remaining solution containing impurities is washed down the drain [17].

Evaporators using heat pumps can significantly reduce energy costs.

At the same time, with the help of a heat pump, the secondary steam is compressed to a certain pressure, which fully corresponds to the temperature of the primary steam and returns in the form of hot steam to a special device, mixing with the primary steam.

It is worth noting that heat pumps can be supplied with a turbocharger and with a steam jet injector. Installation which consists of an evaporator and an injector.

2. Using reverse osmosis.

Reverse osmosis is a process in which, under a certain pressure, a solvent (usually water) moves through a semi-permeable membrane from a more concentrated solution to a less concentrated solution, in the opposite direction of osmosis. In this case, the membrane passes the solvent, but not the solute.

Reverse osmosis has been used for water purification since the 1970s. Drinking water from sea water, ultra-pure water for medical, industrial, and other needs.

The author conducted an experiment in the laboratory LLC «Expert» which is in town Vidnoye, in Moscow region.

The laboratory has a reverse osmosis system with a new semi-permeable membrane.

The main advantages of a heat pump include low electricity consumption for home heating; no need for regular inspection and maintenance, which makes the cost of operating a heat pump for heating minimal; installation in any area is allowed. The pump can work with heat energy sources such as air, soil, and water. The disadvantage of this system is that to get a liter of clean water at the outlet, we need a stable pressure of at least 3 atmospheres.

1. Samples were taken both from the construction sites of the Expert company, in whic. I currently work, and from the rivers located near the company's facilities.

The first five samples from Nekrasovka (1 sample), Pechatniki (2), Kapotnya (3), Presnensky (4) and Sosensky (5), as well as from the rivers Skhodnya (6), Setun (7), Yauza (8), Pakhra (9) and Desna (10).

Tables No. 1 and No. 2 indicate the data of the first analysis, immediately before the experiment.

For the laboratory research we used the equipment: Milwaukee mw180 max laboratory tester instrument with a calibration date of 10/18/2022.

Table 1

Sample values taken at five sites

Выборочные значения, взятые на пяти объектах

Name	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Iron, mg/l	0.467	0.508	1.292	1.432	2.101
Manganese, mg/l	0.147	0.053	0.195	0.225	0.354
Copper, mg/l	0.0149	0.011	0.0205	0.0185	0.011
Zinc, mg/l	0.06	0.059	0.086	0.1	0.124
Lead, mg/l	0.005	0.0034	0.0124	0.0091	0.0126

Table 2

Sample values taken from nearby rivers

Выборочные значения, взятые из близлежащих рек

Name	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
Iron, mg/l	0.328	0.79	1.335	1.04	0.958
Manganese, mg/l	0.136	0.182	0.221	0.117	0.117
Copper, mg/l	0.0025	0.0075	0.0147	0.0304	0.014
Zinc, mg/l	0.011	0.01	0.056	0.085	0.093
Lead, mg/l	0.0017	0.0031	0.0051	0.006	0.0062

The Milwaukee MW180 MAX is a professional laboratory benchtop meter that can measure up to 6 different parameters: pH, ORP, EC, TDS, salinity (in PSU, g/l, NaCl percentage) and temperature. The main modes of operation are setup, calibration, measurement, and registration.

Advantages of this technology:

1. Easy to read Liquid Crystal Display.
2. Auto-off feature for extended battery life.
3. All measurements can be compensated automatically (ATC) or manually (MTC) with a user-selectable compensation factor.
4. Temperature compensation can be disabled (NO TC) if the actual conductivity value is required.
5. Autorunning feature for EC and TDS measurements automatically sets the most appropriate resolution for the test sample.
6. Available log space for up to one thousand entries. Logged data can be exported via USB.
7. Resolute General Public License key for storing and retrieving system state data.
8. Built-in rechargeable battery with 8 hours of battery life.

To verify the accuracy of the Milwaukee MW180 MAX Laboratory Tester instrument, we will compare data from our five river samples with generally accepted data (See Table 3).

1.Theoretical part.

The efficiency of wastewater treatment from certain pollutants is determined by the following formula:

$$E_{och} = \left(C_{ish} - C_{kon}\right) \cdot \frac{100}{C_{ish}} \qquad (1)$$

where E_{och} – cleaning efficiency, %; C_{ish} and C_{kon} – the content of water pollutants, respectively, before and after treatment. The limit values for the presence of hazardous impurities are strictly regulated by regulatory documents.

