The use of membrane technic in mineralised water treatment for drinking and domestic purposes at „Pokój" coal mine district under liquidation

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Abstract: This paper presents a project on mining water treatment station (MWTS) at „Pokój" coal mine Wawel district for drinking and domestic needs; developed at Zaklad Ochrony Wod „GIG" in Katowice. Membrane station design was based on our own research at pilot station and results obtained from several computer simulations delivered by membrane manufacturers in order to select optimal parameters for the process. Costs estimation of used energy to produce 1 m^3 of treated water are also presented. This project is under construction now (Magdziorz, Seweryński 1999).

1 INTRODUCTION

Coal mines, including those under liquidation, dispose large quantities of mining water which mineralization is close enough to physical and chemical requirements for drinking water. Around 20% of those mining waters show the content of dissolved substances under 800 mg/l; therefore they are within permissible levels of drinking water requirements. However, majority of coal mines dispose significant amounts of water than can be used for technological purposes in mining industry.

Several coal mines draw water from municipal water supply suitable for domestic and industrial purposes (baths, boiler houses, laundries etc). Yearly water supply cost constitutes a significant part in the coal mine expenses structure. Most of mining water and also bath and laundry water properly treated are suitable for drinking and technological purposes.

Technological, technical and economical conditions allow to conduct an analysis of the possible mining water use for drinking and technological needs (Magdziorz, Winnicki 1998). Before mining water can be used for drinking purposes it is necessary to precisely determine all water intakes, physical and chemical contents. It is also necessary to analyse the changes in quantity and quality of water, subsequently creating a long term forecast, elimination of any possible sources of organic impurities underground, introduction of underground protective zones, conducting technological research to select the optimal technology, designing the water treatment station and finally economical assessment (Magdziorz 1996).

This paper presents project assumptions, technical and economical analysis for mining water treatment station at "Pokój" coal mine district under liquidation, at Ruda Śląska, for drinking and domestic needs. It also presents the application of membrane technology.

2 WATER MANAGEMENT AT "POKÓJ" COAL MINE DISTRICT

"POKÓJ" coal mine does not consume drinking water from it's own water intakes. The total of it is supplied by Water Supply and Sewage Works at Ruda Śląska. This water is used for living and domestic purposes (including baths); to a certain degree for industrial purposes as well (supply to the emulsion station for mechanised wall lining, filling up of cooling system at compressor station and central heating).

At the moment about 3300 m^3 out of 8800 m^3/day of pumped water of the mine is used for internal needs like: anti-fire protection, mine filling purposes and filling up the water-slit circulation. Mining water of "Pokój" (Ruch I) districts are managed wholly. The water excess from the liquidated coal mine Wawel district RUCH II in quantity of 5512 m^3/day is discharged into Czerniawka River.

The mineral suspension of the water is filtered out of in a 6 chamber settling tank. However, because of excessive salts content in the water the coal mine does not have a legal permission to dispose it.

To protect the surface water receiver, a joint effort of Wawel and Pokój mines is organized to pump the mining water into the Ruch I district through the water pipeline system. "Pokój" district manages this water wholly for technological needs.

3 DESIGN ASSUMPTIONS FOR MINING WATER TREATMENT TECHNOLOGY

3.1 Localisation

Mining water treatment station (MWTS) shall be located at "Pokój" coal mine area near existing settling ponds.

There are two storage reservoirs of 500 m^3 each, crude water tank of 1000 m^3 capacity and a pump house next to the above station. The partial territorial development includes power supply and pipelines system between tanks and the pump house. Figure 1 shows the localisation draft of the Mining water Treatment Station (MWTS).

