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IRON AND MANGANESE REMOVAL USING OXYGENATION AND FILTRATION METHOD ON AN EXAMPLE OF ARKONKA UNDERGROUND WATER INTAKE

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Abstract

Test was done on Arkonka underground water intake. To perform it, it was constructed the model station composed of the closed gravity filter, oxygen supply system, water supply system and a mixer. For needs of the experiment it was determined the iron reduction degree, manganese reduction degree, pH determination, determination of the oxygen contents in treated water. The above determinations were to be helpful in analysis of that innovatory technology. The background for the comparison were the results of the above determinations for the aeration – filtration technological line in use on Arkona water intake. That comparison comprised the analysis of the reductive effectiveness of the particular methods with the comparison of the costs of their industrial-scale operation.

Key words: underground water intake, oxygenation and filtration method, treated waters

INSTALLATION DESCRIPTION – DIAGRAMS, PRINCIPLE OF OPERATION

Installation (Fig. 1.) prepared for the need of the experiment is composed of four basic elements:
– raw water supplying part (PVC pipe, diameter Φ15),
– oxygen supplying part (flexible hose, diameter Φ8),
– mixer (PVC pipe, diameter Φ50, filled with Raschig rings),
– rapid filter, closed, pressure (acc. to Fig. 3),

Here is applied the oxygenation-filtration technological line, which was compared, as it was mentioned before, with the aeration-filtration line operating on the Arkona water intake (Sozańska and Sozański 1989). In order to secure the objectivity of the comparison, in the prepared installation (fig. 2) remained the same column filling as well as the same filtration rapidity as on the station. It was connected with accepting the same number of nozzles on the square area unit, as well as the identical bed