The current SanPiN2.1.4.1074-01 establishes the following Maximum Permis-

Table 3

Maximum allowable concentrations of metals

Предельно допустимые концентрации металлов

	Name of metals				
	Iron	**Manganese**	**Copper**	**Zinc**	**Lead**
MPC, mg/l	0.3*	0.05	1.0	5.0	0.03
* According to organoleptic characteristics, the limit of iron content in water is universally set at 0.3 mg/l (and according to EU standards — 0.2 mg/l).					

sible Concentrations (MPC) for heavy metals in water (mg/l) (Table 3).

It will also be necessary to conduct calculations for each sample for the first and second methods, respectively. All calculations were conducted using the with the help of a handbook on the thermal and physical properties of substances and materials depending on temperature and pressure (SanPiN 2.1.4.1074-01, 2021). All calculations were conducted using the source (Handbook ..., 2012—2023).

Calculation part for heat pump. At the first stage, we should calculate the heat balance equation of the installation to compare the initial and final volumes of water:

$$DH + WH_{v.p.sj} + G_H c_H t_H = \\ = G_K c_K t_K + WH_{v.p.} + \qquad (2) \\ + G_K \cdot 0{,}01 x_K \Delta q + (D + W) H_K + Q_p$$

where D — consumption of heating steam, kg/s; H — enthalpy of heating steam, kJ/kg; W — mass flow rate of evaporated water, kg/s; $H_{v.p.sj}$ — enthalpy of compressed secondary steam, J/kg; G_H, $G_к$ — mass flow rate of the initial (initial) solution and the final (one stripped off) solution, kg/s; c_H, c_K — specific heat capacity of the initial and one stripped off solution, J/kg·K; t_H, t_K — initial and final temperature of the solution, °C; $H_{v.p.}$ — enthalpy of secondary steam, J/kg; x_K — final concentration of the solution, % wt.; Δq — difference between the integral heat of dissolution of 1 kg of a solute in the initial and concentrated solutions, kJ/kg; H_K — enthalpy of the final solution, J/kg; Q_p — heat consumption to compensate for losses to the environment, W.

From the heat balance equation, the volume loss can be calculated, which will show us the initial loss and the profitability of using a given plant. Since the installation requires a huge amount of water, for stable operation, we had to use all 10 samples at the same time.

Water purification efficiency according to formula 1.1 (Table 4):

Table 4

The percentage of water purification in the first way

Процент очистки воды первым способом

	Initial concentration, kg/l	**Final concentration, kg/l**	**Heat consumption, J**	**Cleaning efficiency, Q**
Fe	12 800.75	7168.4	316 997	85.8
Mn	2580.5	1867.68		81.1
Cu	776.26	245.42		98.1
Zn	1039.9	447.71		91.2
Pb	343.72	219.97		92.1

Table 5

Difference decreases in concentration
Разница в уменьшении концентрации

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Iron, ΔK	2	2	5	5	7	2	3	5	4	4
Manganese, ΔK	1	1	1	1	1	1	1	1	1	1
Copper, ΔK	1	1	1	1	1	1	1	1	1	1
Zinc, ΔK	1	1	1	1	1	1	1	1	1	1
Lead, ΔK	1	1	1	1	1	1	1	1	1	1

The result of the first experiment is obtained. Now, to compare the efficiency, we present the calculations of the second experiment.

2.2 Calculation part for reverse osmosis.

The main goal of this experiment is to understand how much the concentration of heavy metals exceeds the normal values in each sample, using the formula:

$$K = \frac{x_K}{x_N}, \Delta K \qquad (3)$$

The values for each sample are in Table 5.

It follows that a decrease in concentration will follow the value of iron, since in all samples its value is above the norm.

$$\lg(1-\varphi_u) = a - b \cdot \lg\left(\frac{\Delta H_{Fe}}{Z_m}\right) \qquad (4)$$

where $Z_m = 1$.