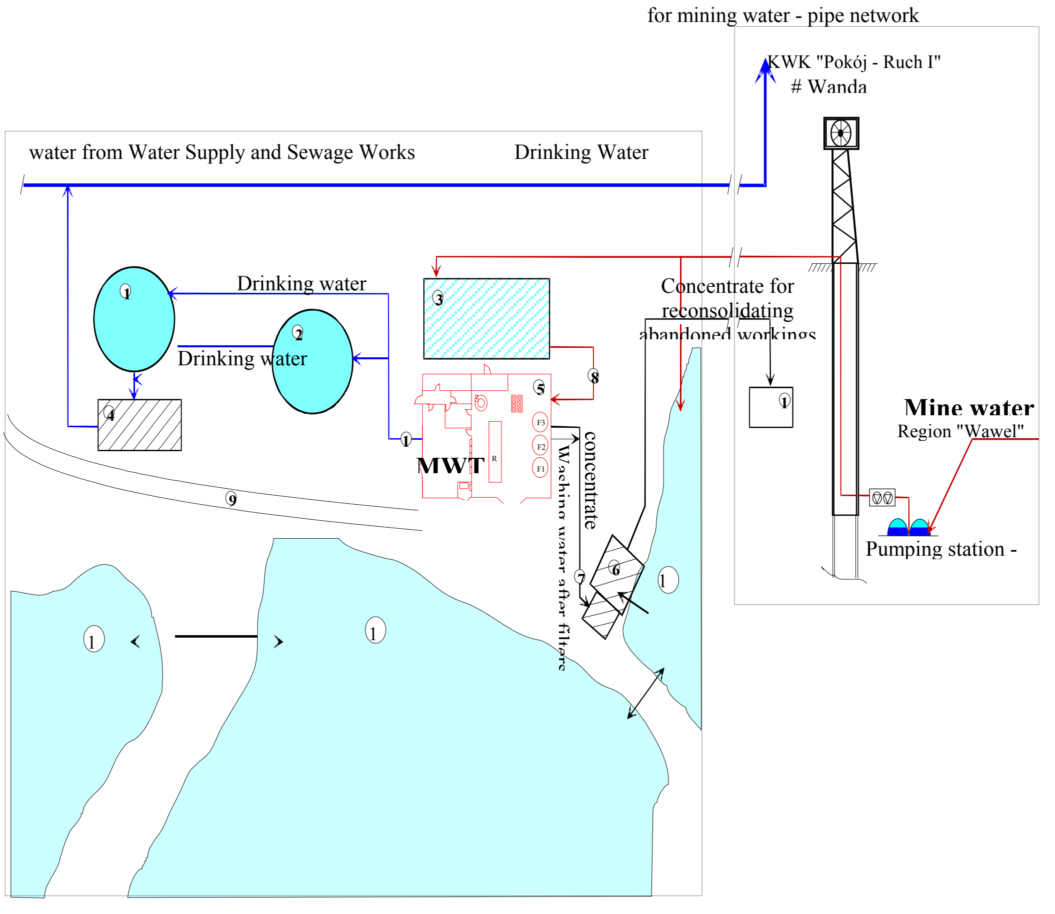


Figure 1 Localisation draft of the Mining Water Treatment Station

Explanation
1, 2 – existnig tank for drinking water (2 x 500 m^3 capacity)
3 - existing tank for raw water (1000 m^3)
4 – existing pumping station
5 – Projected mining water treatment station)
3 – existing pumping station for filling water
7 – predicted concentrate discharge from RO
and washing water after filters
8 – Feed MWTS raw water
9- transport road
10a, 10b, 10c – Deposit pond
11 – Outlet drinking water from MWTS
12 – Settling tanks for filling water near shaft “Lech II

3.2 Water supply – quantity and quality characteristics

As already mentioned, about 1600-1700 m^3/day of water at selected intakes, at 450 m working floor of Wawel district is pumped through an underground 300 m^3 tank at 600 m working floor up to the "Pokój" mine's surface where it shall be treated at the designed **MWTS**. The chemical content of this water exceeds several times parameters levels required for drinking water in the following categories:

- TDS – approx. 4.5 times
- sulphates content – approx. 10 times
- total hardness – approx. 5 times

At present the load of chlorides and sulphates amounting up to 3.52 T/day is disposed into Czerniawka River. After the excess of sulphate, calcium and magnesium ions is removed by using a membrane process it is predicted to achieve about 800 m^3 /day of drinking water and about 800 m^3/day of a concentrate that is mixed with power station waste to form a self solidify mixture used to fill the abandoned workings. The basic physical and chemical properties of raw water are shown in table 1.

