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Master Thesis

“Parameters substantiation of the water treatment plant selection based on the reverse osmosis technology considering conditions given on PrJSC "DTEK Pavlogradvugillya" enterprise.”

“Parameter Begründung der Auswahl der Wasseraufbereitungsanlage auf der Grundlage der Umkehrosmosetechnologie unter Berücksichtigung der Bedingungen des Unternehmens AG "DTEK Pavlogradvugillya".”

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zur Erlangung des akademischen Grades

Master of Science (M. Sc.)

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РЕФЕРАТ

Структура і обсяг роботи. Робота складається із вступу, 3 розділів, висновків та переліку використаних літературних джерел із 47 найменувань, 10 таблиць, 29 рисунків, загальний обсяг – 85 сторінки.

Мета дослідження. Метою роботи є обґрунтування параметрів опріснюючої установки на базі технології зворотного осмосу.

Об'єкт дослідження – процеси демінералізації шахтних стічних вод.

Предмет дослідження - технологічні параметри демінералізації за допомогою зворотного осмосу.

Наукове значення роботи полягає в обґрунтуванні параметрів вибору технології опріснення високо мінералізованих стічних вод методом зворотного осмосу на території шахтного комплексу або району скидання вод ним за умов нестачі водних ресурсів у регіоні.

Практичне значення роботи полягає в наступному**:**

- в розробці методики вибору потужностей опріснюючого обладнання в залежності від об'єму водозабору, її використанні при плануванні собівартості та капітальних інвестицій у промисловий опріснюючий комплекс;
- в розробці методики кількісної оцінки застосування промислових комплексів фільтрації стічної води відповідно до географічних, хімічних, економічних та геологічних параметрів в залежності від місцевого водного та промислового навантаження.

Ключові слова: Очисний комплекс, зворотній осмос, технологічні параметри, солонувата вода, стічні шахтні води, демінералізація, знесолення.

ABSTRACT

Parameters substantiation of the water treatment plant selection based on the reverse osmosis technology considering conditions given on PrJSC "DTEK Pavlogradvugillya" enterprise.

Parameter Begründung der Auswahl der Wasseraufbereitungsanlage auf der Grundlage der Umkehrosmosetechnologie unter Berücksichtigung der Bedingungen des Unternehmens AG "DTEK Pavlogradvugillya".

Structure and scope of work. The work consists of an introduction, 3 chapters, conclusions and a list of used literature sources with 47 titles, 10 tables, 29 figures, the total volume - 82 pages.

The aim of the study. The aim of the work is to substantiate the parameters of the desalination plant based on reverse osmosis technology.

The object of research is the processes of demineralization of mine wastewater.

The subject of research - technological parameters of demineralization by reverse osmosis.

The scientific significance of the work is to substantiate the parameters of the choice of desalination technology of highly mineralized wastewater by reverse osmosis on the territory of the mine complex or the area of water discharge in the conditions of lack of water resources in the region.

The practical significance of the work lays in following:

- in the development of methods for selecting the capacity of desalination equipment depending on the volume of water intake, its use in cost planning and capital investment in the industrial desalination complex;
- in the development of methods for quantitative assessment of the use of industrial wastewater filtration systems in accordance with geographical, chemical, economic and geological parameters depending on the local water and industrial load.

Keywords: Wastewater treatment plant, reverse osmosis, technological parameters, brackish water, mine wastewater, demineralization, desalination, coal mining

CONTENT

INTRODUCTION

Relevance of the topic. The coal industry of Ukraine, formerly a basic branch of the economy, has been on the line of a precipitous decline in production since 2014. The peak of the decline in coal production fell on 2013-2014, which was estimated to be 60% less in 2014 than a year earlier. The downward trend has been observed for almost the entire period of time from the beginning of hostilities on the territory of Ukraine until today. As of 2019, 31,210,000 tons of coal were mined in Ukraine, which is 5.7% less than the planned indicators [1] (Table 1)

Year	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Coal, Mt	83,7 ▼	64,9 ▼	39,7 ▼	40,9 ▲	34,9 ▼	33,3 ▼	31,2 ▼

Table 1 – Coal mined in Ukraine

The number of mines on the territory controlled by Ukraine decreased from 102 enterprises to 33, only 4 of which were profitable. The accompanying problems of the Ukrainian coal industry throughout the entire period of its development also remained: a large number of mines hazardous for methane – almost 90% of the mines [2], government debt to miners, low seam thickness (<1m on average), low wages, difficult geological and morphological conditions. All this forced to increase subsidies to the coal segment of the Ukrainian industry to cover the cost of coal.

However, next to socio-economic issues, the coal industry causes serious, critical, and in some places irreparable damage to the environment. Coal mining enterprises violate and change the landscape of the area, the balance of underground water horizons, which require a significant part of the land plots of the agrarian complex for the use of waste heaps and tailings [3].

Returning to the source of civilization and the primary resource of human existence – water, as the most important resource of surface and underground mining, it becomes obvious the importance of its rational and energy-efficient operation and understanding the problem of its use and preservation of its quality.

Dnipropetrovsk region is one of the busiest industrial regions of Ukraine, which leads to the intensive use of water resources, and, as a result, pollution and accumulation of large amounts of wastewater.

Water resources of the Donetsk region are formed due to the transit inflow of surface waters of the Seversky Donets River, local river runoff, which is formed within the region, sewage, mine and quarry water, as well as operational groundwater reserves [4]. Water supply of local natural river runoff in the region is 6 times less than the average in Ukraine. Water quality does not meet the requirements for drinking water.

In the ecologically burdened territory of Donbass, Western Donbass and Kryvbas due to the influence of mining operations of existing and closed mines, groundwater levels increased, water inflows decreased, land subsidence processes intensified, flooding processes spread in the fields of previously flooded coal mines, where upper horizons were mined and hydraulically bonded with mines that are closed.

In the Western Donbass, highly mineralized (3000-37600 mg/dm3) mine water caused significant pollution to groundwater and was pumped out by the mines of PrJSC Pavlogradugol. Accumulating in filter reservoirs, they continued to pollute aquifers in the Quaternary, Berek and Mezhigorsk deposits. The main pollutants are chlorides and sulphates. Groundwater mineralization in salinization zones reached 8500 mg/dm3. Salinity depth up to 28 m [5].

Underground waters of Ukraine satisfy only 25% of its needs, surface water – 75%, while for the countries of the European Union the use of groundwater can reach 90% of the total use of water resources. This is due to the fact that groundwater, in contrast to surface water, is characterized by the constancy of its quality and higher recoverability of aquifers.

In general, the gradual transition of Ukraine to the standards of the EU and other developed countries from year to year is changing the tendency to use, control and discharge pollutants into water bodies. The distribution of groundwater use in Ukraine, a country considered to be poorly supplied with water resources, will inevitably shift towards the use and increase in the extraction of groundwater sources.

Thus, the analysis and use of modern technologies for demineralization and desalination of wastewater for mining enterprises, especially those that are subject to conservation or closure, is an urgent socio-economic problem and a scientific task for the calculation and selection of appropriate equipment.

The idea. The idea of the work is to assess the possibility of using a still unused resource – water, from the sources of its greatest pollution, while simultaneously solving several pressing issues of a socio-economic nature.

Purpose of the study. The aim of the work is to substantiate the parameters of desalination plants based on reverse osmosis technology.

To achieve this goal in the work, it was decided to choose the following tasks:

- to investigate the state and quality of drainage of the mine complex and the place of accumulation of mine waste waters;
- to conduct a comparative assessment of the optimal parameters of desalination technologies for mine water in terms of the physical and chemical properties of water sources in the Western Donbass region;
- on the basis of the analysis performed, select an appropriate technology for desalination of mine water, determine the technological parameters of desalination plants and quantify its efficiency;
- to carry out an economic analysis of the introduction of desalination complexes.
- processes of demineralization of mine wastewater.

The object of research is the processes of demineralisation of mine wastewater.

The subject of research – technological parameters of demineralisation via reverse osmosis.

The practical significance of the results obtained:

- development of a methodology for selecting the capacity of desalination equipment, depending on the volume of water intake, its use in planning the cost and capital investments in the industrial desalination complex;

- in the development of a methodology for the quantitative assessment of the use of industrial wastewater filtration complexes in accordance with geographic, chemical, economic and geological parameters, depending on the local water and industrial load.

The scientific novelty lies in the use of the technology of purification of highly mineralized wastewater by the method of reverse osmosis on the territory of a mine complex or an area of water discharge in conditions of a lack of water resources in the region.

1. STUDY OF THE CONDITION AND QUALITY OF THE MINE DRAINAGE AND THE PLACE OF ACCUMULATION OF DISCHARGED MINE WATERS

1.1 Review of the situation of access to water resources on the territory of Ukraine

In the modern world based on the processes of globalization, it is almost impossible to find a single country with completely unique problems and challenges. The accumulation of experience allows speeding up the solution of many tasks and problems in a faster and more proven way. Thus, the countries of Central and Northern Europe already 50 years ago were responding to the challenges of the coal industry. Taking the UK as an example, which began to move away from underground coal mining in its territory since the 1970s, one can trace how the industry had whopping 1,191,000 employees down to 2,000 in 2015. The use of coal for power generation declined from 157 million tonnes in the 1970s to 18 million tonnes in 2016, of which 77% (14 million tonnes) are imports from Colombia, Russia and the United States [6].

All mines in European countries with geological conditions similar or the same as in the Ukrainian reality of the Donetsk basin have long been closed. The main reason for the closure of mines was the unprofitability of enterprises and the burden on the budget, as the environmental aspect was not a pressing topic even 30 years ago. The large-scale task, that the closure of a number of mining enterprises can bring with it, is the reintegration of entire cities and towns and the re-profiling of the working population. Also, mines, even without the development of mining operations, require constant investment, because the destruction of the aquifers by mine workings led to a large concentration of underground mine waters in the places of mining operations.

Natural resources are evolutionary. The nature and degree of use of the natural environment, as one of the conditions of production, is determined by the level of development of productive forces and production relations. If, for instance, a hundred years ago in the Donbass underground waters, which are at great depths, did not find any practical application, with the population growth, the high rates of industrialization, including the creation of water-intensive industries, mine water as a product of special water use , becomes a valuable and scarce resource. As a result, it becomes necessary to evaluate it as an additional natural resource, which has a value form [3].

The problem of the availability of drinking water has been brewing for more than a decade. During the dry period in Ukraine, about 52.4 km^3/year of runoff is formed. Provision of predicted drinking groundwater resources of the population of Ukraine by region is within 0,3-5,5 thousand m^3/year per person, and on average – 1,4 thousand m^3/year per person, for the population permanently residing in the country[1] [5,13]. The distribution of the predicted groundwater resources across the regions is uneven, which is due to the difference in geological-structural and physical-geographical conditions of different regions of Ukraine. The predominant part of the forecast resources is concentrated in the northern and western regions of Ukraine, the resources of the southern region are limited. The distribution of the specific supply of water resources in the regions of Ukraine are given in table 1.2.

According to the UN Economic Commission for Europe, a country whose water resources do not exceed 1,7 thousand m^3/year is considered to be poorly supplied with water. So, in Canada, for instance, this value is 94.3, in Russia – 31.0, Sweden – 19.7, USA – 7.4, Belarus – 5.7, France – 3.4, England – 2.5, Germany – 1.9, Poland – 1.6 thousand m3/year [7].

Special attention should be paid to the volume and proportion of water use from surface natural sources to underground ones, whereas in European countries 75% of the population rely on underground sources as the main source of drinking water [8]. At the same time, the ratio of surface water use to groundwater was 64% from rivers and 24% from groundwater in 2017 [9]. For Ukraine, the ratio of meeting the gross demand for water from surface sources and underground sources, one might say, significantly differs from European ones. There is a tendency to use more accessible and cheaper sources – 85% of all needs were met by surface water bodies,

[1] According to the alternative census for the current population as of December 1, 2019.

while underground – only 10% (2.68% of which were discharged without use, that is, after being taken from mine water). The data on water consumption are given in table 1.1.

Indicator	***2017y***	***2018y***	***+/- 2017***
Provision of gross demand for water in percentage on account of:		%	
- intake of fresh water from surface sources	80,84	84,45	+3,61
- water abstraction from underground sources	12,77	10,31	-2,46
- *including the intake of mine water*	*3,42*	*2,68*	*-0,74*
- seawater abstraction	6,17	5,08	-1,09

Table 1.1 – The use of water in Ukraine according to the data of the State Agency of Water Resources

Part of the extracted groundwaters is pumped out from the subsoils (mainly from mine workings during the extraction of minerals), and is discharged without use. This part of the total groundwater production in 2018 amounted to 485,446 thousand m^3/ day or 18,1%, and in 2017 – 537,186 thousand m^3/ day or 19.2%. The use of groundwater in Ukraine as a whole in 2017 amounted to 2 262 926 thousand m^3/ day. In 2018, it decreased to 2 190 742 thousand m^3/ day, or by 72,184 thousand m^3/ day (3.2%) [8].

It is important to note that groundwater is an excellent source of drinking water for rural and suburban areas. After all, laying a pipeline for tens of kilometres from the power source does not seem rational. Connecting towns and rural populations to local water resources is a key task of the state to provide the population with drinking water.

Unfortunately, today the population in only three regions was provided with 100% centralized water supply services - Kiev, Odessa, Kherson. The statistics of round-the-clock water supply have even more obvious signs of a shortage of water resources, for example, only 28% of the settlements of the Dnipropetrovsk region are provided with round-the-clock water supply, which is one of the worst indicators of all regions.

Region	Population as of 01.04.19, thousand people	Underground operational reserve	Average water year		Low water year	
			Total river	Total	Total river	Total
Ukraine	42078,5	0,136	4,98	5,160	3,60	3,740
Vinnytska	1555,7	0,030	7,03	7,060	3,83	3,860
Volinska	1034,3	0,121	3,91	4,031	1,84	1,961
Dnipropetrovska	3198,3	0,079	16,57	16,649	10,16	10,239
Donetsk	4157,2	0,093	1,05	1,143	0,41	0,503
Zhytomyrska	1217,0	0,062	3,05	3,112	1,05	1,112
Zakarpatska	1255,6	0,098	10,59	10,688	5,80	5,898
Zaporizka	1701,2	0,067	31,16	31,227	19,45	19,517
Ivano-Frankivska	1371,1	0,072	6,85	6,922	3,48	3,552
Kyivska	4722,2	0,150	9,82	9,970	6,10	6,250
Kirovogradska	942,3	0,085	53,27	53,355	33,21	33,295
Luhanska	2148,1	0,304	2,36	2,664	0,93	1,234
Lvivska	2517,7	0,192	2,21	2,402	1,19	1,382
Mykolaivska	1127,8	0,025	3,55	3,575	1,51	1,535
Odesska	2378,8	0,052	57,31	57,352	43,21	43,262
Poltavska	1397,2	0,211	36,85	37,061	22,62	22,830
Rivnenska	1156,1	0,142	6,05	6,192	3,08	3,222
Sumska	1077,9	0,196	5,36	5,556	2,51	2,706
Ternopilska	1043,8	0,092	6,96	7,052	3,92	4,012
Kharkivska	2672,1	0,141	1,38	1,521	0,55	0,691
Kherson	1035,0	0,325	52,56	52,885	35,75	36,075
Khmelnitsk	1262,0	0,126	7,78	7,906	4,21	4,336
Cherkasy	1202,5	0,089	39,43	39,519	24,20	24,289
Chernivetska	903,2	0,069	11,18	11,249	6,20	6,269
Chernigivska	1001,9	0,187	29,51	29,697	19,37	19,557

Table 1.2 – Specific provision of water resources in the regions of Ukraine, thousand m3/year per person [10]

1.2 State of water resources in the Western Donbass

First of all, it is important to decide what exactly is included in the territorial concept of "Western Donbass" in order to pay maximum attention to specific settlements, cities and mining coal enterprises.

Western Donbass represents a new coal region (the earliest of the currently operating mines was put into operation in 1964, the last in 1982). The Western Donbass region differs significantly in its mining, technical, morphological and geological parameters from other mine fields in Ukraine. The depth of development in almost all mines in Western Donbass does not exceed 400 m, while in most old mines near the Donbass regions it ranges from 600 to 1200 m. The mines are hazardous in terms of methane content [11].

Western Donbass covers an area of about 12,500 km^2, up to 250 km long and 40-50 km wide. Among total industrial reserves of more than 985 million tons, 535 million tons lie beneath the floodplain of the Samara River, its tributaries and settlements. Currently, 10 mines are in operation, the designed capacity of which is 18,6 million tons; for 2019 production amounted to 17,970,000 tons of coal. Coal extraction is carried out along a pillar system with a roof landing, leading to subsidence of the earth's surface, which reaches 90% of the total thickness of coal seams, and is removed from 3 to 6,4 m and causes flooding of lands. As of the end of 2019, the mines of the Pavlograd group have undermined more than 4,000 hectares, of which 2,700 hectares are in the floodplain, 2,100 hectares have been reclaimed.

The fields of all mines are located in the near-edge part of the southeastern wing of the Dnieper-Donetsk deep. The geological structure is composited from deposits of the Lower Carboniferous (series C_1^2, C_1^3, C_1^4), covered by a cover of Paleogene-Neogene and Quaternary deposits. The Samara Formation, C_1^3, is coal-bearing, located between the $C_1 - D_1$ limestones. The coal-bearing strata is characterized by a small cyclicity in sedimentation with a wide development of bog formations in the form of coal seams and layers. The strike of the Lower Carboniferous rocks is southeast, the dip is north and northeast at an angle of 2-5 °.

The fields of the Western-Donbasskaya, Dneprovskaya and Ternovskaya mines are classified as closed-type deposits. The depth of the coal seams reaches 600 m (min. “Dneprovskaya”). Coal seams within the mine fields “Samarskaya”, “N.I. Stashkova”, “Blagodatnaya” in the southern part come to the surface of the Carboniferous under the Paleogene-Neogene deposits. The depth of coal seams does not exceed 400 m (“Blagodatnaya” mine) [12].

Given the fact that large enterprises are city-forming, it would be advisable to classify settlements near the mines as those whose existence depends on the profitability and sustainability of the enterprise. So, the following settlements of the Dnepropetrovsk region were allocated for consideration in the context of water supply and water supply. Pavlograd, Ternovka, Bogdanovka and town Pershotravensk.

Today, there are about 9 coal mines in the mining part of Western Donbass. To discharge mine water and maintain the balance of mine runoff, 7 water intakes, 4 storage ponds and one tailing dump are used.

Coal mining in this area is the main type of large-scale industrial activity. It combined with itself not only close towns and urban-type settlements, but also the water resources of the entire region. The delivery of coal / rock mass to the surface is accompanied by large emissions of wastewater into ponds built on the territories of mine fields in the gullies of Kosminna, Taranov, Nikolina and Svidovok.