From here,

$$\Delta H_{Fe} = \sqrt[3]{827 \cdot 562 \cdot 562} = 640\text{, kJ/mol} \qquad (5)$$

We calculate the true selectivity for the MGA-100 membrane using formula 2.2.2: $\varphi_u = 0{,}993$, according to the technical data sheet, follows:

$$|\lg(1-0{,}993)| = 2{,}16. \qquad (6)$$

Assuming in the first approximation that the observed selectivity is equal to the true one, we determine the average con-

Table 6

The percentage of water purification in the second way
Процент очистки воды вторым способом

Name	x_2, kg metal / kg water	L_φ, kg/s	θ, %
Sample 1	0.0047	2.4	75
Sample 2	0.0052	2.4	76.5
Sample 3	0.0129	3.07	95.9
Sample 4	0.0143	3.07	95.9
Sample 5	0.021	3.13	97.8
Sample 6	0.0033	2.4	75
Sample 7	0.0079	2.84	88.8
Sample 8	0.0134	3.07	95.9
Sample 9	0.0104	3	93.8
Sample 10	0.0096	3	93.8

centration of the dissolved substance in the sample (Table 6):

Results

When comparing the percentage ratio between the two purification methods, we determined that water is purified much more efficiently using a heat pump according to the "water-steam-water" system, where it is not necessary to increase the concentration for each water to obtain more purified water from heavy metals.

The solution to this problem is possible only if there is a system complex for water filtration, which will be observed by all standards and contribute to the prevention of geoecological risk.

It is with this that an in-depth study of the issue and conducting an experiment are connected, since my research is to prove a solution to the global problem of urban pollution and the possibility of an integrated solution, where water filtration using a heat pump has allowed for a more efficient use of natural energy, where after sedimentation of most soil metals, the second half was purified as a result of processing using this installation.

According to the results of a laboratory study, it was found that water purification using a heat pump system is more efficient if it is fully equipped with electricity, which will be generated from natural energy. The construction of hydroelectric power plants on the territory of Moscow is impossible due to the huge congestion of land space, and in the case of the construction of new dams, flooding of land, including residential complexes. Regarding solar panels, the issue is debatable since there will be about 100 days of sunny days a year for Moscow. This method will be cost-effective for sunny regions where drinking fresh water is required, such as the Krasnodar Territory, Donetsk Region, African countries, etc.

Following the foregoing, we are left with only the option of using electricity with the help of wind turbines. There is one "but" that interferes, these are huge, heavy, and noisy structures, which in their current form do not provide efficient use, but in the case of upgrading large wind turbines like their younger counterparts called "spider", it will be environmentally cost-effective to use this installation H.C. Karmaker [18]. It is necessary to consider such a technique for heating water, where it will be heated with the help of the bowels of the earth. The underground space will be developed in the future, in connection with this it will be possible to place special pipes for supplying water to the surface, directly under the transport infrastructure.

Conclusion

During this experiment, we found that efficient installations often require additional costs and conditions for stable operation. The suggested method is proved to be more efficient than other methods of water purification, requires a huge energy consumption, and has the disadvantage of wasting water in the form of steam, which, if the system is properly designed, can be used to heat houses, as is done in many developed countries. If water which flows through the pipes has been pre-heated, the consumption of power decrease. Water purification using magnetic tubes can be an effective method for removing certain heavy metals such as iron, copper, zinc, lead, etc [19]. However, the effectiveness of this method may be limited, since not all heavy metals can be effectively removed using magnetic fields.

Also, the efficiency of water purification depends on the power of the magnetic field used in magnetic pipes. Higher magnetic field strength may be needed to remove more toxic heavy metals [20].

When using metal-coated magnetic tubes, it must be considered that these tubes can become soiled and clogged with heavy metals. Therefore, double-sided pipes and overpasses can be important elements for the stable operation of a heavy metal water purification system. However, it is necessary to verify the effectiveness and safety of using such a system, as well as to carry out the necessary tests and tests to determine its performance.

In conclusion, the solution of almost every problem turns out to be economically unprofitable, but we are on the verge of the time when it is worth choosing a technology that is more complicated and more expensive than its counterparts, but at the same time it will win in a complex due to the structured work and interacting with other technologies.

This is the only way we can contribute to the prevention of geo-environmental risk, as well as continue to provide comfortable living for the population in large cities.

Every problem must be solved without harming the environment. Often, by choosing a cheaper construction option or methods to combat one pollution problem, another appears and in any case the ecosystem suffers. This study is intended to show how the issue of environmental pollution can be solved by combining with other measures to protect the environment. Thus, showing how during the construction of objects in Moscow it is possible to simultaneously improve the city's ecosystem.

The result of my research proves that this method has a novelty in the combined method. The water-steam-water heat pump system makes it possible to purify water for drinking purposes using mainly natural energy. The result of laboratory studies has proven that this method is more effective than reverse osmosis, which is often used in water purification.

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