3.3 Technological design assumptions of the mining water treatment station

The suggested mining water treatment technology has been developed bearing in mind the following assumptions:

- according to the quantity of pumped water and the forecast made in the current hydrological documentation of the liquidated Wawel coal mine it's 2500 m^3 of water available daily shall be treated,
- daily drinking water demand and other internal needs of the active coal mine part are estimated to be 800 – 1000 m^3.

The coal mine has a legal permission to draw water for it's internal purposes and to supply MWTS with 1600 m^3 daily which includes:

- 800 m^3 of drinking water for mine's supply,
- 800 m^3 of water for filling machinery supply.

The project assumes the use of several investment objects from the existing structure owned by „Pokój" coal mine:

- several existing drinking water tanks of 500 m^3 each shall be used to store the drinking water produced at MWTS; 1000 m^3 tank shall be used for raw water storage; drinking water pumping station shall be for piping the treated water into the mine's water supply system,
- 4500 m^3 settling pond and it's near-by mining water pumping station shall be used to pipe the concentrate obtained at MWTS to filling stations at abandoned workings,
- existing drinking water pipeline shall be used to supply water for the mine's internal needs,

- existing pipelines shall be used to pipe the concentrate from the pond's membrane installation to a 7500 m³ tank; a station shall be used to prepare self solidify filling mixes.

Table 1 Raw water content from "Pokój" coal mine "Wawel" district (maximal component content)

Parameter	Units	Value	Standard *
Colour	mgPt/l	10 – 80	20
Turbidity	$mgSiO_3/l$	5 – 10	10
pH	pH	7.65	6.5 – 8.5
Hardness	$mgCaCO_3/l$	2565	500
Conductivity	μS/cm	3550	
Alkalinity m	mval/l	7.85	
Alkalinity p	mval/l	0,00	
Temperature	^0C	15	
Ammonia	$mgN\text{-}NH_4/l$	< 0.15	0.5
Potassium	mgK/l	54.35	
Sodium	mgNa/l	32.19	
Magnesium	mgMg/l	320.80	
Calcium	mgCa/l	499	
Barium	mgBa/l	< 0.03	
Strontium	mgSr/l	4.20	
Iron total	mgFe/l	0.20	0.5
Manganium	mgMn/l	0.60	0.1
Carbonates	$mgCO_3/l$	0.00	
Acid Carbonates	$mgHCO_3/l$	478.90	
Nitrates	$mgN\text{-}NO_3/l$	0.90	10
Chlorides	mgCl/l	60.60	300
Fluorides	mgF/l	< 0.1	1.5
Sulphates	$mgSO_4/l$	2070	200
Phosphates	$mgPO_4/l$	< 0.2	
Silica dissolved.	$mgSiO_2/l$	19.2	
Bacteria	ml after 24 h	70	20

* - Ordinance of the Minister of Health and Welfare – 4 May 1990 (Dz.I. 35 pos. 205).

At the stage of designing the water treatment station a maximal content of ions found during physical and chemical water analysis had been assumed (Table 1). For the design of particular sections of the installation, results obtained from tests, measurements and computer membrane process simulations, had been assumed. Those were carried out at Water Desalination Lab of Central Mining Institute. (The following software programs were used: Hydronautics RO System Design, FilmTec Reverse Osmosis System Analysis and WinFlow by Osmonics). It is concluded that to remove the content excess of sulphate, calcium, magnesium ions and temporary hardness (set by the drinking water standard) it is best and optimal to apply a low pressure membrane method (reverse osmosis – nanofiltration). The best advantage of the membrane process is achieved at 50%

yield of treated water, but that requires a daily supply of 1600 – 1700 m³ of crude water. In order to reduce the use of chemicals, to improve physical and chemical parameters of treated water and to increase the station's yield it is intended to mix the treated water with filtrated raw water in quantities of up to 10%.