The volume of mine wastewater at a given time is determined by the amount of coal released to the surface. Thus, taking into account that 33,286 mil. tons of coal were mined in Ukraine in 2018, and the volume of mine waste water discharged without use amounted to 623,01 thousand m^3/day or 227,4 million m^3/year, it can be roughly stated that 1 ton of coal accounts for 6-8 m^3 of mine wastewater.

Mine water flow increases when such factors appear as a large amount of atmospheric precipitation, the location of rivers, water bodies, lakes in the immediate vicinity of the mine field, reservoirs. As the mine deepens, the amount of water inflow increases. Weighing the fact that mines in the Western Donbass region are relatively shallow (<400 m depth of development), the water inflow in them fluctuates around 1000 $m^3$of water h and sometimes reaches 1600 m^3/h. This volume of mine wastewater plays a direct role in contamination of adjacent aquifers and surface water bodies. On average, mine waters at PrJSC DTEK Pavlogradugol have a high mineralization in the range from 3000 up to 37600 mg/dm^3 in some cases [5]. Generally, the following assessment criteria are distinguished, according to which environmental stress is created:

- high mine mineralization (all mines – more than 1000 mg/dm^3, 60% of mines – up to 3000 mg/dm^3, 40% of mines – above 3000 mg/dm^3);
- high presence of suspended particles in mine waste water (90-105 mg/dm^3 before the settling tank and 40-45 mg/dm^3 after);
- the presence of bacteria is possible, which introduces an imbalance in the ecosystem of both flora and fauna;
- increased content of heavy metals by 1.5-15 times (iron, copper, nickel)

It is permissible natural mineralization of groundwater, but under certain conditions and chemical composition. It is divided into the following categories depending on the degree of its mineralization:

- table water (fresh water), mineral waters suitable for daily use without any indication, with a salt content of not more than 1000 mg/dm^3;
- slightly mineralized – 1000-2000 mg/dm^3 (referred to as medical application)
- medical-table water (brackish) – with salt content from 1000 to 10000 mg / dm3

The chemical composition and mineralization itself are formed on the basis of the mineralogical composition of mountain masses, the intensity of water inflow, the frequency of water exchange, climatic conditions and other anthropogenic factors. Due to diffusion, minerals of various salt deposits dissolve in water, saturating it with carbonates, alkali metal chlorides and sulphates. At a high saturation of iron ions in an aqueous solution, contact with oxygen from the air and/or bacteria, which has affinity for acidic environments, can significantly reduce the pH value to 4-2.1.

1.3 Analysis of the literature on solving the problem of using mine wastewater

The problem of the accumulation of a large amount of impurities, salts, heavy metals and mineral solutions in surface waters is apparent, therefore it is an extremely important issue for their further implementation and control. Discharges from the enterprises of the household and communal sector play grand role in the environmental impact, which accounted for 585.3 million cubic meters of contaminated wastewater. The largest were discharged in the Dnieper basin – 637,4 mil. m^3, the next indicator is the Azov basin – 145,2 mil. m^3.

The enterprises of the coal and mining industry in general discharged 227.4 million m^3 of mine and quarry waters into surface waters without preliminary purification from a significant concentration of impurities. The following toxic substances were discharged to surface water bodies in 2018: oil products – 239.3 tons, nitrates – 36.59 thousand tons, iron – 423.4 tons, etc. [7].

Scientific works are devoted to solving the problem of mine water in Ukraine of following authors: E.S. Matlak, Merkulova V.A., Mongaita I.L., Permyakova R.S., Krasavina A.P., Gorshkova V.A., Shpirt M.Ya., Matlak E.S., Tekinidi K.D., Nikoladze G.I. The following authors abroad were selected to extend the results of the study: Mattia Giagnorio, Francesco Ricceri, Alberto Tiraferri, Pamela Chavez-Crooker, Johanna Obrek-Contreras Obreque-Contreras, Danilo Pérez-Flores and Andrea Contreras-Vera.

First of all, it is worth highlighting the main methods on which the system of water purification, filtration and deprivation of harmful impurities is based. Each of the technologies has its own purpose for use and the requirement for the input solution and its mineralization. All methods of using energy for demineralization can be divided according to two criteria: with and without a change in the state of aggregation.

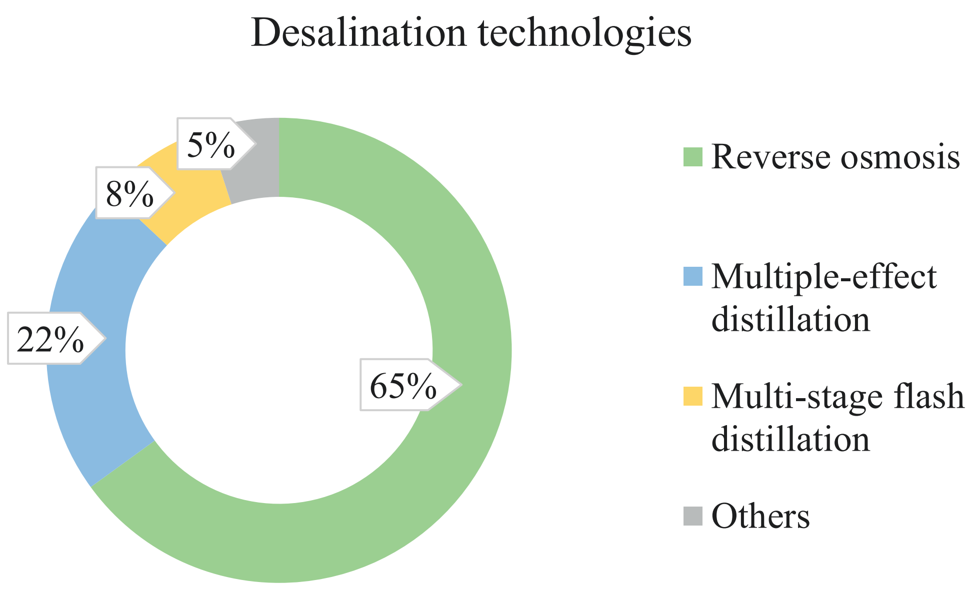


Fig 1.1 – Desalination technologies breakdown in relation to world capacities

Today, there are about 50 different technologies for demineralisation of salt water, thought 90% of all industrial methods are multi-stage distillation, reverse osmosis and multi-stage evaporation [13].

In terms of frequency of application in the world for desalting sea and brackish waters, demineralisation technologies are distributed as follows: reverse osmosis systems - 65% of the share of installed industrial desalination systems in the world, flash evaporators - 22%, multi-stage evaporation and thermal methods in general - 8%, others methods - 5% [14] The data are shown in Figure 1.1.

In the work E.S. Matlak, analysing the problems of mine waters and the prospects for their solution, emphasises the need for preliminary purification of the solution to bring it up to acceptable preconditions for stable performance of equipment. So, the level of suspended solids should not exceed 1,5 mg/dm^3, which in the realities of Western Donbass corresponds to 100 mg/dm^3 before settling basin and about 40 mg/dm^3 after, with a discharge standard of 22.5 mg/dm^3. This level of filtration is achieved by coagulation the suspension. It is also important to determine the purpose for which the water will be used, because there are strict requirements for drinking water.

Softening desalinated water can be carried out in two stages: 1) partial, using hydrated lime $CaCO_3$; 2) deep softening by ion exchange methods.

In a comparative analysis, the author was inclined towards the choice of the following desalination technology: the membrane method (electrodialysis and reverse osmosis), the ion exchange method and the distillation method. A graph is given in the cost price of using various technologies for the corresponding salt content. Based on Figure 1.2, it was concluded that the distillation method is the most stable in use, but effective only when the salt content exceeds the mark of 16000 mg/dm^3, as well as with a capacity of about 4000 m^3/h.

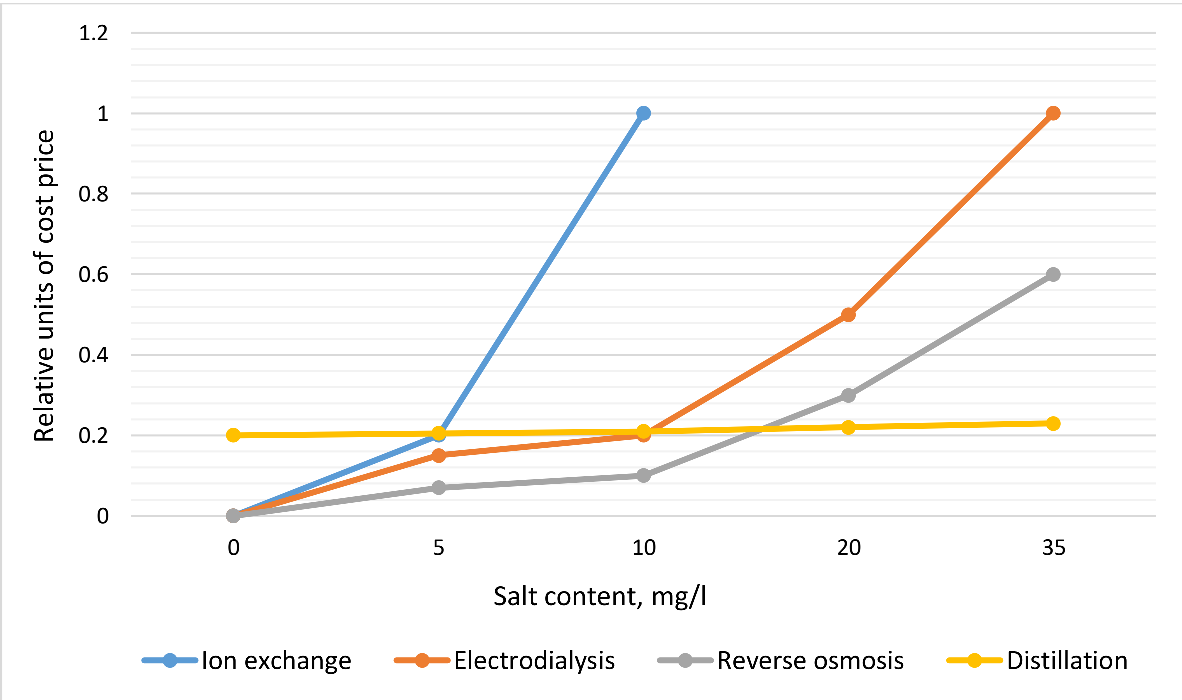


Fig. 1.2 – Diagram of the cost of mine water desalination using industrial technologies

Considering that the given conditions of Western Donbass are similar to the conditions given in the work of Matlak, the relatively insignificant volume of mine waste water predicted for use (400 m^3/h) and the relatively low salt content (4500 mg/dm^3 on average) does not make it possible to fully realize the potential of using the distillation method as the main one in desalination of waste water [15].

In general, the analysis of the comparative characteristics of desalting methods confidently confirms the hypothesis that in the range from 2000 ppm to 10000 ppm the osmotic method is preferred, namely the reverse osmosis method.

On the other hand, Italian scientists Mattia Gianyorio, Francesco Ricceri and Albert Tiraferri conducted a study on the use of systems based on a direct osmotic process to delimit slightly saline groundwater or wastewater from pure concentrate. For the experiment, ground waters with a content of dissolved particles of 4000 mg/dm^3 were used, while the sample of discharged waters consisted of secondary discharged waters. After the primary treatment of the solutions in a direct osmotic type unit, a recovery of >60% was achieved. Subsequently, the diluted feed solutions were nanofiltered to restore their original osmotic pressure.

As a conclusion, it was highlighted that a relatively low decrease in flux was observed in the experiments with both samples, while physical purification proved to be promising for the release of permeate associated with productivity loss. All the waters in the final product were of very high quality, suggesting the potential of this combined system for reuse and desalination. Some problems are associated with a relatively low water flow at the stage of direct osmosis, as well as with the loss of initial solutions and a gradual change in the composition of the initial development, therefore further analysis is required to establish the technical and economic feasibility of the system.

Analysing and summarizing the above works, we can conclude that direct osmosis systems are one of the most promising in the realities of Western Donbass, but they have not yet been sufficiently studied to be used to solve the problem of regulating the water flow at mining enterprises. So, to ensure project success and greater confidence in the result, a focus was chosen on systems, the experience of using which is no longer in doubt and can be designed for Ukrainian conditions.

1.4 Conclusions, purpose and objectives of the study

Based on the analysis, it was concluded:

1. The mines of the Western Donbass, and wider, mines in general, upsetting the balance of the hydrogeological system and the geological integrity of the rock mass, require continual pumping of mine water to the earth's surface. That negatively impacts, forming subsidence of the earth's surface.
2. Upon contact with disturbed rocks, the water flow dissolves and is saturated with rocks present in the mine field. Mine waste water, in contrast to ordinary groundwater, has a significantly higher salinity (from 1000 mg/dm^3 - 37600 mg/dm^3 in some cases), oil products and heavy metals are also saturated with contact mine groundwater.
3. The level of inflow of a mine depends on its depth, the amount of precipitation in the area of development of deposits (climate), the proximity of the location of surface water bodies, lakes, rivers, reservoirs, in the case of mines in the Western Donbass, mine "Stashkova" solely produces 1000 cubic meters of water on the surface per hour.
4. The planned closure of two mines "Stashkova" and "Blagodna", as well as the prospective closure of another 4-5 mine facilities give a bright signal to use the dying capacity of coal production in order to mothball the mine with a properly regulated and streamlined use of the water flow in accordance with the ecological and socio-economic plan.
5. There are many technologies for desalting and purifying an aqueous solution. To choose the necessary and appropriate one, it is necessary to clearly establish the goals and purpose of desalting aquatic products and the calculation volume of feed solution from the water intake facility. It is also essential to consider the existing technological processes in a complex, since the versatility of the technology is reflected in the cost of desalination.

Taking into account all of the above, the goal and objectives of the study were formulated.

Objective. The aim is to analyse and substantiate the parameters of the social, technological and economic feasibility of using water treatment plants at mining enterprises to ensure control and sustainability of water resources in the Western Donbass region, compensate for the lack of drinking water in the region and reduce the environmental load on surface and ground waters of the Dnieper basin.

To achieve the above goal, the work sets out the following tasks:

- to investigate the state and quality of drainage of the mine complex and the place of accumulation of mine waste waters;
- to carry out a comparative assessment of the optimal parameters of technological methods of clarification and water purification with the physical and chemical properties of water sources found in the Western Donbass region;
- on the basis of the analysis carried out, select the appropriate technology for desalination and demineralisation of mine brackish waters;
- make a calculation of the treatment complex in accordance with the selected technology, water intake, climatic and physicochemical conditions of the mine enterprises present on the territory of water discharge;
- to carry out studies of the economic and environmental impact of the use of the water desalination complex on the existing and planned for conservation mines.

The idea of the work is to assess the possibility of using a valuable natural resource for existence - water, from the sources of its greatest pollution, while simultaneously solving several pressing issues of a socio-economic nature.

2. COMPARATIVE CHARACTERISTICS OF DEMINERALIZATION TECHNOLOGIES OF MINE WASTEWATER

2.1 Productive flows of mining enterprises in the Western Donbas region

Laying a coal mine and commencing mining changes the surface and subsoil environment, which maintained an equilibrium at that moment. The development of mining operations is accompanied by an increasingly large-scale transformation of the natural environment, its deterioration; after a certain period of time, the environment will lose its ability to restore itself and to return to its original state, still it will tend to move to a new equilibrium state, different from the initial one. In this case, a conflict of interests may arise between the newly formed environmental balance, on the one hand, and human production activities on the other, a change in the states of which will lead to large expenditures of production resources to eliminate the negative consequences of environmental changes and mining operations.

Humanity throughout its history has been engaged in the transformation of nature and environment. Separated from nature and striving for knowledge of themselves, man began to transform (change) the environment to meet particular needs. Waiving to change the natural environment is tantamount to refusal of human development, and will inevitably lead to progress degradation. However, the process of change itself can be managed and controlled, or it can be chaotic and unpredictable. In the first case, the subject of management represents the desired result, assessing the costs of its achievements and the possible consequences of economic activity, minimizing the negative aspects of its impact on the environment and natural environment. In the second case, the subject of management is guided by considerations of obtaining the maximum effect in the shortest period of time, and the more distant consequences of the activity are ignored.

The particularity of the coal industry is that it does not produce its own products, but draws the finished product from the natural environment. As a result, the main and secondary productive components are delivered to the surface, including coal, rock, mine water, and methane. From the standpoint of the efficiency of coal mining, as well as rational resource and nature management, these components can also be factors that can have a negative impact on the environment. Possible approaches to the management of coal mine flows will be discussed below.

Let us consider coal as a basic motivating factor for exploration, planning and mining. It can be argued with caution that coal for the next few decades will still occupy a key position in the share of electricity generation due to its cheapness and availability. While developed countries are reducing the share of coal in electricity production, for emerging markets, this is a great opportunity to provide enterprises and the population with such a vital resource for development as cheap electricity. Today coal supplies about 40% of the world's electricity production. There are 10 countries that consume electricity produced from coal, accounting for 86% of the total use. China ranks first with 49.1%, the United States - 12%, India in the third place with 11.2%, followed by Russia, Japan, Germany, South Africa , South Korea, Indonesia and Poland [16].

The world is on the verge of a serious crisis due to a pandemic that will affect every country without exception. Prices for mineral and energy resources are constantly falling, leaving once large-scale enterprises out of the market, forcing them to declare bankruptcy one after another. The price of coal has been steadily declining since July 2018, allowing TECs to accumulate their coal reserves at low prices. To date, the price of thermal coal [17] is $ 66, which in hryvnia equivalent is ₴1787[2], while the cost of Ukrainian coal at government mines in June 2019 was ₴3966 [18]. The decline in industrial production over the global crisis has led to low demand for energy and industrial resources, increasing pressure on prices. An even greater drop in prices on world markets and a recession in the world economy are expected.

That is why the decisive condition for the survival of an enterprise in market relations is its technical level and technological mobility, which, if necessary (depending on the market), promptly and with the lowest costs, make the transition

[2] As of 23.04.2020. Exchange rate 1 USD = 27.0815 UAH

from goods that have exhausted themselves to new types of products, more progressive, in which an urgent need arose on the market. There is a need to develop a mechanism for diversifying the production capacities of mining and processing enterprises, an interest in reconstruction and re-profiling. In the new economic conditions, only economically independent complexes "extraction-processing-consumption" can function normally. They are able to ensure the production of competitive products (goods) of a wide range, carry out expanded reproduction at their own expense, independently form the production program and investments, have a stable market and modern methods of forecasting and management.