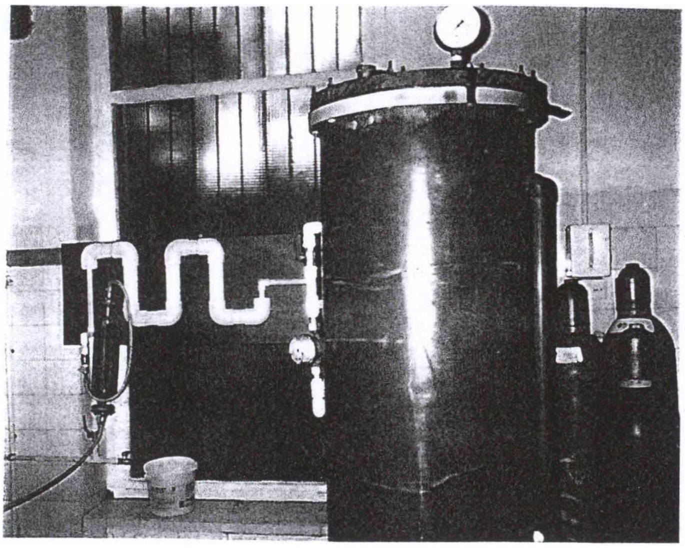

Fig. 1. Model station, where the experiment was done

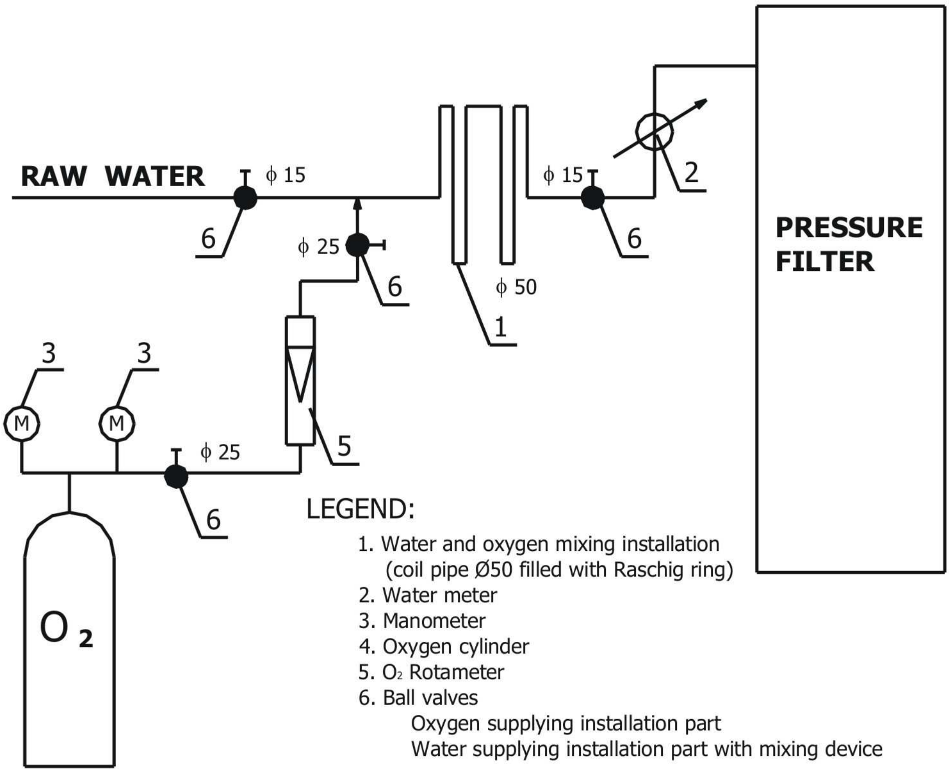

Fig. 2. Schematic diagram of model station

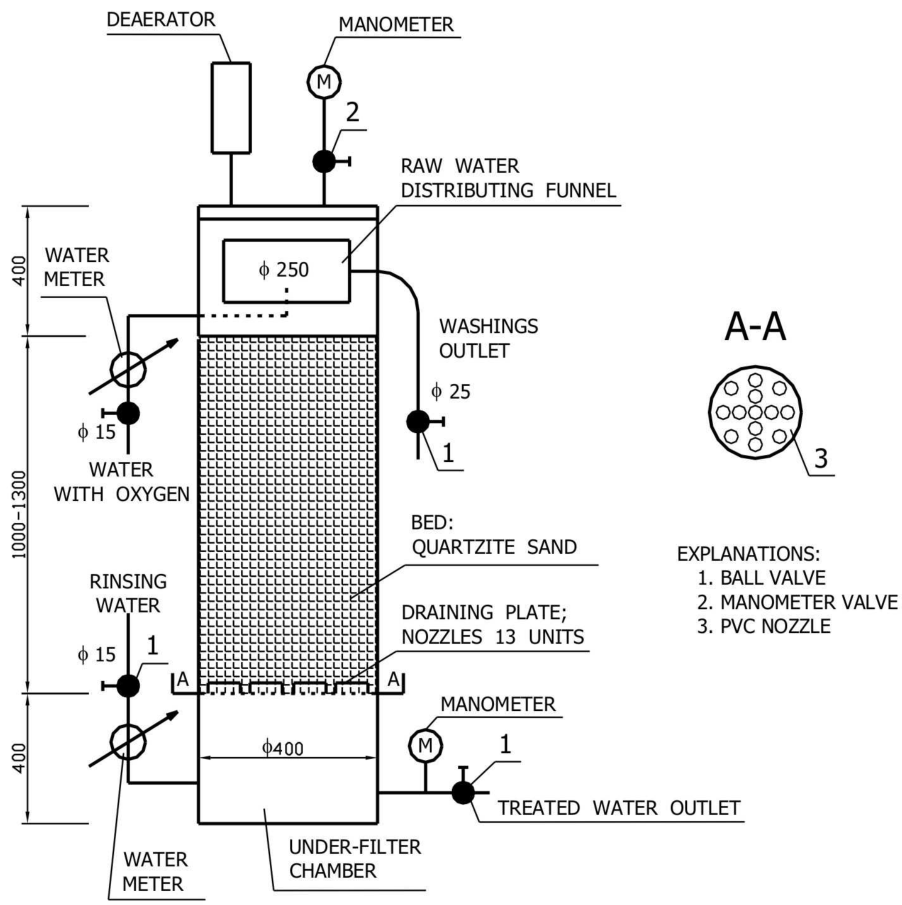

Fig. 3. Schematic diagram of model pressure filter

deepness in the starting phase of the experiment (Kowal and Świderska-Bróż 1987). At the same filtration rate we could see, whether the achieved reductions were better, or worse than those achieved on the aeration-filtration system existing on that intake (Trzeciak 1983).

INSTALLATION OPERATION DESCRIPTION

Water coming from the intakes (raw water) was supplied through a pipe (PVC pipe, diameter Φ50), where oxygen was supplied too (flexible hose, diameter Φ8). At the same part of the installation took place the mixing of those two components. To increase the process effectiveness, the mixer was filled with the Raschig rings.

To determine the oxygen flow was used the oxygen rotameter with the range of 0-6 dm^3h^{-1}.