3.4 Technological analysis for membrane system installation

The membrane process optimisation for this water treatment station was based on testing and computer calculations. Bearing in mind the reliability of the water treatment process, achieving a complex water yield and investment costs, the obtained results prove that the following items are to the best advantage of the mining water treatment process (the station being designed):

- the application of two stage membrane system, (it's diagram and configuration are shown on figure 2)
- the application of Hydranautics membranes with their favoured parameters: low energy consumption, high efficiency and durability,
- mixing the treated water with filtrated crude water in quantities of up to 10% (after the reverse osmosis stage),
- disinfecting the mixed water,
- the use of anti-scaling agent,
- water pH correction before the reverse osmosis stage,
- de-gassing and alkalising of the treated water,

The following sections are included in the designed station:

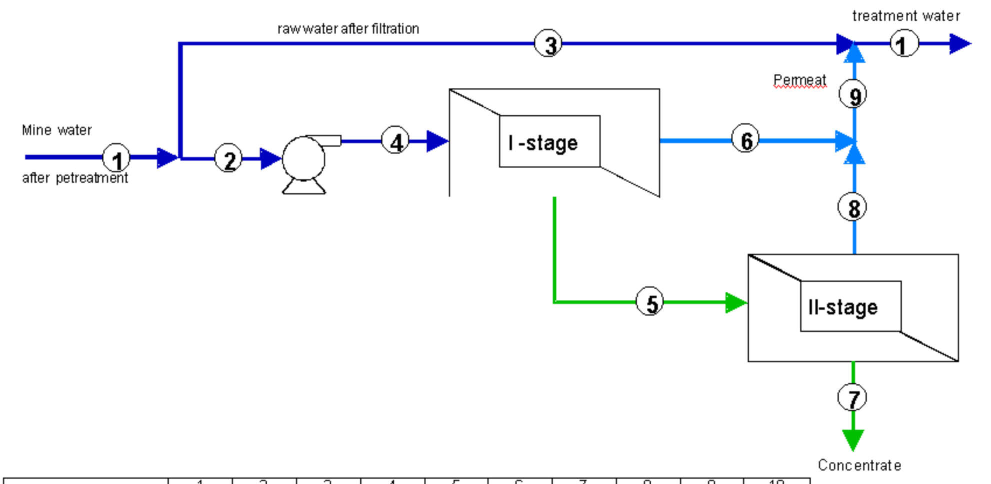
- preliminary water treatment,
- membrane filtration,
- water chemical content correction and disinfecting,
- chemicals dosing station, some sections which are outside the station's building use the existing mine's pipelines,
- treated water storage and piping

The following sequence takes place at the preliminary water treatment stage:

- water pH correction by hydrochloric acid,
- dosing flocculating or alternatively coagulating agents,
- filtration within dual-media pressure filters,
- dosing an anti-scaling agent to prevent the sediment precipitation of sparingly soluble sulphate salts on the surface of fine filters or membrane modules during the graduation process,
- fine filtration by the use of 25 μm filters,
- fine filtration by the use of 5 μm filters.

The above processes should assure that Slit Density Index (SDI) has it's value below 4.

In the membrane section the filtrated water is supplied by pressure pumps (15bar) into the two stage membrane system and after passing through the membranes the permeate (treated water) travels to the section of chemical content correction and disinfecting. Here it is de-gassed in a CO_2 desorber to remove the accumulated carbon dioxide. Then treated water is mixed with



	1	2	3	4	5	6	7	8	9	10
Flux [m^3/d]	70,2	66,7	3,5	66,7	42,0	24,7	33,4	8,6	33,3	36,8
Mineralisation [mg/dm^3]	3592,2	3592,2	3592,2	3592,2	5685,7	30,0	7139,4	87,5	45,4	367,5

Figure 2 Two steps reverse - osmosis - technical parameters

filtered crude water (8-10%), sodium hypochlorite disinfecting and finally sodium hydroxide is used to correct the pH of water.