Therefore, the issue of diversification of the production nomenclature of a mining enterprise through the use and attraction of products to the economic field of activity is especially acute, which, first of all, are secondary to the main field of activity of the enterprise. They can be defined as building materials, accumulations of gas (methane), precious metals of the rare earth group, and water as the main focus of this work.

The tasks of controlling the flows of coal mines should be solved as follows:

- processing of slag waste in order to extract volatile and rare earth elements;
- creation of adjacent infrastructure for industrial (production of building materials) and agricultural enterprises (greenhouse complexes and processing)
- processing of mine water for the technological needs of a coal enterprise, and in the future to obtain drinking water. The main products are heat and electricity, ferroalloys (semi-finished product), construction materials, technical (drinking) water, agricultural products.

At the same time, failure to carry out the above-mentioned systems management measures can lead to the following consequences:

- flooding of settlements, waterlogging of lands, the appearance of "salt marshes", deterioration of forest soils;
- pollution of aquifers, as well as surface water bodies with mineralized mine waters (increase in mineralization, hardness, violation of acid-base balance); changes in the components of underground and surface runoff;

- the formation of a new technogenic relief (additional precipitation or uplift of the territory, activation of the deformation of the day surface, land reclamation, dismantling of waste dumps or their reclamation;
- release of mine gases on the day surface, which is accompanied by the formation of new migration routes of methane with the creation of unpredictable explosive underground areas and the occurrence of explosive situations when methane penetrates into buildings and structures; chemical and radioactive contamination of soils and territories;
- loss of significant areas of valuable agricultural land with their subsequent and irreversible deterioration and degradation.

Paying attention to each of the streams is worth separate work and a scientific approach to each, so that in this work the focus will be on the water resource, as key to human existence, important for ensuring the sustainability of agricultural development, industrial processes, even the existence of individual cities and towns.

2.2 General overview of water purification technologies

2.2.1 Thermal systems

Before a direct examination of existing systems for water purification, its demineralization and desalination, it is worth highlighting the basic concepts and terms to which attention will be repeatedly drawn. First of all, it is worth noting what is water desalination in general. [19] As defined by the American Heritage Scientific Dictionary: Desalination is the process of removing minerals from salt water. Water, depending on the degree of mineralization and the percentage of dissolved particles, is divided into the following four groups:

1) Fresh water - total mineralization up to 1000 mg/dm^3 (ppm);
2) brackish - mineralization from 1000-10000 mg/dm^3
3) saline - 10000-50000 mg/dm^3;
4) brine - more than 50,000 mg/dm^3.

Total water mineralization - the total content of minerals in water (dissolved ions, salts and colloids), which is usually expressed in the form of one of the following values: experimentally determined dry residue; the sum of ions; the amount of minerals; calculated dry residue.

Title	Mineralisation, g/dm^3	Application
Fresh water	<1	<0,5 – drinking ; <1 – irrigation
Brackish	1-10	Some industrial use
Saline	10-50	-
Brine	>50	Agent in food processing, chlorine production, refrigerating fluid, water softening and purification

Table 2.1 – Classification of degrees of water mineralisation [20]

According to publicly available data, in Ukraine, given the 42.5 million total population, 4,25 million do not have direct access to fresh water, and 22% of the total population live in low water, dry regions. Therefore, the rational use of groundwater and the discharge of wastewater should be controlled and subject to constant monitoring and verification. In order to improve the ecological state of the Ukrainian lands, provide people with high quality drinking water and remove the environmental load on river basins and underground water sources, it is necessary to start work with the commissioning of desalination plants.

In general, desalination technologies can be divided into three main groups: 1. Thermal (distillation, evaporation), which are based on the evaporation and condensation of an aqueous solution; 2. Membrane systems based on the application of pressure, separating the saline solution with dissolved minerals by overcoming (or initialising) the osmotic pressure 3. Systems are activated under the influence of chemical processes [14].

Thermal distillation and water desalination systems are proposed for initial consideration, as the most used method of purifying water to a drinking state. Distillation is one of the oldest methods of water purification and is still rather widespread in the world. Distillation method is the process of separating components or substances from a liquid solution by boiling and condensing. The result of distillation can be essentially complete separation, leaving an almost pure component, or partial separation, increasing the concentration of the selected substance in the mixture.

It is worth highlighting a single-stage distillation, as a separate part of the system, with the following sequence of action: the input solution is fed through a condenser water heater to the evaporator, where warm steam transfers part of the heat to the solution, which in turn is heated and evaporated. The formed secondary vapor enters the condenser, where it is cooled by the inlet solution and, giving off heat, turns into a distillate. At the same time, the water supplied to the installation is heated even at the first stage of supply.

Multi-effect distillation system (MED)

Multistage distillation methods are used for industrial processes and large-scale desalination of water. This method is due to the complex operation of simultaneously connected in series single-stage installations. Steam from the first condenser water heater is used as a thermal element for the next, heating each subsequent tank. As the number of stages increases, the installations become more economical, but the increase in the number of stages directly affects the surface area of the heating.

Saline feed/solution is sprayed onto hot tubes to improve evaporation efficiency. In order to avoid mixing the chemical from the boiler with the pure distillate, the distillate from the first heater goes back to the boiler. Brine is collected from the base of each stage, or moves on to the next. To increase the productivity of the installation, each stage occurs with a consistent decrease in pressure.

Thus, the maximum boiling point at low-temperature desalination complex can reach 55 ° C, which reduces corrosion and scale formation, as well as the use of low-potential waste heat [21]. Nevertheless, relatively hight operational costs hold this solution back from being advantageous, especially without waste heat available during the distillation process.

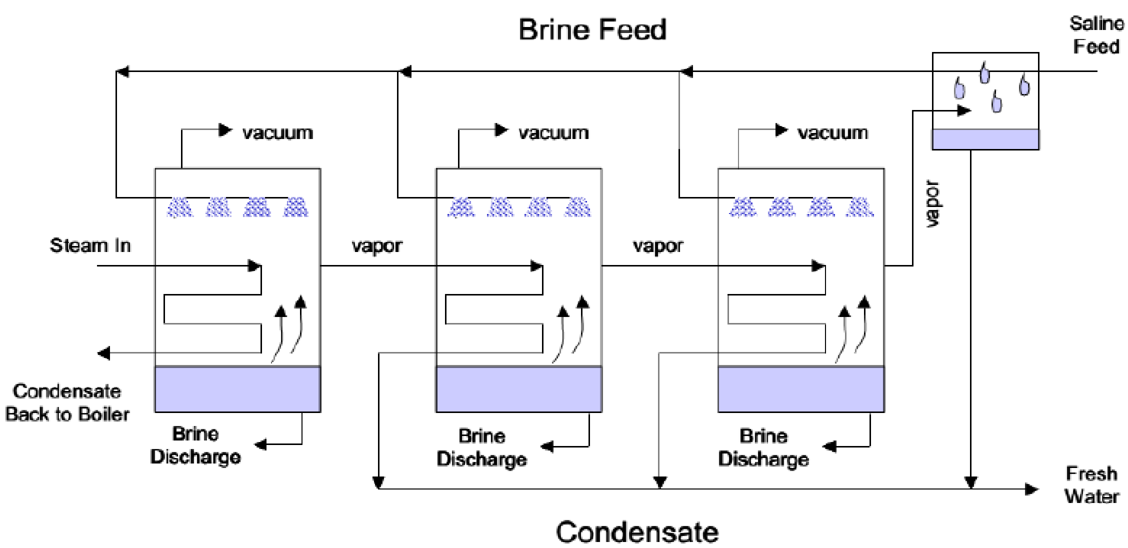


Fig. 2.1 – Schematic representation of multistage distillation

Multi-stage flash distillation

Another type of multi-stage distillation system is the so-called multi-stage flash (instantaneous) evaporation system, which accounts for the largest share of desalinated municipal water in the world and is also used in general for seawater demineralization.

Multi-stage flash distillation (MSF) (Fig. 2.2) are equipped with a system of stage cascades with different pressure levels. A heat exchanger and a condensate collector are installed at each stage [21]. At the final stage, the heated solution is fed to the high-pressure chamber, where the portion of water is instantly boiled due to the pressure drop. At each stage, as the brine enters, its temperature exceeds the boiling point due to the set lower pressure, and a small proportion of water in the brine boils ("flashes"), thereby lowering the temperature to equilibrium. The resulting steam is slightly hotter than the water supplied to the heat exchanger. The steam is cooled and condensed relative to the heat exchanger tubes, thus, heating the water supply as described previously.

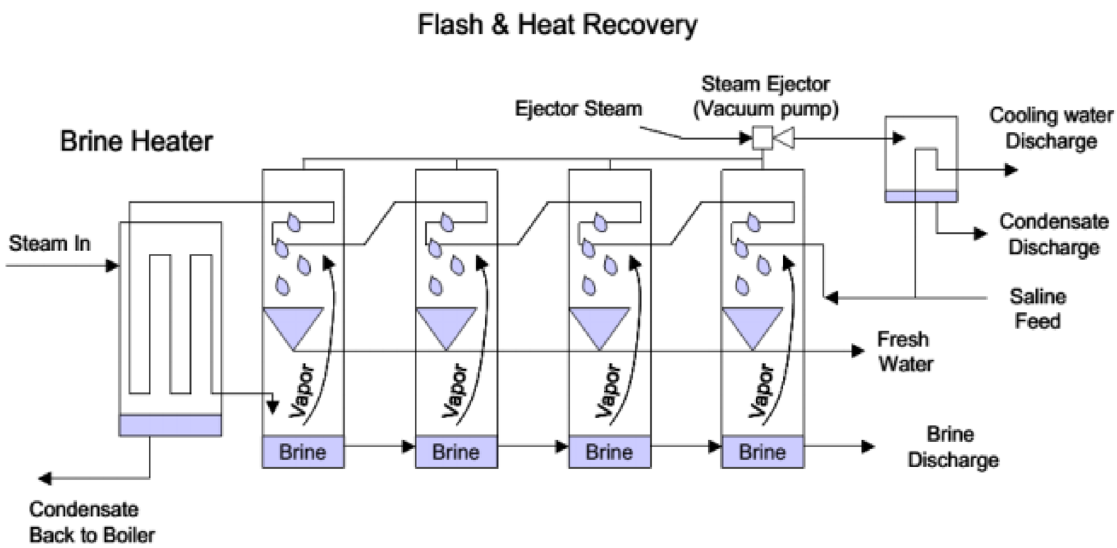


Fig. 2.2 – Schematic representation of the cycle of flash distillation units

When using multi-stage distillation methods, the volume of desalinated water obtained per unit of primary vapor is significantly increased, undoubtedly regarded as the main advantage of the method. For instance, about 1 ton of desalinated water per 1 ton of primary steam comes to one stage of evaporation, a 50-60 stage installation produces from 15-20 tons of purified water per 1-ton primary steam. However, it should be taken into account the specific use of heat and electricity for the production of one cubic meter of desalinated water. The data are shown in chart 2.1.

The weak side can be indicated as the formation of scale on the heating elements due to the high primary salinity of the solutions. Scale negatively affects the heat transfer and operation of the plant units over time. The measures against the formation of scale is the use of chemicals (special additives, inhibitors, etc.) and the methods of physical influence to prevent the formation of scale. Often, for complete protection against scale formation, a vacuum is used, the maintenance of which takes about 10 $kW*h/m^3$ of the finished product (desalinated water).

As a feature, the possibility of using waste heat can be distinguished, therefore it is rational to install such a treatment complex next to the power plant to use excess heat that remains for operational needs. The possibility of such a use can simultaneously act as both an advantage and an obstacle for the desalination station, as the absence of excess heat leads to an increase in the cost of desalting an aqueous solution and reduces the economic potential of the method.

Both desalination technologies are based on the physical property of a substance to pass from a liquid to a gaseous state – volatility, designated as *f*. At low temperatures and high pressures, the values of volatility and pressure can fluctuate greatly; therefore, the vaporisation property parameter γ is introduced, which is a function of the temperature T and pressure P of the thermodynamic system. These parameters are worth noting, because the volatility at different temperatures and pressures is the basis for the use of multistage desalination methods.

$$f = \gamma \cdot P$$

$$\lim_{P \to 0} f = P$$

Vapour compression (VC) distillation

Another method of distillation is based on the use of steam as the main source of system's heat transfer agent. The method of vapour compression is based on evaporation of the feed solution, compression of the formed steam and the use of compressed steam for further evaporation of additional water supplied to the unit. Steam compression can be achieved in two ways: 1) by a mechanical compressor, called distillation with mechanical steam compression [22] (Fig. 2.3); 2) steam ejector – thermal steam compression system. Mechanical compression systems generally do not exceed a capacity of 3000 m^3/day and have only one stage. Instead, thermal steam compression systems vary in size up to 20,000 m^3/day and have several stages in their cycle.

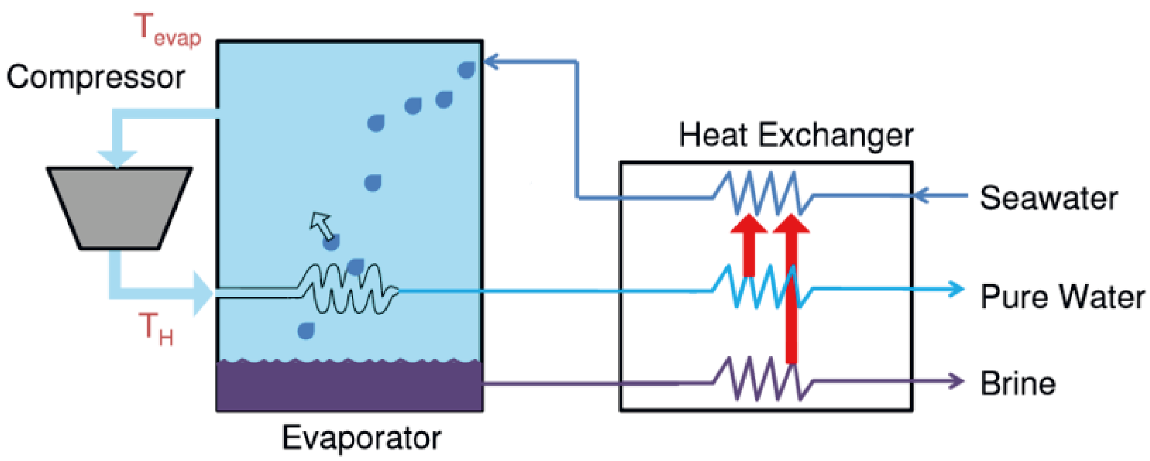


Fig. 2.3 – One-stage mechanical-compression distillation

The difference in the number of stages is due to the fact that the system with mechanical compression, regardless of the number of stages of purification, has a constant specific energy consumption, while thermal compression increases its efficiency with each subsequent stage. In practice, steam compression distillation is expedient for application in small and medium-sized enterprises. The strengths include reasonable capital costs, simple and reliable operation. However, the disadvantage of this method is the need to use large and expensive compressors.

Moreover, as with any distillation method, scaling and corrosion are serious challenges due to the fact that the components of the evaporator are directly exposed to the water supplied.

2.2.2 Membrane systems

Membrane technologies are used in many engineering approaches to transport and transfer a substance from one fraction to another using partially permeable membranes. The following desalination technologies can be referred to membrane systems, which are most often used in the industrial water treatment sector:

1) Reverse osmosis technology
2) Direct osmotic systems
3) Electrodialysis

Reverse osmosis

The use of reverse osmosis as a technology for water desalination is constantly increasing in its volume relative to other technologies due to the absence of a thermal component making reverse osmosis filtration energy efficient and economical. Based on the numbers, reverse osmosis already dominates the water treatment market and occupies 55% of the total market for desalination of water resources in 2019 [23].

Reverse osmosis technology is based on a membrane particle separation system that traps ions, unwanted molecules, and particles larger than a water molecule by overcoming the osmotic pressure of the liquid. So, the applied pressure in the solution is used to overcome the colligative properties of a liquid with a large number of solutes in it. The more dissolved substances in the solvent is, the higher the osmotic pressure and the lower the chemical potential of the system.

Therefore, the process of water purification in reverse osmosis systems uses high-power pumps, supplies a solution of water under pressure, exceeding the osmotic pressure through membranes, separating pure water from brine through a semi-permeable barrier due to the pressure difference in the feed solution and effluent. A schematic representation of the reverse osmosis process is illustrated in Fig. 2.4 [24]. For brackish water, the pressure on the feed solution is 15-25 bar, or for seawater 52-80 (osmotic pressure of seawater is 25 bar on average). In general, the use of reverse osmosis is the most appropriate, as long as the dry residue ranges from 100 to 10,000 mg/dm^3 [25].

Reverse osmosis systems have the following advantages: no use of thermal energy in the technological process as a result – low energy consumption compared to other methods. The membrane acts as a kind of conductor from the brackish solution to the purified water, at the same time, the membrane does not accumulate heavy mineral particles, but only distributes productive flows. The treatment complex is relatively compact and its operation is stable in terms of water composition. There is no urgent need for highly qualified personnel to service the equipment. The equipment can be automated as well. An important factor in reverse osmosis desalination is the absence of chemical impurities for the preparation and treatment of water, but a small number of reagents can be used as a precaution against salt deposition and partial cleaning of membranes.

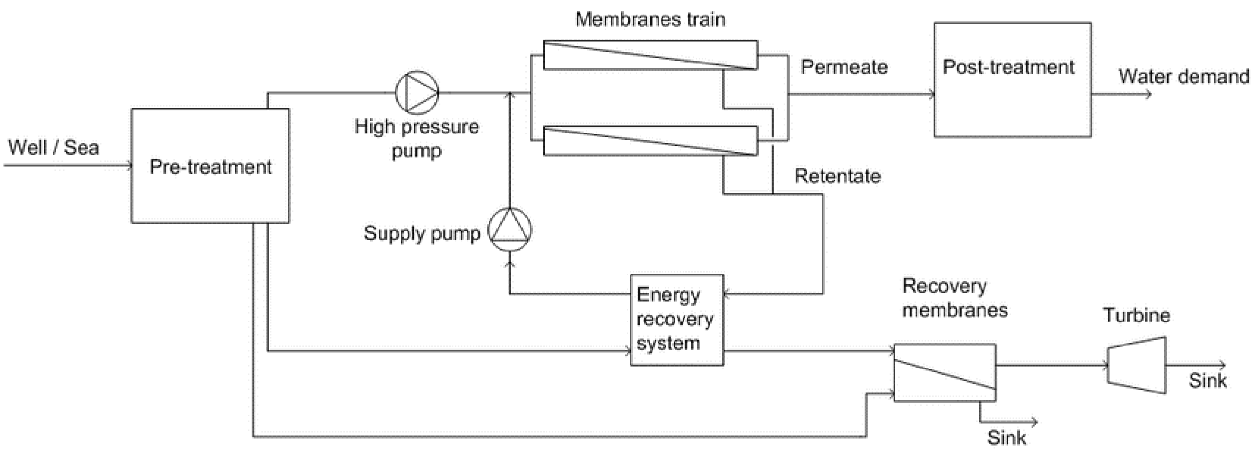


Fig. 2.4 – Schematic diagram of the complex based on reverse osmosis

The convenience of planning a complex based on reverse osmosis lies in the flexibility and possible expansion of production capacity by adding modules to the existing system. Part of the operating costs is the regular replacement of reverse osmosis membranes given that their service life is 2-5 years. To prolong the performance of the membranes, it is recommended to pre-purify the water from heavy impurities such as petroleum products, suspended particles (turbidity). Particularly sensitive indicators that directly affect the life cycle of the membrane are pH level, oxidants, a wide range of organic substances, and other pollutants. Therefore, pre-treatment plays a key role and should be considered as an important economic factor in reverse osmosis desalination systems.

Electrodialysis

The basis of electrodialysis is the process of ion exchange for the transfer of ions of salts of one solution through the ion exchange membrane to another, by the influence of the difference of electrostatic potentials forces. The electrodialysis process is shown in Figure 2.5. The solution is fed through the power channels. Cationic and anionic active membranes are located on both sides of the channels. Under the action of the difference of electrostatic potentials, negatively charged particles - ions (chlorides, phosphates) in the flow of solution migrate to the positively charged anode, passing through the positively charged anion-selective membrane. Such ions easily pass through the oppositely charged membrane, but are restrained by identically charged ones, so the separation of salt particles occurs in each individual membrane unit or membrane package. The membrane package consists of one cation exchange membrane, anion exchange membrane and two gaskets [21].

The use of electrodialysis does not require additional chemicals during direct desalination, and does not generate substances harmful to the surrounding element. At the same time, the use of water by electrodialysis requires careful pre-treatment of suspended particles and biological substances, iron and manganese compounds. The main disadvantage of this method is low efficiency, and the limits of use of the technology are reduced to the concentration of dry residue to several thousand milligrams, since the energy consumed directly depends on the concentration of mineral salts. For desalination of brackish water with a concentration of 3500-5500 mg/l specific electricity consumption increases several times and reaches several dozens of kW*g/m^3.

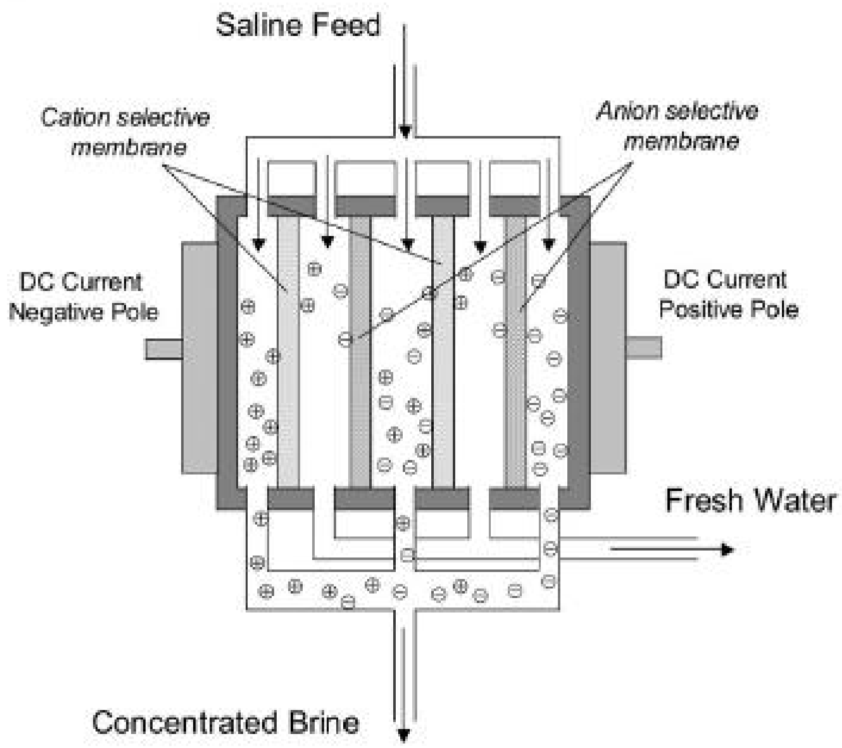


Fig. 2.5 – Schematic representation of distillation by electrodialysis technology

An important factor in the organization of the water purification complex on the basis of the method of electrodialysis is the protection of workers. At high concentrations of chloride is the release of chlorine into the atmosphere, which is toxic and destructive to oxygen saturation and iron oxides processes. Maintenance requires regular assembly and disassembly of electrodialysis discs for their chemical treatment of the accumulated substance. In addition, before commencing assembly of the unit, the material selection process for membranes and stacks should be considered thoroughly, in order to ensure alignment with the inlet solution.

Forward osmosis method

The forward osmotic system (i.e. FO), using partially permeable membranes, creates conditions for the transfer and transition of liquid from a solution of one concentration to a more saturated solution with less chemical potential. The difference from the reverse osmosis system is that the use the natural process of unilateral diffusion directly, while the purpose of reverse osmosis is to overcome the osmotic pressure and turn around the process of natural diffusion. The use of hydraulic pressure to overcome the osmotic pressure requires relatively high energy consumption compared to forward osmosis [26].

The technology of using FO is as follows: to create an osmotic pressure gradient, two types of solution are used - solution extract and inlet solution (feed), shown in Figure 2.7 [27]. The solution extract is a concentrate and essentially highly saturated and is used as one with a higher osmotic pressure to initiate the transition of water from a more saturated solution to the feed water, either brackish water or saline (marine).

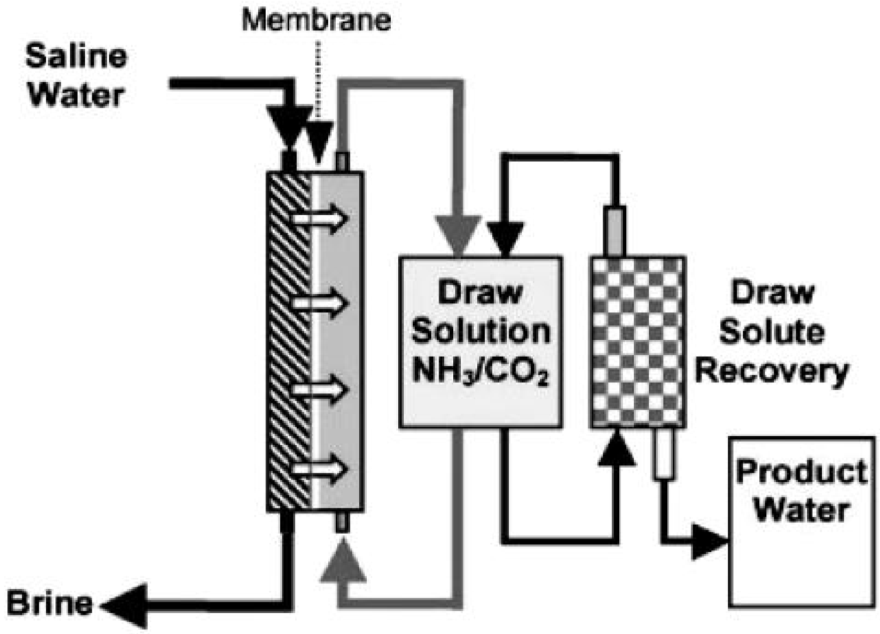


Fig. 2.7 – Schematic representation of the forward osmosis principle

However, in order to ensure the degree of permeate yield within> 60%, taking into account that the degree of permeate yield in reverse osmosis ~ 80-85%, as well as to achieve the level of drinking water quality, it is necessary to use direct osmosis system paired with other desalination methods – distillation or membrane filtration for secondary treatment of the solution.

The process of forward osmosis is characterized by relatively low potential for membrane contamination, reliability, ease of use and low power consumption. Due to the small practice of use and the lack of a sufficient theoretical array of data, it can be assumed that the process of direct osmosis is not yet ready for full industrial use, nevertheless can be used as a pilot project [28].

Membrane distillation

The process of membrane distillation is a kind of symbiosis of technologies in the use of the method of membrane purification, as well as changes in the state of water to remove unwanted substances and impurities in solution.

The technology of the process is that the two phases of the aqueous substance are separated by a hydrophobic membrane, which allows the penetration of free water molecules – steam, but does not let to pass the liquid state of water, with a higher density of molecules. The driving force of this method lies in the difference in temperature or concentration. If the temperature on one side of the membrane rises, then at the same time there is a difference in partial vapor pressures on different sides of the membrane, which occurs due to the temperature gradient. The steam will move in the direction where the pressure of the medium is lower.

The steam transition is divided into the following stages [29]:

1) On the side where the temperature was raised, liquids evaporate and steam is formed;

2) The temperature gradient leads to the movement of vapor molecules from a lower temperature to a larger one through the hydrophobic membrane;

3) Penetrating through the membrane, the vapor is subjected to pressure and temperature differences, due to which condensation of pure liquid occurs [30].

To date, the relevance of the use of membrane distillation is low, especially given the conditions of the Western Donbass, considering the main direction of the method application is the demineralization of sea salt water with a salt saturation of 20-40 g/l (20000-40000 ppm). It is important t bear in mind the low efficiency of the installation, not exceeding a few hundred cubic meters per day.

The use of membrane distillation requires significant thermal energy from 1 to 60 kW*h/m^3, reducing the selectivity of membranes in the presence of surfactants. It is rational to use waste heat to reduce energy consumption in order to fit in comparability to other methods. It would be possible to use this technology in conjunction with a power plant or implement a geothermal source, taking into account the experience of using heat pumps at the “Blagodatna” mine of PrJSC DTEK Pavlogradugol, which would reduce energy consumption but not solve the problem of low plant productivity.

2.3 Comparative characteristics of methods of desalination of brackish water

In order to choose a method that will have a successful economic application in the coal enterprises of Western Donbass, it is necessary to start from the primary indicators of mine water at the place of its intake, before and after settling tanks, to determine the location and volume of waste mine water. As noted, there are 11 mines in the Dnipropetrovsk region of the Western Donbas region, 2 of which are to close in 2020, and all five – by 2023. The list of such mines includes the mine “Stashkova”, “Blagodatna” and “Stepova”, “Samarska”and “Yuvileyna” mines.

Unfortunately, with the closure of mines, the problem of waste mine water does not become less relevant, on the contrary, becomes even more acute, as the pumping of mine water is a process that cannot be stopped and neglected. The disturbed balance of the groundwater system cannot be released and left one-on-one against itself, as close contact between the human field of interests and nature’s desire to restore the balance of the system may be incompatible with peaceful undisturbed life of the contiguous settlements with serious consequences for the region, such as flooding and salinization farmlands, soil subsidence, changes in surface water supply that violate the terrestrial ecosystem and more.

Let us consider the scheme of discharge of mine waters of the Western Donbass into water reservoirs (Fig. 2.8) [31]. To begin with, it is necessary to determine the input data on the state of the water complex used for the accumulation and discharge of mine wastewater on the surface. Table 2.2 shows the data on the mine discharge and the degree of mineralization.

The reservoirs of polluted saline waters are the impoundment that were built near the mine fields, namely the gully Kosmina, Taranova, Nikolina and Svidovok (Figure 2.8). Flooding and penetration of highly polluted highly mineralized waters are already observed in the adjacent territories of the agricultural complex and not only. All because of the lack of a primary protective layer (screen) on the walls of the ponds, which would ensure the content of discharged waters at the point of their discharge, and would also contribute to passive filtration of brackish waters [32].

Умовні позначення:

– ставок-накопичувач скидних шахтних вод; – діючі шахти; 1 – Героїв Космосу; 2 – Благодатна; 3 – Павлоградська; 4 – Західно-Донбаська; 5 – Тернівська; 6 – Дніпровська; 7 – ім. Сташкова; 8 – Самарська; 9 – Степова; 10 – Першотравнева (законсервована); 11 – Ювілейна; – центральна збагачувальна фабрика (ЦЗФ); – відбір річкових вод на зрошення; – скид шахтних вод з ставків-накопичувачів у річкову мережу; – скид шахтних вод у ставки.

Fig. 2.8 – Scheme of discharge of mine waters of the Western Donbass

Containment pond title; volume; discharge	Mines	Discharge water quantity, thou. M^3/day	Salt content, g/l
Gully Svidovok; 5000 thou. m^3; 13,56 mill. m^3/year	"Ternivska" "Blagodatna" "Heroiv Kosmosu" "Zahidno-Donbasska"	6,48-6,74 5,16-7,78 1,0 1,13-1,67	2,6-2,8 13,3-15.0 32,2-37,1 27,38-29,4
Gully Taranova; 2100 thou. m^3; 17,8 mill. m^3/year	"Samarska" "Dniprovska" "im. Stashkova"	6,5-26,6	3,8-7,5
Gully Nikolina; 425 thou. m^3; 2,8 mill. m^3/year	"Pavlogradska"	6,86-7,47	6,3-6,4
Gully Kosminna; 5300 thou. m^3; 19,8 mill. m^3/year	"Yubileyna" "Pershotravneva" "Stepova"	20,98-24,39 - 20,93-21,6	2,2-2,4 - 3,2-3,4

Table 2.2 – Characteristics of mine discharge and the degree of mineralization of wastewater [33]

From the table, it can be concluded that the general condition of wastewater entering the aquatic systems of surface sources is extremely unsatisfactory. In order to accurately distinguish the appropriate system, it is necessary to reduce the parameters of the application of the above-mentioned desalination systems into one table, which will help to make a comparative characteristic of water desalination systems.

The data are given for the use of desalination technologies in the conditions of supplying sea water and obtaining fresh drinking water at the outlet (if technology is applicable). A set of relative data on the strengths and weaknesses of using the main technologies in the process of desalination of saline and brackish waters is shown in Table 2.4.

Technology	Recovery ratio	Advantages	Disadvantages
Multi-effects distillation (MED)	0-65%	• Minimum pre-treatment of the feed solution • Reliability • Ease of use • Ability to use waste energy • Operates at low temperatures (<70 ° C) • Low specific energy consumption • Scale effect	• Energy-intensive process • Higher capital and operating costs • Necessary cooling and blending before drinking • The need for quality materials to prevent corrosion
Multi-stage flash distillation (MSF)	25-50%	• Prone to use at higher capacities • Proven reliability with a long service life • Possibility to use waste heat or power plant heat • Minimal need for pre-treatment • High quality output regardless of the mineralization of the feed water • Aspect of technology reduces scale	• Specially trained personnel with a high level of technical knowledge is required • Larger area is occupied • Grander capital investments • Maintenance requires the suspension of all industrial production • The need for quality materials to prevent corrosion

Table 2.4 breakover

Table 2.4 breakover

Electrodialysis	85-94%	• Relatively low energy consumption • Possibility of desalination of highly mineralized water • Does not use hydraulic pressure, which prevents the membrane from clogging • High degree of recovery • Longer service life of membranes (7-10 years) • Possibility of desalination of brine with salt concentration> 70.000 mg/l,	• The need for secondary processing due to the lack of disposal mechanisms of bacterial contaminants. • Energy consumption increases with increasing mineralization • Capital investment increases with decreasing salt concentration • Impossibility to work across the current density limit
Reverse osmosis	70-80% for brackish water (30-65% for saline water)	• Relatively low energy consumption • Relatively less investment • Modular design • Maintenance does not require shutdown the entire production • Complete removal of all components from the solution	• Appropriate technical knowledge of personnel is required for maintenance • Relatively high costs on membrane and chemical replacement • The tendency of membranes to be clogged with biological components • Service life of membranes is 5-7 years

Table 2.4 – Comparative characteristics of methods of desalination of saline water [34]

The main parameter of efficiency and rationality of use of one or another desalination method consists of specific and general consumption of the electric power on cubic meter of the finished product. Due to the fact that some methods are based on the conversion of electrical energy into thermal energy to ensure the technological process of distillation, the equivalent of electrical energy was presented for easier and precise comparison.

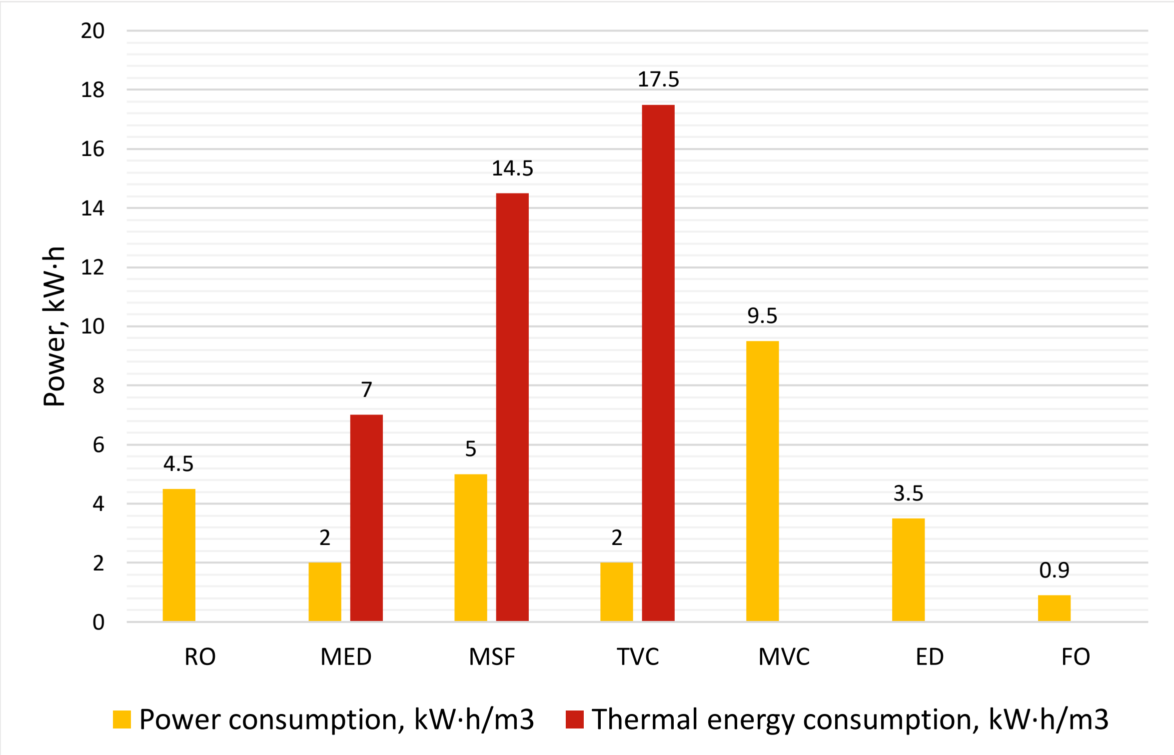


Fig. 2.9 – Graph of use of thermal and electricity for the production of 1 m3 of desalinated water

First of all, thermal energy is used in large quantities in technologies based on the transfer of fluid from one state to another. Such technologies seem to be successful in the presence of excessive/waste thermal energy (energy or steam from a power plant), geothermal or renewable energy (Figure 2.9, 2.10). However, in the conditions of the Western Donbass, taking into account the location and purpose of the desalination complex, the use of excess heat from the surrounding areas is not possible. This reduces thermal desalination systems to a very narrow range of uses, taking into account the fact that the vast majority of scientific work and practical experience indicates the rational use of distillation desalination methods to be for sea or highly mineralized water. Table 2.5 shows the typical size of the main methods of desalination: MED – multi-effect distillation system, TVC – thermal vapour compression, MVC – mechanical vapour compression distillation, MSF – multi-stage flash distillation, RO – reverse osmosis, ED – electrodialysis, NF – nanofiltration, I.Ex – ion-exchange desalination.