Water treated as described above shall be stored in the existing and operated drinking water tanks and then it shall be piped to the existing mine's pumping station of drinking water. The concentrate from the membrane installation and filter washings shall be piped to the pumping station next to the settling pond of the designed water treatment station. Finally the concentrate is piped into the existing 7500 m³ tank; it shall supply the station where filling mixes are prepared and deposited at abandoned underground workings.

The treated water should posses the following content parameters presented in table 2. Water piped into the mine's pipeline system should have the characteristic as shown in table 3.

Table 2 The basic physical and chemical parameters of raw water, water after RO and the concentrate from MWTS

Parameter	Units	Water type		
		Raw water	Treated Water (after RO)	Concentrate (after RO)
PH	-	7.7	6.2	7.8
Ca^{2+}	[mg/l]	499	4.5	993.5
Mg^{2+}	[mg/l]	321	2.9	639.1
Na^{+}	[mg/l]	32.2	1.7	62.7
K^{+}	[mg/l]	54.4	4.1	104.7
CO_3^{2-}	[mg/l]	0	0	0
HCO_3^{-}	[mg/l]	479	20,3	858.9
SO_4^{2-}	[mg/l]	2070	11.1	4128.9
Cl^{-}	[mg/l]	112	2.9	267.1
NO_3^{-}	[mg/l]	0.9	0.1	1.7
SiO_2	[mg/l]	19.2	1	37.4
Mineralization	[mg/l]	3576.1	48.7	7103.5

The design assumes that the treated water shall be used within the mine's drinking water pipelines system. The concentrate, however, is planned to be used in self solidify mixes together with power station waste to reconsolidate abandoned workings. Additionally filter washings from the Stage I of MWTS are to be deposited with the concentrate as well. One of settling ponds shall be selected as a storage reservoir for the concentrate to supply filling material tanks. Until now 3300 m³ per day of mining water is being used for this purpose.

Table 3 The MWTS Treated water parameters versus the maximal standard values according to Health Ministry decree on the quality of drinking and domestic use water.

No.	Parameter	Units	Raw water	MWTS Treated Water	Health Ministry Decree 4th May 1990
1.	**Mineralization TDS**	[mg/l]	3000 – 4500	360 – 390	800
2.	**pH**	-	7.2 – 8.2	8.25 – 8.45	6.5 – 8.5
3.	**Hardness total**	[mg$CaCO_3$/l]	1800 – 2600	250	500
4.	**Chlorides**	[mgCl^-/l]	130 – 150	12 – 17	300
5.	**Sulphates**	[mgSO_4^{2-}/l]	1500 – 2100	180 – 198	200
6.	**Iron**	[mgFe/l]	0.1 – 0,2	0	0.5
7.	**Calcium**	[mgCa/l]	370 – 500	50	Depends on the water hardness
8.	**Magnesium**	[mgMg/l]	250 - 350	70	Depends on the water hardness

Table 4 The basic physical and chemical parameters of water used in filling preparation.

Water type	**Mineralization [g/l]**	**Ca^{2+} [mg/l]**	**Mg^{2+} [mg/l]**	**Cl^- [mg/l]**	**SO_4^{2-} [mg/l]**
Filling water	3903.8	287.5	201.1	992.9	1458.5

When comparing the data in tables 2 and 4 it can be found that the concentrate mineralization is 4.8 times higher than this of water used in preparation of self solidify mixes so far. The use of such concentrate shall increase the load of salts (chlorides and sulphates) deposited in the abandoned working along with the sky ash. So this amount of load is effectively eliminated from dumping into the surface water courses (Czerniawka River - Kłodnica River tributary).

Figures 3 and 4 , below, present the balance of load piped along with mining waters through a surface settling pond to Czerniawka River before and after MWTS realisation.

Comparing the above balances (Figures 3 and 4) it can be found that after starting the MWTS (supplied by 1600 m³/day of mining water from 450 m floor of Wawel district) the amount of salts (chlorides and sulphates) dumped by

"POKÓJ" coal mine into the Czerniawka River has been diminished by approximately 24% (3.52 t/day).