Title	**MED**	**TVC**	**MSF**	**MVC**	**RO**	**ED**
Typical unit size, m^3/d	5.000 - 15.000	10.000 - 35.000	50.000 - 70.000	100 -2500	24.000	<100-20000
Power consumption, $kW \cdot h/m^3$	1.5 - 2.5	1.5 - 2.5	4 - 6	7 - 12	3 - 5.5	6,73
Thermal energy consumption, kJ/kg	230 (GOR[3]=10) – 390 (GOR=6)	145 (GOR=16) – 390 (GOR=6)	190 (GOR=12) – 390 (GOR=6)	None	None	None
Electrical Equivalent for Thermal Energy, $kW \cdot h/m^3$	5 - 8,5	9,5 - 25,5	9,5 - 19,5	None	None	None
Total Equivalent Energy Consumption $kW \cdot h/m^3$	6,5 - 11	11 - 28	13,5 - 25,5	7 - 12	3 - 3.5 (Up to 7 with Boron treatment)	6,73 (Increase with salt concentration)

Table 2.5 – Power consumption by main desalination processes [35]

[3] GOR – Gain Output Ratio

Electrodialysis remains the main rival of reverse osmosis technology. When considering the electrodialysis system, it is important to determine the purpose of desalination, as electrodialysis alone is not capable of complete purification of water from mechanical impurities and bacteria. The task set in the qualification work is to bring the highly mineralized waters of the mine discharge complex to drinking quality with minimal secondary waste of industrial desalination.

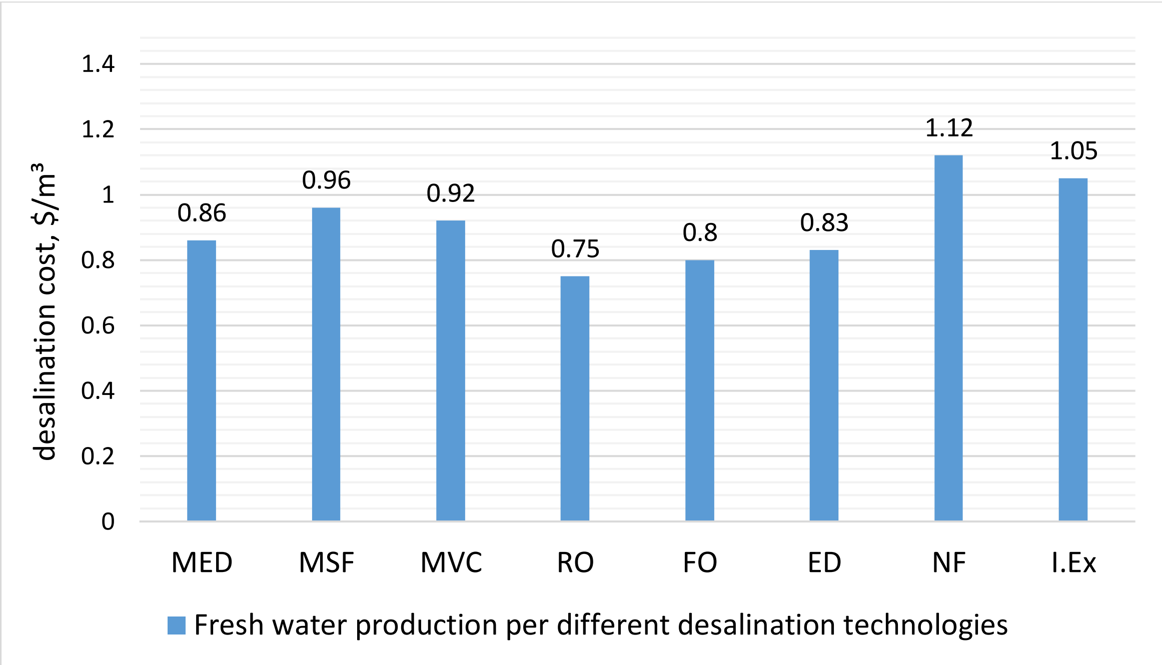


Fig. 2.10 – Fresh water production cost breakdown by desalination technologies

Electrodialysis is a quite good method in terms of electricity consumption and permeate yield, but studies indicate that it is advisable to use at low and medium capacities ranging from volumes <100 m^3/d to more than 20,000 m^3/d, as well as water salinity from 1000 to 5000 mg/l of dry residue [36]. However, given the starting bar of the plant of more than 24,000 m^3/day, the potential for expansion, further possible increase in production capacity, salt concentration, which can reach > 7-8 g/l of dry residue, complete purification of water from biological impurities through the smallest pores membranes (<0.001 m) electrodialysis is on the verge of its feasibility, requires greater investment, additional equipment in order to bring water to potable state, as well as the replacement of ion exchange membranes, which are often more expensive than membranes designed for osmotic pressure.

#	Controlled substance	Mine water prior to settler	Mine water after settler	Potable water standards
1	Aluminium, mg/l	-	<0,02	≤0,2
2	BOD_5, mgO_2/l	-	5,8	5,2
3	Hydrogen potential, pH	8,15	8,05	6,5-8,5
4	Hardness, ppm	28,25	27,44	≤7,0
5	Water colour index,	10,79	10,35	≤20
6	Iron, mg/l	0,64	0,63	≤0,2
7	Suspended particles, mg/l	99,8	41,4	≤0,001
8	Calcium, mg/l	287,10	279,01	No guidline
9	Cobalt, mg/l	-	<0,02	<0,1
10	Magnesium, mg/l	169,30	164,39	Not determined
11	Manganese, mg/l	-	0,11	Not determined
12	Copper, mg/l	-	< 0,002	≤1,0
13	Petrochemicals, mg/l	0,64	0,62	≤0,1
14	Nitrates, mg/l	<0,5	<0,5	<50,0
15	Polyphosphates, mg/l	-	0,07	≤3,5
16	Sulphates, mg/l	385,58	378,99	≤250
17	Dry residue, mg/l	6410,00	6272,67	≤1000
18	Temperature, t °C	13,3	13,0	Not determined
19	Free chlorine	-	-	≤0,5
20	Chlorides, mg/l	3384,08	3313,79	≤250
21	Zinc, mg/l	-	<0,005	≤1,0

Table 2.6 – The results of analytical control of mine water as for 07.03.2019

Based on the above conditions, reverse osmosis was chosen as a comprehensive desalination system that meets the required parameters and is a universal technology, with extensive global experience (60% of all desalination equipment uses reverse osmosis and only 6% - electrodialysis technology) in various conditions, especially in conditions similar to those in the Western Donbass.

The paper proposes to consider a practical example of discharge of water resources at the mine “Stashkova “, since the mine is the most flooded in the Western Donbass. The water inflow of the mine reaches 1600 m^3/h at certain intervals, in general the water inflow of the mine fluctuates within 1200 m^3/h, which is a huge amount of wastewater from only one mining facility. Waste mine waters were checked by the sanitary-preventive laboratory and are given in table 2.6 [47].

Three analytical controls of mine water were identified for the first, second and third quarters of 2019, respectively. The greatest pollution was observed during the first quarter, so it is advisable to choose data with the most difficult conditions, so that the reverse osmosis installation meets the demanding criteria of mineralized water.

Reverse osmosis, as a system quite sensitive to the chemical and physical state of the water resource, requires some primary treatment before it is directly fed to the unit. The main indicators to pay attention to for pre-treatment are given in table 2.7

Traditional methods of water pre-treatment are applied before the water is fed to the reverse osmosis unit. Purification occurs from the largest fraction to the smallest. Therefore, small and coarse grids with a size of 1-100 mm are pre-installed for shielding large particles.

The next technological step is coagulation and flocculation, which is due to the high content of suspended particles. In case a sufficiently small particle size were present in the solution, Brownian forces would overcome gravitational forces, which makes it impossible to use traditional settling to completely eliminate suspended particles. There are organic and inorganic coagulants. Inorganic coagulants such as aluminium and iron salts (Al2 (SO4) 3, Fe2 (SO4) 3, 2FeCl2) are used to neutralize suspended particles. The advantages of inorganic coagulants are lower cost per unit weight, wide availability on the market, and, when used properly, allows to effectively get rid of suspended particles [38]. When coagulants are combined with chlorides, a disinfectant by-product is formed, which removes some of the organic matter and compounds. However, inorganic coagulants require a high concentration of alkalinity and also require the necessary storage in corrosion-resistant structures and equipment.

Parameter	Baseline pre-treatment
Nephelometric Turbidity Units (NTU)	The level of suspended particles exceeding 0.1 mg/l will lead to rapid clogging of the membranes. At values >16 mg/l (> 50 NTU) coagulation and filtration are required
Langelier Saturation Index (LSI)	At high values> 4 primary treatment is necessary, as the index measures the susceptibility of the solution to the formation of sediment and scaling
Suspended particles (mg/l)	The parameter gives a quantitative description of the presence of suspended particles in the solution
Iron (mg/l)	The level of iron saturation is important for the preservation of the membrane. Therefore, for iron in reduced form (Fe (II)) the acceptable concentration is ≤ 2 mg/l, while more oxidized states > 0.05 mg/l can have a detrimental effect on productivity
Manganese (mg/l)	Divalent manganese Mn (II) ≤ 0.1 mg/l More oxidised manganese in a concentration of >0.02 ppm is harmful
Temperature	The effective temperature is> 12 ° C and <35 ° C. Lower temperatures lead to energy losses, because the density of the liquid increases. Temperatures above a certain limit intensify mineral deposition and scaling.
Oil products	Concentrations greater than 0.02 mg/l accelerate organic clogging of membranes
pH	The optimal acidity of the feed solution varies between pH> 4 and pH <11, prolonged exposure to solutions of other acidity can cause irreparable damage to the membranes.

Table 2.7 – Basic parameters of primary water treatment before feeding to desalination plant [37]

Polymers are considered as organic coagulants, they are effective in a wider range of acidity, do not neutralise the alkalinity of the solution and can be used in smaller doses. Organic polymers produce a smaller volume of a more concentrated mixture of flocculated sludge. The disadvantage is the price, several times higher than inorganic salts.

The selection of the required flocculant must be carried out by trial method in a measuring cylinder while simulating the conditions of the desalination station, and subsequently by testing on a pilot plant project. Taking into account the fact that the next technological process is the softening of water, which causes the pH value to rise to the mark of 10-11, it will be rational to use inorganic metal salts of iron and aluminium.

The process of water softening is based on the principle of chemical catalysis of precipitation of cations of calcium (CaCO3) and magnesium (MgCO3), which are the main components of hardness. So, for water at the mine "Stashkova" water hardness was 27.44 mg/l, which is several times higher than the limit of very hard water. Lime (calcium hydroxide Ca (OH) 2) and soda ash (sodium carbonate Na_2CO_3) are usually used to reduce the water to the required concentration. Lime, in turn, removes chemical compounds of carbonate hardness, while soda ash removes other compounds that affect hardness. When the solution is saturated only with calcium carbonates, it is enough to bring the alkalinity of the solution to 10.3-10.6 pH.

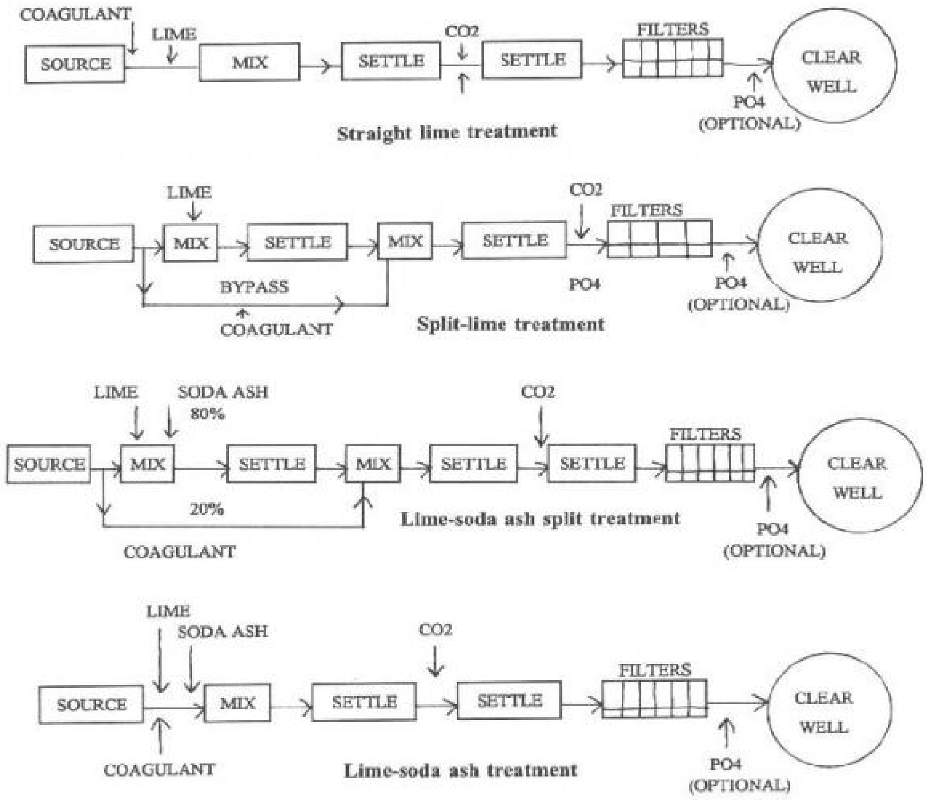


Fig. 2.11 – A variety of algorithms for pre-treatment

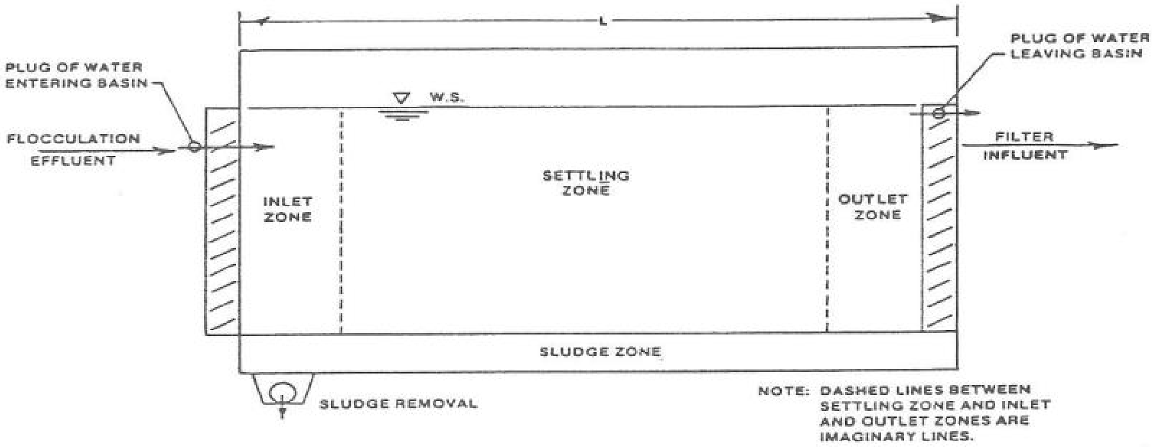
However, considering that more than 40 mg/l of magnesium carbonate is present, the alkalinity of the solution must be brought to a state higher than 10.6 in order for the magnesium compounds to precipitate.

Hard water leads to scale formation and causes corrosion, which reduces the service life of expensive equipment. The index by which the degree of water before scale formation is determined is called the Langelier Index [39]. Calculated by the following formulas:

- Input data:
  - pH = 8,05
  - Dry residue = 6272 mg/l
  - Calcium = 279 mg/l (ppm) as $CaCO_3$
  - Alkalinity = 65 mg/l (ppm) as $CaCO_3$
  - Temperature = 13ºC
- Langelier Saturation Index (LSI):
  - LSI = pH - pH_s

- $pH_s = (9.3 + A + B) - (C + D)$, where:
- $A = \frac{(log_{10} C3 - 1)}{10}$
- $B = -13{,}2 \cdot log_{10}(t° + 273) + 34{,}55$
- $C = log_{10}[Ca\ in\ CaCO_3] - 0{,}4$
- $D = log_{10}[Alkalinity\ in\ CaCO_3]$

To enhance the effect of the above measures, the next step is to mix the reagents and precipitating them. A rectangular pool was chosen for the precipitation, as it is most common on enterprises with medium and high capacity. Rectangular pools owe their popularity to predictable efficiency, lower operating costs, lower capital costs, and shock tolerance. Schematic representation of the pool for settling is shown in Fig. 2.12, 2.13 [40].



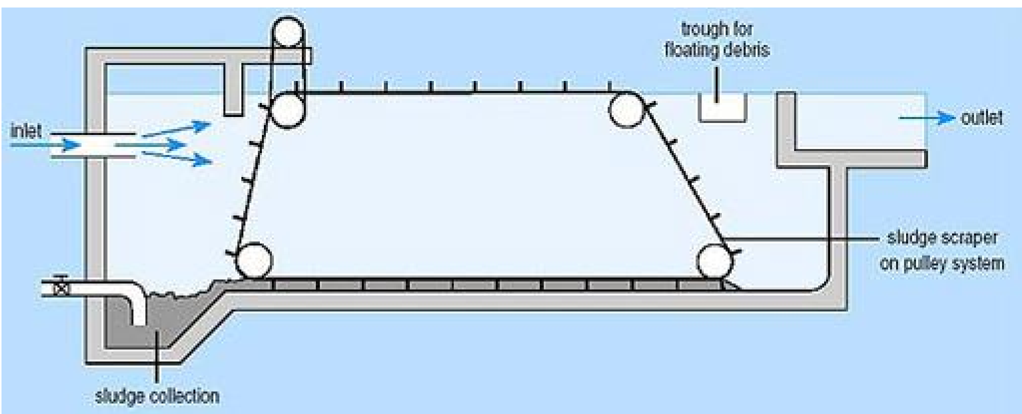


Fig. 2.12, 2.13 – Schematic representation of a rectangular sedimentation basin

IMSDesign and WinFlows software were used to outline the above parameters and reduce them to one system of calculation and selection of the necessary equipment. The following equations were used to calculate the parameters of osmotic systems:

Item	Equation	Equation Number
Total permeate flow	$Q = N_E S_E \overline{A}\overline{\pi}(TCF)(FF)P_f - \frac{\overline{\Delta P_{fc}}}{2} P_p - \pi_f \left[\frac{\overline{C_{fc}}}{C_f} p_f - (\overline{1} - \overline{R})\right]$	20
Ratio: average concentrate-side to feed concentration for system	$\frac{C_{fc}}{C_f} = \frac{-\overline{R}\ln(1 - Y/Y_L)}{Y - (1 - Y_L)\ln(1 - Y/Y_L)} + (1 - \overline{R})$	21
Limiting system recovery	$Y_L = 1 - \frac{\pi_f(\overline{pf})(\overline{R})}{P_f - \overline{\Delta P_{fc}} - P_p}$	22
Approximate log-mean concentrate-side to feed concentration ratio for system	$\left.\frac{C_{fc}}{C_f}\right\|_{Y_L, \overline{R}=1} = -\frac{\ln(1 - Y)}{Y}$	23
Average element recovery	$Y_i = 1 - (1 - Y)^{1/n}$	24
Average polarization factor	$\overline{pf} = EXP[0.7\overline{Y_i}]$	25
Average concentrate-side osmotic pressure for system	$\overline{\pi} = \pi_i \left(\frac{\overline{C_{fc}}}{C_f}\right)\overline{pf}$	26
Average concentrate-side system pressure drop for FILMTEC 8-inch elements; 2 stages Individual FILMTEC 8-inch element, or single-stage concentrate-side pressure drop	$\overline{\Delta P_{fc}} = 0.04\overline{q}_{fc}^{\,2}$ $\Delta P_{fc} = \left[\frac{0.1(Q/1440)}{YN_{V2}}\right]\left(\frac{1}{N_{VR}} + 1 - Y\right)$ $\Delta P_{fc} = 0.01 n\overline{q}_{fc}^{\,1.7}$	27a,b,c
FILMTEC membrane permeability as a function of average concentrate-side osmotic pressure	$\overline{A}(\overline{\pi}) = 0.125; \overline{\pi} \le 25$ $\overline{A}(\overline{\pi}) = 0.125 - 0.011\left(\frac{\overline{\pi} - 25}{35}\right); 25 \le \overline{\pi} \le 200$ $\overline{A}(\overline{\pi}) = 0.070 - 0.0001(\overline{\pi} - 200); 200 \le \overline{\pi} \le 400$	28a,b,c
Permeate concentration	$C_p = BC_{fc}\overline{pf}(TCF)\left(\frac{N_E S_E}{Q}\right)$	29

Fig. 2.14 – Formulas for calculating the main technological indicators of the desalination plant type reverse osmosis

Q_i	permeate flow of Element *i* (gpd)	$\sum_j$	summation of all ionic species
$A_i\pi_i$	membrane permeability at 25° for Element *i*, a function of the average concentrate-side osmotic pressure (gfd/psi)	Y	system recovery (expressed as a fraction) = permeate flow/feed flow
S_E	membrane surface area per element (ft²)	$\prod_{i=1}^{n}$	multiplication of n terms in a series
TCF	temperature correction factor for membrane permeability	n	number of elements in series
FF	membrane fouling factor	Q	system permeate flow (gpd)
P_{f_i}	feed pressure of Element *i* (psi)	N_E	number of elements in system
ΔP_{fc_i}	concentrate-side pressure drop for Element *i* (psi)	$\overline{Q_i}$	average element permeate flow (gpd) = Q/N_E
P_{p_i}	permeate pressure of Element *i* (psi)	$\overline{A}\pi$	average membrane permeability at 25°C: a function of the average concentrate-side osmotic pressure (gfd/psi)
$\overline{\pi}_i$	average concentrate-side osmotic pressure (psi)	$\overline{C}_{fc}$	average concentrate-side concentration for system (ppm)
π_{f_i}	feed osmotic pressure of Element *i*	$\overline{R}$	average fractional salt rejection for system
π_{p_i}	permeate-side osmotic pressure of Element *i* (psi)	$\overline{\pi}$	average concentrate-side osmotic pressure for system (psi)
pf_i	concentration polarization factor for Element *i*	$\Delta\overline{P}_{fc}$	average concentrate-side system pressure drop (psi)
R_i	salt rejection fraction for Element *i* $= \frac{\text{feed conc.} - \text{perm. conc.}}{\text{feed conc.}}$	Y_L	limiting (maximum) system recovery (expressed as a fraction)
C_{fc_i}	average concentrate-side concentration for Element *i* (ppm)	$\overline{Y_i}$	average element recovery (expressed as a fraction)
C_{f_i}	feed concentration for Element *i* (ppm)	$\overline{pf}$	average concentration polarization factor
C_{c_i}	concentrate concentration for Element *i* (ppm)	$\overline{q}_{fc}$	arithmetic average concentrate-side flow rate (gpm) (=1/2(feed flow + concentrate flow)
Y_i	recovery fraction for Element *i* $= \frac{\text{permeate flow}}{\text{feed flow}}$	N_V	number of six-element pressure vessels in system ($\approx N_E/6$)
π_f	treated feed water osmotic pressure (psi)	N_{V1}	number of pressure vessels in first stage of 2-stage system ($\approx$ 1/3 N_V)
T	feed water temperature (°C)	N_{V2}	number of pressure vessels in second stage of 2-stage system ($\approx N_V/3$)
m_j	molal concentration of j^{th} ion species	N_{VR}	stage ratio ($=N_{V1}/N_{V2}$)

Fig. 2.15 – Definition of formula units to Fig. 2.14

SUEZ Water Technologies & Solutions					
Winflows Version 3.3.3				**DataBase Version 3,22**	
		Results Summary			
Flow Data	**m3/hr**		**Analytical Data**		**mg/L**
Raw Feed:	1200,00		**Raw Feed TDS**		6433,36
Product:	891,07		**Product TDS**		48,82
Concentrate:	309,01		**Concentrate TDS**		24980,34

System Data				**Single Pass Design**		
Temperature:	C	RO-1:	13,00			
					System Rec.	74,3 %
Average Flux (lmh), Pass and Stage						
Pass	Average		Stage 1	Stage 2		
Pass 1	25,41		31,89	14,39		

Array Data — **Pass 1**

Recovery %:	78,00	Conc. TDS(mg/l):	24980,34	Conc. Flow:	309,01	m3/hr

Stage	Total		Element Type	Flow, m3/hr		Pressure, atm		Perm TDS
	Housing	Element		Feed	Perm	Feed	DP	mg/l
1	90	540	AG-440	1200,00	703,99	24,00	1,44	26,68
2	53	318	AG-440	496,05	187,08	22,56	1,07	132,10
Total	143	858						

Analytical data

Cation	mg/l Product	mg/l Feed	mg/l Conc	Anion	mg/l Product	mg/l Feed	mg/l Conc
Ca	0,67	327,48	1213,22	**SO4**	0,45	400,72	1485,56
Mg	0,23	173,86	644,43	**Cl**	28,07	3676,03	13563,01
Na	17,72	1982,18	7306,41	**F**	0,00	0,00	0,00
K	0,10	2,06	7,38	**NO3**	0,01	0,32	1,19
NH4	0,24	0,33	0,57	**Br**	0,00	0,00	0,00
Ba	0,00	0,00	0,00	**PO4**	0,00	0,00	0,00
Sr	0,00	0,00	0,00	**B**	0,00	0,00	0,00
Fe	0,00	0,63	2,33	**SiO2**	0,00	0,00	0,00
Mn	0,00	0,11	0,39	**H2S**	0,00	0,00	0,00
TDS mg/l	48,82	6768,44	24980,34	**HCO3**	1,22	115,35	416,71
pH	9,38	9,99	9,86	**CO2**	0,00	0,02	0,05
				CO3	0,11	89,38	339,15
Saturation Data							
BaSO4 %	0,00	0,00	0,00	**CaF2 %**	0,00	0,00	0,00
CaSO4 %	0,00	9,02	45,69	**SiO2 %**	0,00	0,00	0,00
SrSO4 %	0,00	0,00	0,00	**LSI**	-2,20	2,75	3,39
Struvite %	0,00	0,00	0,00	**Pi atm**	0,04	4,55	16,74

Table 2.8 – Calculation of equipment and technological complex of reverse osmosis

2.4 Conclusions on the section

1) The analysis of the basic productive flows of the mining process - coal, their potential and utility relevance was carried out. The coal industry is approaching the peak of its utilisation, demand is expected to decline further, however, the current volume and share of coal in energy generation suggests that the trend towards the use of carbon sources for energy production will continue for the next few decades.

2) The classification and comparative characteristics of the main desalination methods used in the world was consolidated. The main methods were considered in relation to the region of Western Donbass and the implementation of a treatment complex on the territory of one of the mines or their complex.

3) The main parameter for assessing the effectiveness of the technological method was chosen as specific electricity consumption per 1 cubic meter of product. Due to the lack of thermal sources (thermal power plant, etc.) near the potential location of the desalination complex, the use of thermal distillation methods is not rational and efficient, as well as due to the relatively low salinity in most groundwater in the region.

4) The main two competing technologies are reverse osmosis and electrodialysis. Despite electricity consumption for desalination is small in both cases, reverse osmosis was chosen as the main desalination method for a number of reasons: the potential for complex expansion, the limit of rational use of electrodialysis by volume and mineralization, much more experience in reverse osmosis systems in the world.

5) For practical application in the work it is proposed to choose the mine. “Stashkova”, as the object of research before the use of the desalination complex due to large volumes of polluted wastewater (1200 m^3/h) and the planned closure of coal production at the mine with possible further wet or dry preservation.

6) For full and effective use of reverse osmosis, it is necessary to carry out a set of works on pre-treatment, shielding, coagulation and flocculation, softening and sedimentation (settling) of water. Reverse osmosis membranes are most vulnerable to turbidity, chlorides (and other heavy metals), organic compounds and water hardness.

3. ECONOMIC CALCULATION OF THE PURIFICATION COMPLEX OF REVERSE OSMOSIS SYSTEMS

3.1 Specifying parameters of economic assessment of filtration and demineralization systems to be put into operation

An important factor is that water, as a continuous productive flow, is delivered upwards 24 hours a day, 365 days a year and cannot be suspended, as working conditions in the mine galleries become impossible as the inflow increases.

Mine inflow depends on many factors, including the depth of the mine, its location near water bodies, the amount of precipitation in the area and more. Mine water has always been seen as an obstacle to valuable resources, but experience and the development of technology demonstrates that coal is leading off to recede into the background, and mine water, which was disposed of as a by-product, is becoming increasingly important and is beginning to be considered as a valuable resource and a potential source of drinking water.

In order to understand the volume of mine water discharged and the costs faced by mine financial statements, the dependence of water inflow on the flood basin area was shown in Figures 3.1, 3.2, 3.3.

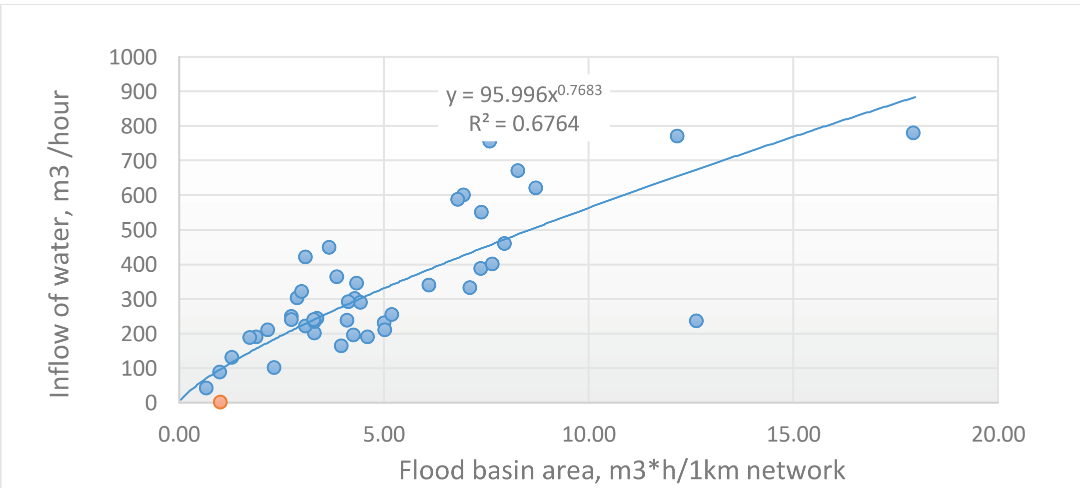


Fig 3.1 – Graph of the dependence of water inflow on the flood basin area

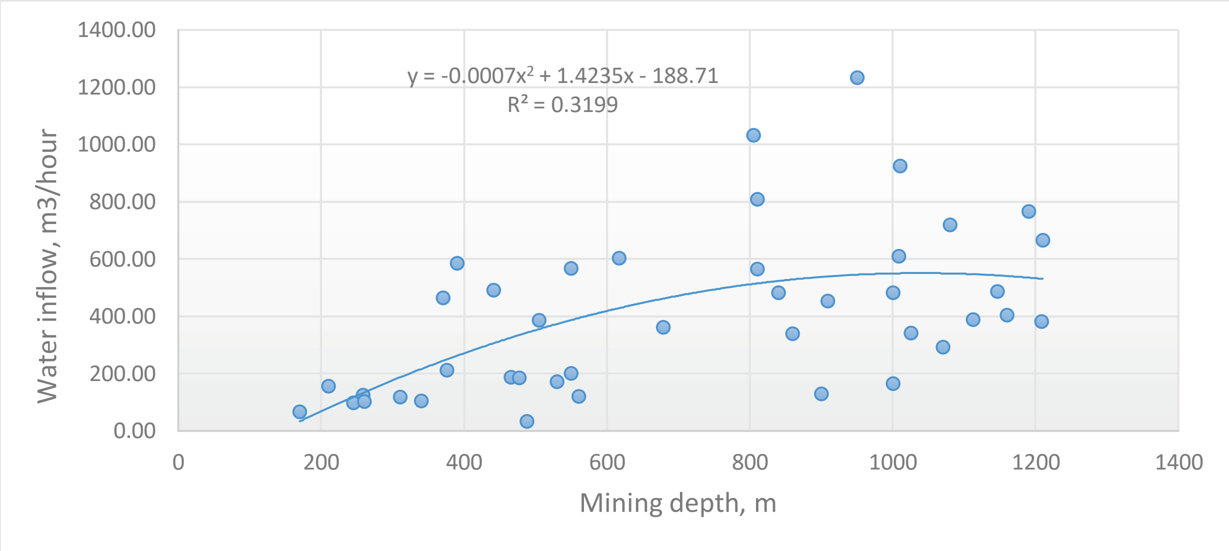


Fig. 3.2 – Dependence graph of the water inflow function on the depth of mining

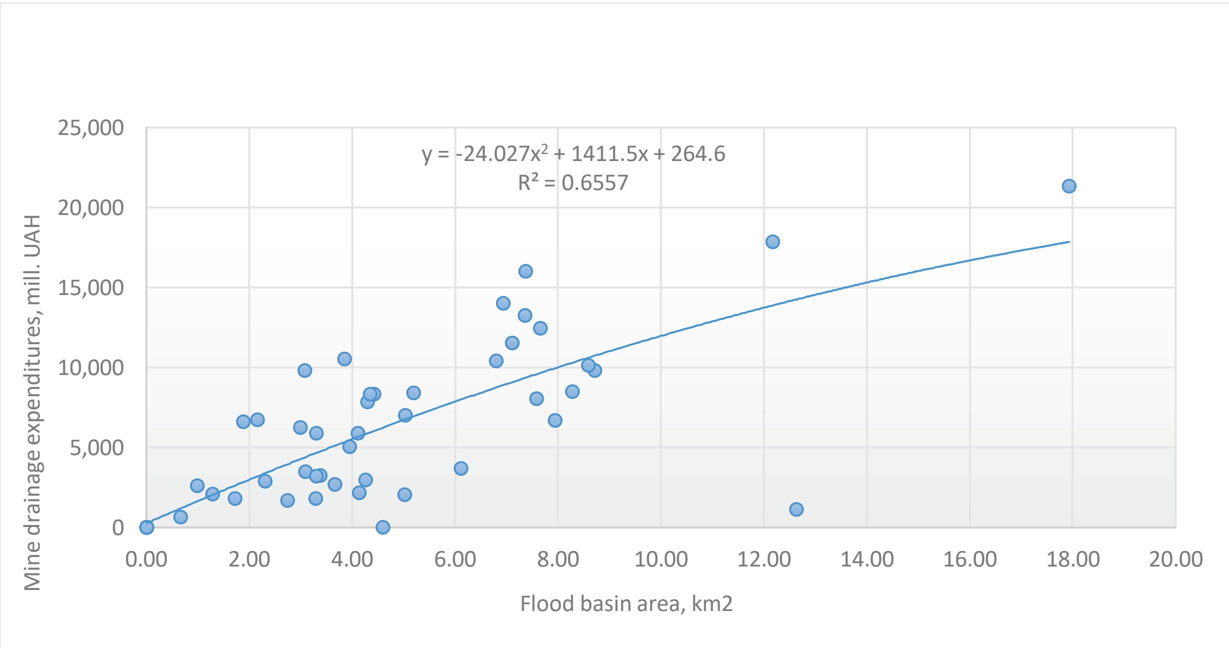


Fig. 3.3 – Dependence of drainage costs on the flood basin area

3.2 Calculation of the cost of fresh water production for the conditions of Dnipropetrovsk region

The Desalination Economic Evaluation Program (DEEP) software, developed by the International Atomic Energy Agency and publicly available, was selected to calculate the productivity, cost and capital investment of the demineralization and water desalination plant. The program allows you to compare and display patterns of different configurations under different input conditions. The program provides an opportunity to calculate not only the indicators of reverse osmosis, but also MED and MSF in pair or separately with the calculations of the power plant, taking into account the type of plant and fuel. Due to the functionality of this software, it is possible to perform a comparative description of the indicators in relation to the price aspect of the rational use and selection of a particular equipment.