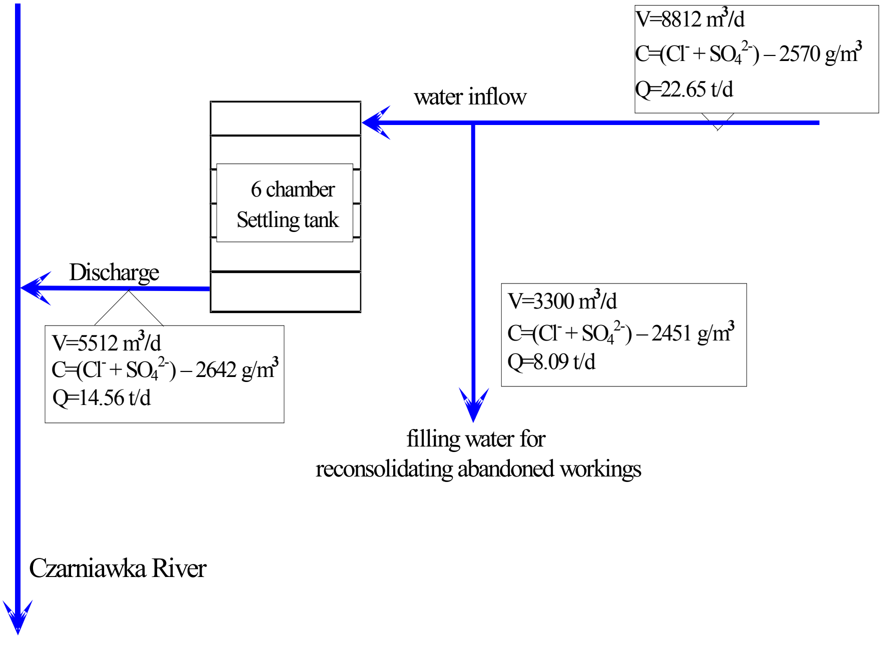


Figure 3 The balance of load and mining water discharged through the surface settling tank into the Czerniawka River (1997)

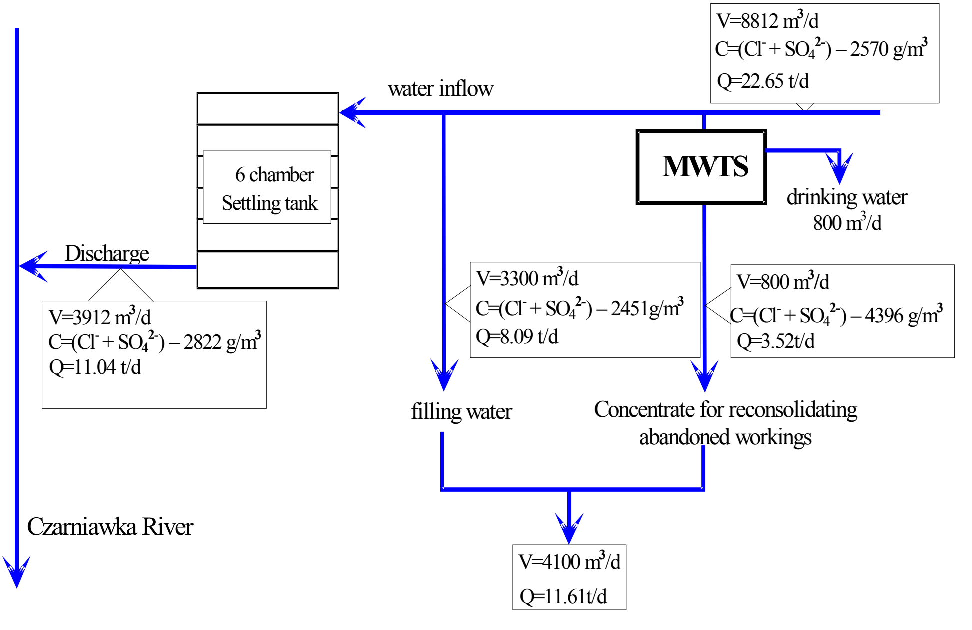


Figure 4 The balance of load and mining water discharged through the surface settling tank into the Czerniawka River after MWTS has been finalised.