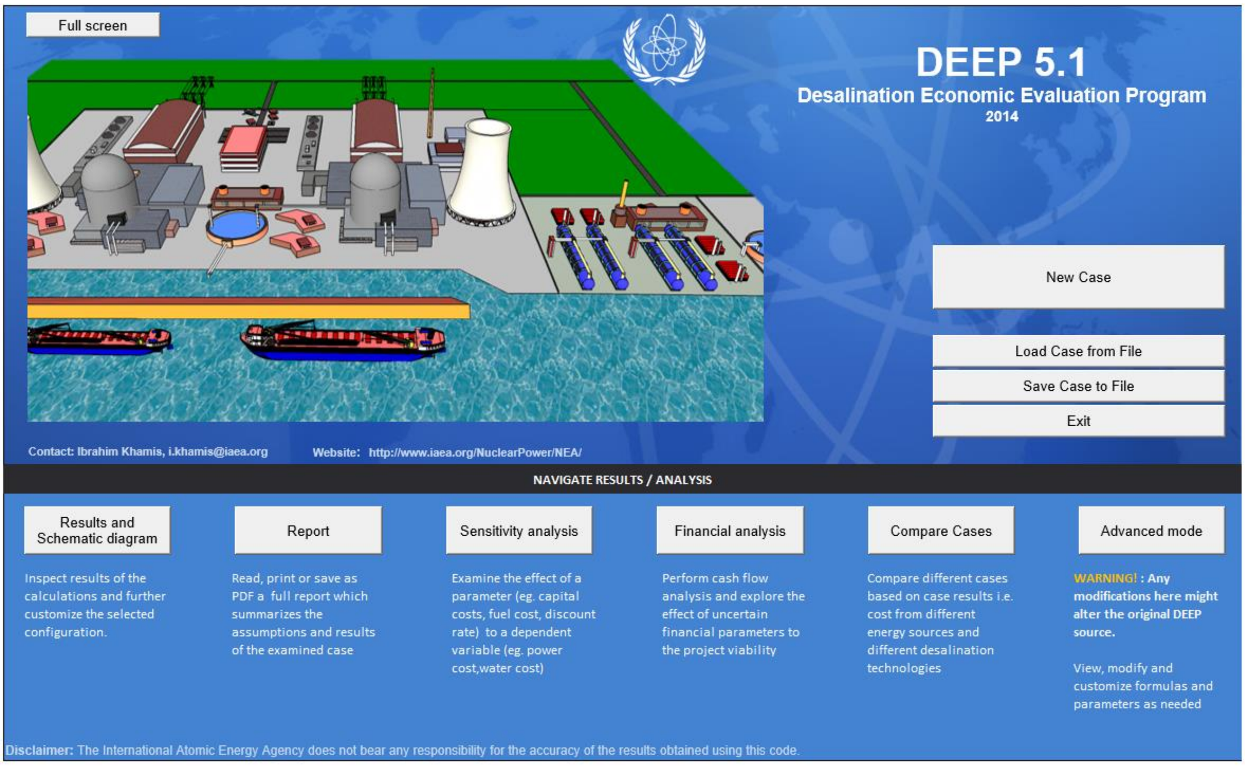


Fig. 3.4 – DEEP 5.1, software for calculation and planning of complex water purification systems

Given the fact that water pumping can be taken as a constant, it would be appropriate to compensate for the cost of pumping water from mine workings, selling water as a finished product for consumption. Therefore, the first and most important parameter of expediency can be chosen water inflow Q, from 1200 m^3/h. Given that the volume of mine water intake is not a constant value, the volume of the feed solution will also vary depending on the season. Thus, the limits of fluctuation can be determined from 24,000 m^3/day to 31,000 m^3/day. For the average value of water supply to the desalination system was chosen $Wroh\ = 1200\ m^3/$h, i.e. per day $Wro = 28800\ m^3/$day. The annual production of water ready for consumer needs will be $Wpd = Wro \cdot Apm\ \cdot 365 = 9460800\ m^3/$a, where Apm- The volume of treated water directly affecting the cost of the finished product. The dependence is shown in Figure 3.4.

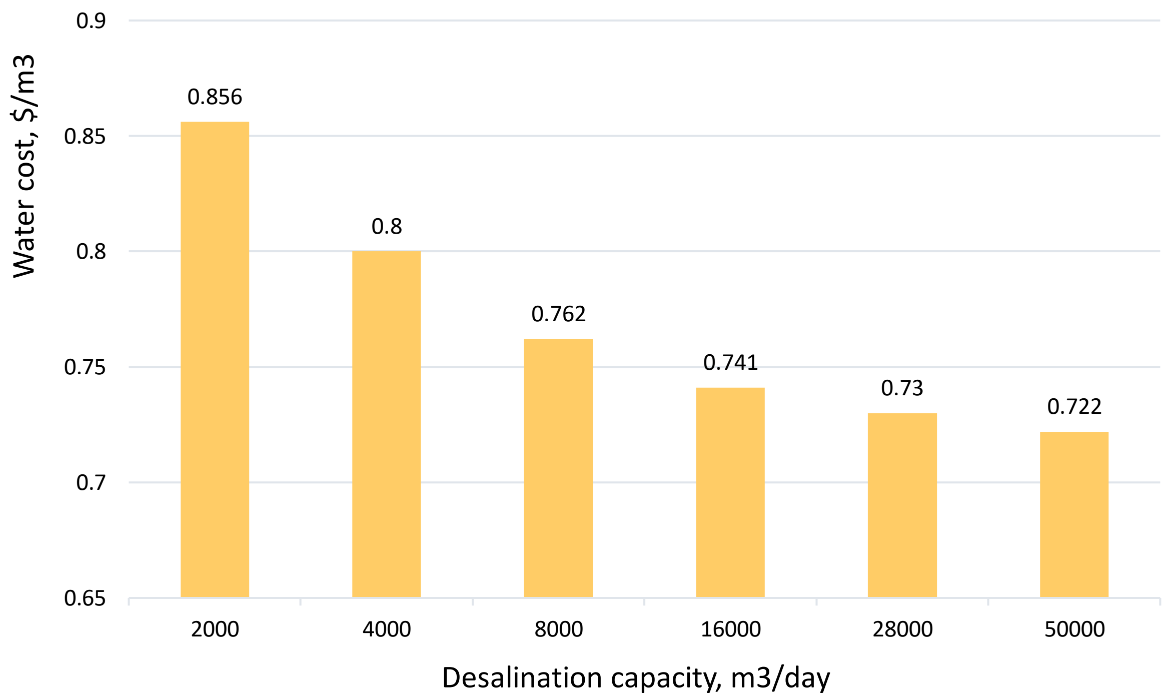


Fig. 3.5 – Dependence graph of the production cost function on the capacity of the desalination complex

According to the graph, the law of economies of scale comes into effect with the increase of desalination capacity, however, along with the increase of fresh water production, the initial capital costs for equipment also increase. The costs of the enterprise are usually calculated according to the following algorithm, shown in Figure 3.6. To determine the capital costs were used the following calculation formulas shown in Fig. 3.7, 3.8.

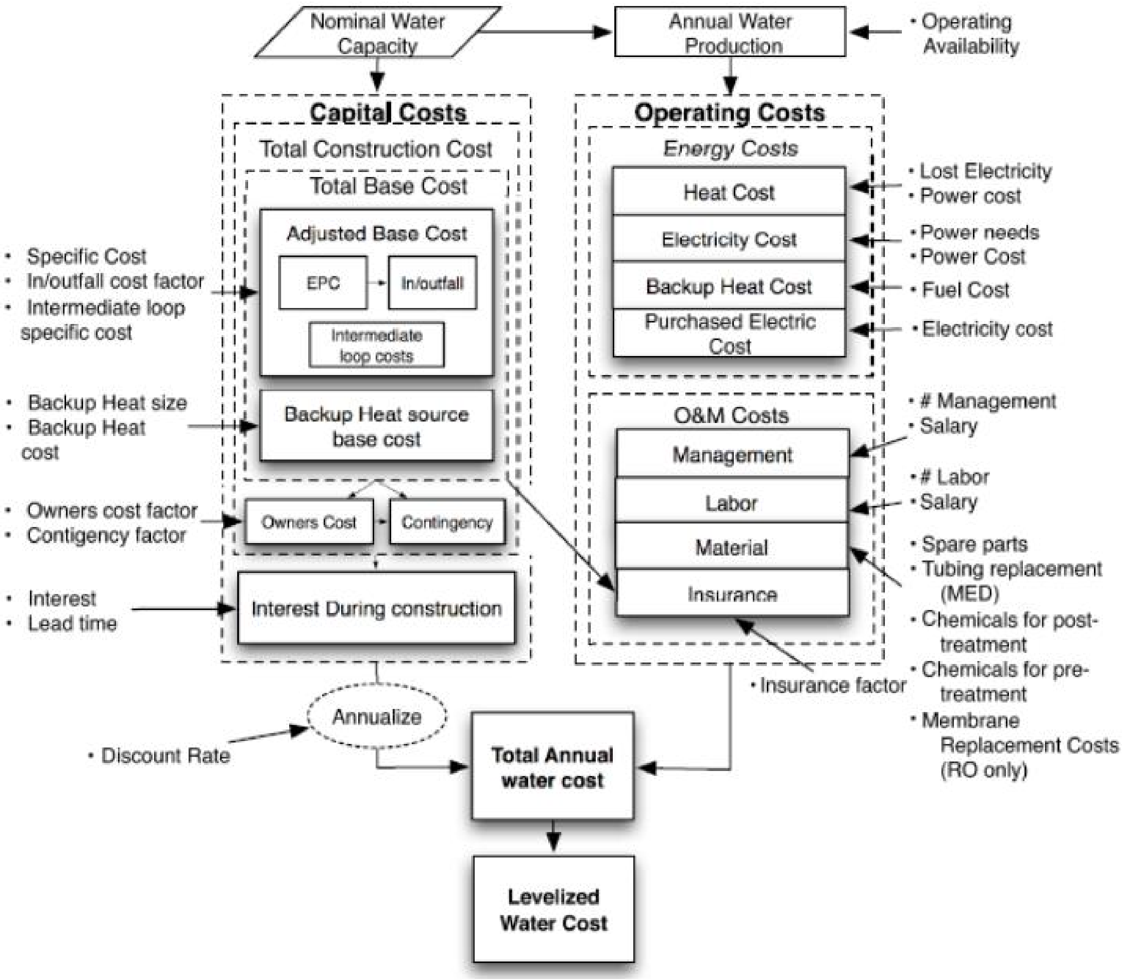


Fig. 3.6 – Schematic representation of the algorithm for calculating total investment [41].

O&M Cost Calculations

$Cdm = Ndm \cdot Sdm$	Management cost
$Cdl = Ndl \cdot Sdl$	Labour cost
$Cdmt = (csds + cdtr + cdcpr + cdcpo) \cdot Wpd$	Material cost
$Cdins = kdi \cdot Cdt$	Insurance cost
$Cdom = Cdm + Cdl + Cdmt + Cdins$	Total O&M cost

Water Plant Total annual Cost

$adrev = adfc + adhc + adfbh + adepc + adepu + Cdom$	Total annual cost
$sdfc = adfc / Wpd$	Sp. WP capital cost
$sddc = (adhc + adfbh) / Wpd$	Sp. WP heat cost
$sdepc = adepc / Wpd$	Sp. WP electricity cost
$sdepu = adepu / Wpd$	Sp. WP purchased electricity cost
$sdoamc = Cdom / Wpd$	Sp. WP O&M cost
$Wdt = adrev / Wpd$	Water production cost

Capital Cost

Water Plant Capital Costs Calculations

$Cdio = Csdo \cdot Cdu$	In/Outfall specific cost
$Cdst = Cdu \cdot kdus + Cdio + Cinl$	Total specific base cost
$Cda = Wacd \cdot Cdst$	WP adjusted Base cost
$Cbh = Cbu \cdot Bhs$	Backup heat source base cost
$Cdt = Cda + Cbh$	Total WP base cost
$DCdo = Cdt \cdot kdo$	WP owners cost
$DCdc = (Cdt + DCdo) \cdot kdc$	WP contingency cost
$Cdcon = Cdt + DCdo + DCdc$	WP total construction cost
$IDCd = Cdcon \cdot \left((1+ir)^{\frac{Ld}{24}} - 1 \right)$	Interest during construction
$Csinv = Cdcon + IDCd$	Total investment
$adfc = Csinv \cdot lfc(i, Lwp)$	Annual WP fixed charge

Fig. 3.7, 3.8 – Equations for calculating capital and operating costs

WinFlows was used to calculate electricity consumption. The specification of the pump installation is given in fig. 3.9, where the total power of the high pressure pump is equal to $Qhp = 887{,}4$ kW, and the specific power consumption per unit of permeate output is $Qcms = 0{,}99$ кkW $\cdot$ h$/m^3$, taking into account the loss factors and performance of the pumping unit is recommended to take $Qcms = 0{,}99 + 10\% = 1{,}1\ \mathrm{k}W \cdot \mathrm{hour}/m^3$. In general, with the price of electricity about $Cpe = 0{,}1\$$ for enterprises of the second category, the total electricity consumption Spel is equal to:

$$Qms = Qcms \cdot Wroh = 1320\text{кВт} = 1{,}32\ MW/hour$$
$$Cpel = Qcms \cdot Cpe \cdot Wpd = 1{,}04\ \text{mill.}\,\$/\text{year}$$

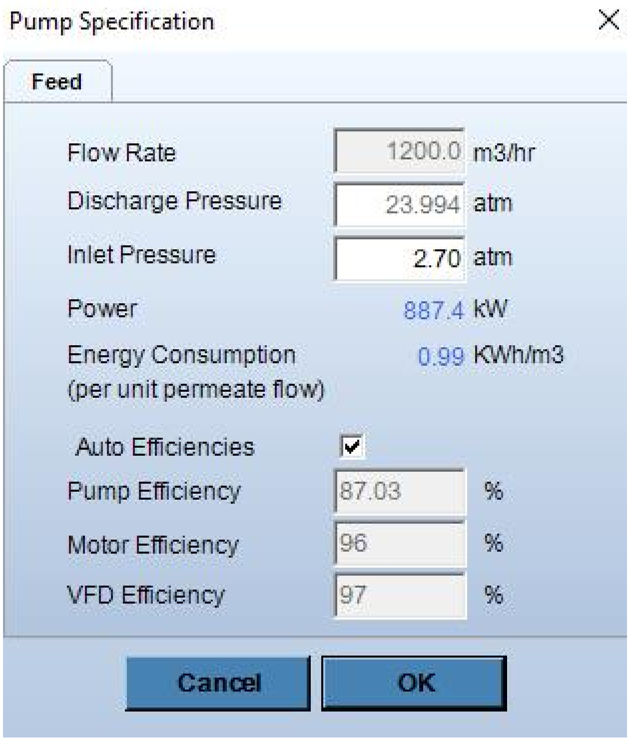


Fig. 3.9 – High pressure pump specification

Capital expenditures on electricity are rounded to the nearest higher value with a correlation regarding possible losses and peak loads:

$$Cpel = 1\ mill.\$/year$$

The pressure created by the pumps has a clear correlation with the degree of permeate yield, as well as the amount of energy used. For optimal capacity utilization, and therefore in compliance with the equipment and type of membranes selected, the pump outlet pressure of 24 atm was chosen, however, adjusted for system pressure drop (2 atm), loss of permeate output (1 atm), pump efficiency (%), it is preferably to take the value of the pressure of the main pump at 33 atm.

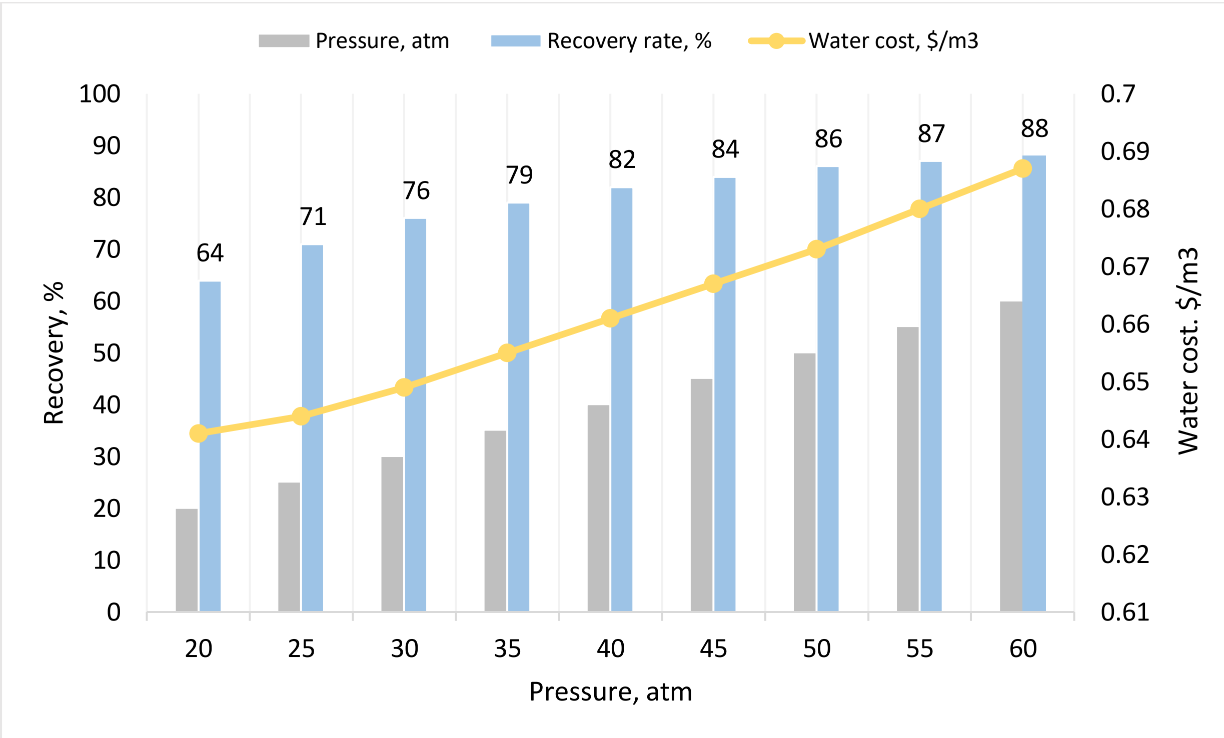


Fig. 3.10 – Graph of the function of permeate recovery and water cost by the pressure of the main pump

The optimal value of permeate yield was selected $Rr = 75\%$ to satisfy the parameters of the flow through the membranes, the difference in pressure change and other. To calculate operating and capital costs, the initial data was selected according to the basic parameters of construction and operation of the desalination plant, as well as international experience. The main indicators are given in table 3.1

№	Economic parameters	Reverse osmosis
1.	Water plant lead time	12 months
2.	Lifetime of water plant	20 years
3.	Water plant operating availability	90%
4.	Management Salary[4]	25000 $/year
5.	Labour Salary	13000 $/year
6.	Base Unit Cost	900 $/m^3/d$
7.	Specific O&M spare parts cost	0,03 $/m^3$
8.	Specific O&M chemicals cost for pre-treatment	0,05 $/m^3$
9.	Specific O&M chemicals cost for post-treatment	0,02 $/m^3$
10.	O&M membrane replacement cost (RO)	0,09 $/m^3$
11.	Water plant owners cost factor	5%
12.	Water plant cost contingency factor	10%
13.	Water plant O&M insurance cost	1%

Table 3.1 – The main indicators of the estimate of the demineralization and water desalination plant

Water plant operating availability indicates the ratio of the operating hours of the system in which the system is ready for operation to the designed number of operating hours. With the coefficient $Adp = 0.9$, in working hours, this equivalent is equal to 877 hours per year. Temporary shutdown may be due to membrane replacement, cleaning and chemical treatment, and maintenance. The contingency ratio was set at 10%.

Taking into account the specific costs of electricity, the price of an industrial unit per unit of output, and economic indicators, it is possible to calculate the expected cost of desalination of 28,800 m^3 of water per hour.

[4] The necessity to take into account the local labour market

Capital Costs of Desalination Plant					X
	MSF	*RO*	*Total (M$)*	*Specific ($/m3 d)*	*Share*
Construction Cost	-	28	28	963	80%
Intermediate loop cost	-	-	-	-	0%
Backup Heat Source	-	-	-	-	0%
Infall/Outfall costs	-	-	2	63	5%
Water plant owners cost	-	1	1	48	4%
Water plant contingency cost	-	3	3	101	8%
Interest during Construction	-	1	1	27	2%
Total Capital Costs	-	33	35	1203	
Annualized Capital Costs			3		
Sp. Annualized Cap Costs				**0.28**	$/m3

Operating Costs of Desalination Plant					
	MSF	RO	Total (M$)	*Specific ($/m3)*	Share
Energy Costs					
Heat cost	-		-	-	0%
Backup heat cost	-		-	-	0%
Electricity cost	-	-	-	-	0%
Purchased electricity cost	-	1.0	1.0	0.11	35%
Total Energy Costs	-	1	1	0.11	35%
Operation and Maintenance Costs				-	0%
Management cost	-	-	0.05	0.01	2%
Labour cost	-	-	0.18	0.02	6%
Material cost	-	1.56	1.6	0.17	52%
Insurance cost	-	0.16	0.2	0.02	5%
Total O&M cost	-	2	2	0.21	65%
Total Operating Costs	-	3	3	**0.32**	

Total annual cost	**5.63**	**M$**
Water production cost	0.595	$/m^3
Water Transport costs	-	$/m^3
Total water cost	**0.595**	**$/m^3**

Fig. 3.11 - Table of consolidated costs and cost of 1 cubic meter of desalinated water

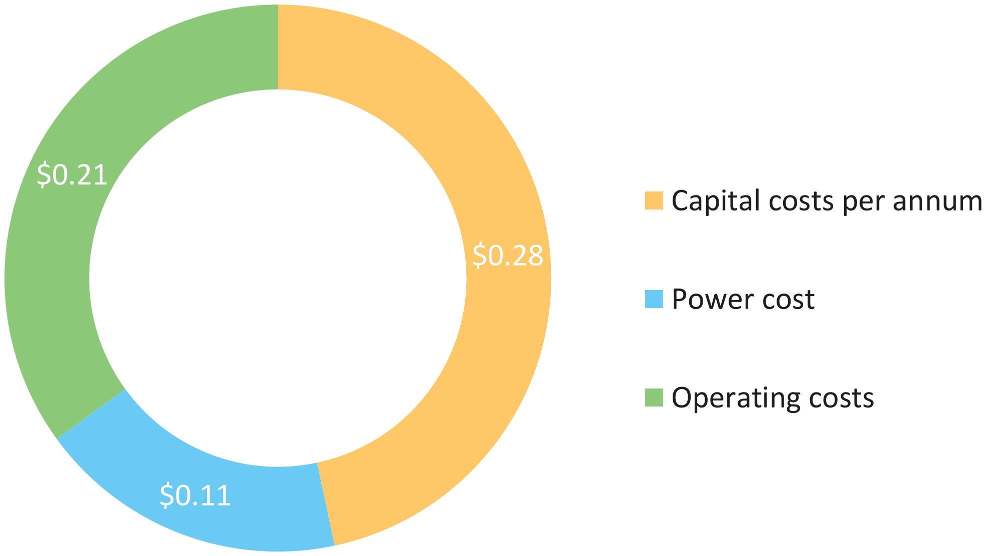


Fig. 3.12 – The cost of 1 cubic meter of fresh water, $/m^3

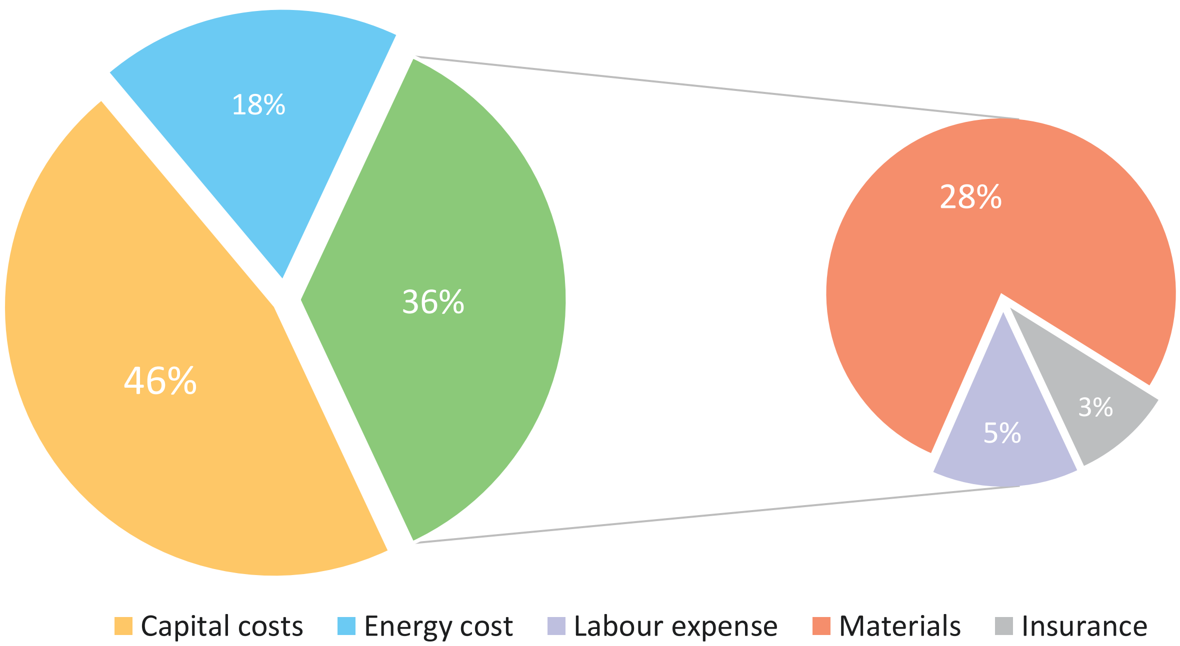


Fig. 3.13 – Cost breakdown of 1 cubic meter of fresh water, %

3.3 Derivation of the economic effect from the desalination complex and economic feasibility of the investment

Any investment model assumes the economic effect and predictability of an investment. Considering the problems of drinking water shortage in the eastern region of Dnipropetrovsk region, as well as the problems of pollution of the surrounding inventory of water resources, economic feasibility and rationality are inferior to natural necessity. Neglecting alarming environmental indicators leads to both natural and socio-economic disasters. The cost of restoring the natural balance always exceeds the cost of maintaining the current.

However, technological progress and energy efficient use of equipment enable a project preserving environmental integrity to have a solid economic basis for implementation. Owing to the pressure exchanger proposed in the work, energy consumption was reduced from $0{,}99\ kW \cdot h/m^3$ to $0{,}8\ kW \cdot h/m^3$, in conversion to nearly + 20% economic effect. Pre-treatment of water supplied to the reverse osmosis unit also has a significant economic effect, as the extension of the service life of precious membranes is the main task of competent design and operation.

Considering the cost of fresh water from the proposed treatment plant, it is worth noting the relatively low price achieved, although a more accurate calculation can be made after receiving the exact price from the manufacturer and supplier of equipment and chemical evaluation and physical modelling of pre-treatment. To derive an economic estimate of the cost obtained, it is necessary to enter data for comparison. As for February 5th, 2020, state water service company "Vodokanal" set the tariff for centralized water supply and sewerage services at the level of: UAH 12.78 (including VAT) per 1 m^3 and UAH 8.64 (including VAT) per 1 m^3 of water supply and drainage, respectively. The total amount of the tariff was UAH 21.42 (including VAT) per 1 m^3 [42], which in equivalent is $ 0.80 as of May 22, 2020. The price of water in Ukraine is unprecedentedly low compared to European prices. For England, the price of water ranges from £ 4.74 to 5.1 (for water supply - £ 1.9; for drainage - £ 2.84-3.34), which is $ 5.84 per 1 m3 of water, for Germany - € 5.34

or \$ 5.74, for Poland - zł11.11, or \$ 2.37. Even in such difficult conditions of economic profit, the cost of water desalination was reached at \$ 0.6, leaving room for a positive economic effect. The internal rate of return was calculated as an economic indicator [43]:

$$\sum_{t=0}^{n} \frac{S_t}{(1+IRR)^t} = 0,$$

where S_t – net cash flow in the period (usually year) t, i.e. the sum of all income minus the sum of all expenses for this period;
n – number of the last studied period (investment horizon);

Given that the life cycle of the enterprise is 20 years, the construction period is 12 months. The optimal selling price of fresh water was chosen as \$ 1.2/m^3, whereas, despite the financial determination of the selling price of fresh water, it is important to take into account the purchasing power of consumers. Therefore, the Internal Rate of Return (IRR) concluded $After\ tax\ equity\ IRR = 31\%$. The payback period is 3.2 years.

Due to the lack of the water supply infrastructure or its significant deterioration in the region, for the sale of drinking water it is necessary to conduct a pipeline to the settlements and central water supply systems. The length of the pipeline is assumed as theoretical for 30 km, the capacity of pumping equipment is 1 MW, the service life is 25 years, the construction of the pipeline is accepted for 60 months. The construction of the pipeline adds to the cost of \$ 0.24, i.e. is almost 30% of the price.

3.4 Labour protection

3.4.1 Harmful factors in the process of desalination of mine wastewater at desalination stations

The following harmful factors have been identified in the production during desalination of water resources by reverse osmosis with pre-treatment, which can have a detrimental effect on the health of employees in the process of maintenance of equipment and process [44]:

1. Chemical hazard that leads to damage and disease associated with chemicals. Chronic and acute forms of reaction to interaction with reagents, lesions of the respiratory system, skin and physical injuries.
2. Mechanical danger, which consists in interaction with rotating equipment, mixing, compressing. In the process of physical settling of the aqueous solution with coagulants, concentrated slaked lime and chlorides - there is a risk of damage and getting into the solution of the operator of the sedimentation basin.
3. Electrical hazards associated with the use of electrical equipment in the immediate vicinity of water, so insulation is an extremely important precaution against high voltage surges. The placement of high-pressure pumps and pressure recovery systems requires powerful electrical loads and poses additional threats to human life.
4. Basic hazards, such as the organization of an enclosed working space, the impact of intermittent sound waves, fire hazard, work at altitudes above 1.5 meters, sampling and analysis from underground and ground sources, lifting heavy parts and equipment parts.

3.4.2 Measures to reduce the impact of these risk factors on human health when working on a water treatment plant

To prevent chemical hazards, it is necessary to carry out three basic approaches to production control:

- The first stage is to develop and design a plan of the treatment complex, integrating safety developments into the project. Identification and early planning of potentially dangerous areas saves money on their further re-equipment and redevelopment, as well as reduces unwanted accidents at work.
- Replacing chemically and physically hazardous factors in the workplace with less hazardous counterparts can have a positive effect on the statistics of injuries and the impact of harmful substances on the health of workers [45].
- Ventilation avoids the concentration of toxic gases in a tight confined space and minimizes the possibility of acute respiratory diseases. There are local ventilation and general. Local ventilation is used to remove toxic hazardous substances from the immediate place of their formation. General ventilation helps with low concentrations of volatile substances, with relatively low toxicity, and ensures the circulation of clean air with low emissions of pollutants into the atmosphere.
- Staff safety briefing is the most common and effective method of dealing with injuries in businesses and reduces the risk of injury or illness. Employees must be aware of the working conditions and the consequences of these conditions.
- Regular medical examinations are installed at enterprises with potentially dangerous working conditions and allow to monitor the health of workers, the effectiveness of measures taken to ensure safety at work.
- Personal protective equipment consists of respiratory protection, protective clothing, protection of vulnerable parts of the body such as eyes, head, arms, legs.

When operating pump units and auxiliary equipment, the following labour protection measures must be taken into account:

- Operation of pumping units and auxiliary equipment is organized on the basis of operating instructions, which are developed taking into account the instructions of manufacturers and these Rules.

- The operating instructions must specify: the sequence of operations for starting and stopping the units, the permissible bearing temperatures, the minimum oil pressure (in circulating lubrication systems), a list of the main equipment failures and methods for their elimination.
- Each pump set must have a nameplate indicating the manufacturer, serial number and technical data.
- Each pump unit must have a technical passport in accordance with the requirements of paragraph 2.6 of these Rules.
- Each pump set and auxiliary equipment must be provided with a set of spare parts and a supply of consumables in accordance with the manufacturer's regulations.
- Start and stop of pumping units and auxiliary equipment is performed only by the person on duty who serves this installation (if the start and stop are not carried out automatically or by means of telemechanical control systems) [46].

Conclusions on the section

1. Mining, in essence, leads to a significant accumulation of wastewater and requires constant pumping. It is proposed to compensate for the costs of utilization of contaminated mine water by converting the by-product into a source of income and diversifying the production of the coal complex.
2. A graph of the dependence of the cost of 1 cubic meter was derived. m of pure water as a function of the volume of desalination water in the plant. Given the conditions of water inflow of the mine "Stashkova" and the factor of reducing the cost of production with increasing capacity of the treatment complex, it was decided to select the full volume of the mine inflow in the amount of an average of 1200 m^3/h.
3. The paper presents the calculation of capital investments, the methodology for estimating the volume of operating and capital investments, as well as the main economic indicators of the estimate of the complex of demineralization of mine wastewater.

4. Taking into account the specific costs of electricity, the price of an industrial unit per unit of output, and economic indicators, it is possible to calculate the expected cost of desalination of 28,800 m^3 of water per day. The calculated cost of water not only allows to obtain a positive economic effect from the implementation of the treatment complex to compensate for the costs of disposal of waste mine water, but also a promising profit from the sale of clean drinking water to end users.

CONCLUSIONS

The main results and conclusions obtained during the work are as follows:

1. Mines of the Western Donbass, and more broadly, mines in general, violating the balance of the hydrogeological system and geological integrity of the rock mass, require hourly and solely pumping of mine water to the earth's surface, having a negative impact on the surface and causing subsidence of the earth's surface.

2. Upon contact with disturbed rocks, the water flow dissolves and saturates with rocks present in the mine field. Mine wastewater, in contrast to conventional groundwater, has a much higher mineralization (from 1000 ppm to 37600 ppm in some cases), oil products and heavy metals also saturate the contact mine groundwater.

3. The level of the mine inflow depends on its depth, the amount of precipitation in the area of development of deposits (climate), the proximity of surface water bodies, lakes, rivers, reservoirs, in the case of mines in the Western Donbass, one mine "Stashkova" solely produces 1000 cubic meters onto the surface per hour.

4. Planned closure of two mines "Stashkova" and "Blagodatna", as well as the prospective closure of 4-5 more mine facilities gives a clear signal to use the dying capacity of coal production and preserve the mine with proper regulated and adjusted use of water flow from the ecological and socio-economic plan.

5. There are many technologies for desalination and purification of aqueous solution. In order to choose the necessary and appropriate ones, it is needed to clearly establish the purpose and goal of desalination of aquatic products and the amount of wastewater intake volume, as well as desalination unit capacity. It is also necessary to consider the existing technological processes in the complex, since the versatility of the technology is reflected in the cost of desalination.

6. Classification and comparative characteristics of the main desalination methods used in the world were consolidated. The main methods were considered

in relation to the region of Western Donbass and the implementation of a treatment complex on the territory of one of the mines or their complex.

7. The main parameter for assessing the effectiveness of the technological method was chosen specific electricity consumption per 1 cubic meter of permeate. Due to the lack of thermal sources (thermal power plant, etc.) near the potential location of the desalination complex, the use of thermal distillation methods is not rational and efficient, as well as due to the relatively low salinity in most groundwaters in the region.

8. Reverse osmosis and electrodialysis remain two competing technologies. Despite the electricity consumption for desalination in both cases is relatively small, the main method of desalination was chosen as reverse osmosis for a number of reasons: the potential to expand the complex, reached the limit of rational use of electrodialysis by volume and mineralization, much more experience in reverse osmosis systems.

9. For practical application in the work it is proposed to choose the mine "Stashkova" as a subject of research for application of the desalination complex due to large volumes of polluted wastewater (1200 m^3/h) and planned closure of coal production at the mine with possible further wet or dry mothballing.

10. For the full and effective use of reverse osmosis, a set of works on pre-treatment, shielding, coagulation and flocculation, softening and sedimentation (settling) of water was considered and selected. Reverse osmosis membranes are most vulnerable to turbidity, chlorides (and other heavy metals), organic compounds and very hard water.

11. Mining, in essence, leads to a significant accumulation of wastewater and requires constant pumping. It is proposed to compensate for the costs of utilization of contaminated mine water by converting the by-product into a source of income and diversifying the production of the coal complex.

12. A graph of the dependence of the cost of 1 cubic meter of fresh water to a function of the volume of desalination water in the plant was derived. Given the conditions of water inflow of the mine "Stashkova" and the factor of reducing the cost of production with increasing capacity of the treatment complex, it was

concluded to select the full volume of the mine inflow in the amount of an average of 1200 m^3/h.

13. The paper presents the calculation of capital investments, the methodology for estimating the volume of operating and capital investments, as well as the main economic indicators of the estimate of the complex of demineralization of mine wastewater.

14. Taking into account the specific costs of electricity, the price of an industrial unit per unit of output, and economic indicators, it is possible to calculate the expected cost of desalination of 28,800 cubic meters of water per day. The calculated cost of water not only allows to obtain a positive economic effect from the implementation of the treatment complex to compensate for the costs of disposal of waste mine water, but also a promising profit from the sale of clean drinking water to end customers.

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