3.5 Computations on energy use and production costs in reverse osmosis water system

Computations were performed using appropriate computer programs for the following data input:

A. Data Input:

- raw water supply	1682 m^3/day
- raw water temperature	15º C
- pH of crude water	7.65
- acid dosing	4.7 kg/h
- membrane flow rate	20.9 dm^3/m^2h
- treated water yield	50%
- raw and treated water mixing ratio	9.5% (~84m^3/day)
- treated water flow rate (after RO)	800 m^3/day
- membrane flow rate reduction	7% per year
- increase of permeate salinity	10% per year
- membrane system	two stage
- total number of membrane modules	43

B. Computing the electric power demands.

Assumptions:

- permeate flow rate	800 m^3/h
- pumps' efficiency	83%
- electric motors' efficiency	93%

Results:

- electric power demand per m^3 of treated water	0.57 kWh/m^3
- power required for pumping	22.4 kW
- power recovery	3.2 kW
- power demand	19.1 kW

C. Computations of investment and water recovery costs at reverse osmosis installation.

Assumptions:

- efficiency of water treatment station	885 m^3/day
- station investment cost (without building)	400,000 USD (1 600 000 zł)
- investment instalment	12%
- production capacity coefficient of the membrane system	90%
- electric energy unit cost	0.06 USD/kWh (0.24 zł/kWh)
- electric energy consumption	0.57 kWh/m^3
- routine repairs, conservation and maintenance (as % of the investment costs)	3%
- predicted life time of the installation	15 years

- membrane durability	3 years
- number of modules	43
- costs of ant-scaling agents	USD 4.0 / kg
- cost of hydrochloric acid	USD 0.3 / kg

Elementary costs per 1m³ of treated water (USD/m³)

Costs of Invested capital	0.20
Costs of Electrical energy	0.03
Costs of chemicals	0.08
Costs of membrane changing	0.06
Costs of routine repairs, conservation and labour	0.04
Total cost of 1m³ of water	**0.41 USD/m³ (~1,6 PLN)**

4 SUMMARY

The Mining Water Treatment Station has been designed to process water from the liquidated "Wawel" district of "POKOJ" coal mine at Ruda Śląska. It has a pro-ecological character.

After the project is finished a load of 3.52 t/day of chloride and sulphate ions shall be eliminated from the daily dump to Czerniawka River and shall be deposited as a filling in the abandoned workings.

The realisation of this project shall positively contribute to the environmental issues and shall be beneficial for the Czerniawka River water protection, by limiting the chlorides and sulphates dump by approximately 24%.

After the project is realised the coal mine shall not continue buying water from Water Supply and Sewage Works because daily demands of 800 – 1200 m³ for drinking water and domestic needs shall be provided by the MWTS.

The decrease of the dumping shall also result in saving of approximately 400 000 zł yearly due for fees and fines. The difference between water buying costs and water treatment costs results in further savings of about 100 000 zł/year. In summary "POKÓJ" coal mine shall save about 500 000 zł/year assuming present levels of fees and fines.

The presented project solution of protecting the underground water resources by using them for drinking and domestic purposes could be a good example to follow by other coal mines, particularly those liquidated districts.

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Zastosowanie techniki membranowej do uzdatniania do celów konsumpcyjnych i komunalnych zmineralizowanych wód kopalnianych będącej w likwidacji KWK „Pokój"

Antoni Magdziorz, Jacek Seweryński

Streszczenie: W artykule przedstawiono założenia budowy stacji uzdatniania wód kopalnianych dla celów pitnych i gospodarczych. Stacja uzdatniania ma być zlokalizowana przy kopalni węgla kamiennego „Pokój" w Górnośląskim Zagłębiu Węglowym. Projekt jest realizowany przez Zakład Ochrony Wód w Głównym Instytucie Górnictwa w Katowicach. Uzdatnianie słonych wód kopalnianych ma być prowadzone metodą membranową. Dobór optymalnych parametrów procesu uzdatniania symulowany jest komputerowo. W projekcie określone są również koszty energii potrzebnej do produkcji 1m^3 uzdatnionej wody.