The test was performed for three various oxygen doses: 0.4 dm^3h^{-1}; 1.0 dm^3h^{-1}; 2.0 dm^3h^{-1}.

The demanded oxygen flow was determined using the water meter indicating the quantity of the component, stop watch indicating the time, during which the particular quantity has flown as well as the valve, using which the flux density was controlled. All tests were done for the single, fixed water flow.

After having been mixed with oxygen, water flew through a pipe (PVC pipe, diameter Φ 15) to the filter. In its upper part was designed and made a funnel, diameter Φ 250, whose task was to spread water uniformly onto the bed situated under the funnel. The water, going through the bed, left iron, manganese and other pollutants therein, which took the insoluble form as a result of the oxygenation. Filter, at the starting phase of the experiment, was filled with the bed 1m deep (Kowal 1969, Bohdanowicz and Wierzbicki 1992, Dojlido 1992). During the next phases of the experiment the bed was deepened up to 1.3 m. As the filling material was used the quartzite sand.

Filtered, what means theoretically free of pollutants water was sent through nozzles (13 units) situated in the bottom plate to the under-filter chamber, from where it was collected to make determinations, which should determine its quality, or it was disposed to the sewage system (Kowal et al. 1986).

The entire experiment consisted of six filtration cycles of 72 h each. Three of them at the bed deepness of 1m and respective oxygen dose: 0.4 dm^3h^{-1}; 1.0 dm^3h^{-1}; 2.0 dm^3h^{-1}. The next three – with the bed 1.3 m deep and the same oxygen doses. Length of the filtration cycle was determined according to the pressure fall on the filter below the assumed value, such fall resulted from so called "filter choking" and therefore it meant the considerable reduction of the filtration abilities. Pressure fall was indicated by two manometers situated in the upper and lower parts of the filter. Pressure in the filter amounted, at the beginning of the filtration cycle, to 1.2 bar. The admissible pressure fall – 20% therefore 0.2 bar.

After each filtration cycle the filter was rinsed in order to regenerate the bed (Osmęga-Ernst and Witczak 1991). For the rinsing needs was used the water coming from the local water treatment plant. During that process all inlet valves were closed, therefore the filter did not work.

The rinsing water was supplied through a pipe (PVC pipe, diameter Φ 15) to the under-filter chamber, from where, through the draining nozzles, it went to the filter part containing the bed. Under the influence of the water, the bed has been loosened and expanded. Water coming from rinsing (so called washings) was disposed through the appropriate pipe (PVC pipe, diameter Φ 25) to the sewage system. Rinsing time: 0.5 h, rate: 20 m/h. After the rinsing took place the next filtration cycle.

DETERMINATION OF OPERATING PARAMETERS OF MODEL STATION DETERMINATION OF FILTRATION OUTPUT AND RAPIDITY

Output of one filter operating at ZPW Arkonka:

$Q_f = 41.7\ m^3h^{-1}$

Filtration rapidity:
V_f = 9.2 mh^{-1}
output of the model station keeping the same filtration rapidity (V_f = 9.2 mh^{-1})
Filter made of the pipe Ø 400 therefore its surface amounts to: A = 0.13m^2
$Q_{sm} = V_f$ x A = 9.2 x 0.13 =1.2 mh^{-1}

DETERMINATION OF OXYGEN DOSE

Table 1

Unit consumption of O_2 used for oxygenation of Fe (II) and Mn (II)

oxygenated ion	stoichiometric consumption of O_2 (gm^{-3}) for oxygenation of 1g Fe (II); Mn (II)/m^3
Fe (II)	0.14
Mn (II)	0.29

Table 2

Physical properties of O_2

GAS	Boiling point	gaseous state (m^3)	mass (kg)
O_2	-183°C	1	1.35
		0.74	1

Pollutants quantities in the raw water:

Iron 1.5 gm^{-3}
Manganese 0.4 gm^{-3}
Oxygen demand of l m^3 of treated water:
1.5*0.14 + 0.4*0.29 = 0.326 gm^{-3}
Determination of oxygen flow water flow for the model station:
$Q_{sm} = V_f$ x A = 9:2 x 0.13 =1.2 m^3h^{-1}

l m^3 of water – 0.326 g O_2
1.2 m^3 of water - X g O_2
X = 0.39 g
Oxygen flow determined according to the stoichiometric consumption of oxygen necessary to oxygenate iron and manganese (Table 1, Table 2) as well as to the water flow amounts for the model station to:
0.39 g O_2h^{-1} = 0.29 dm^3h^{-1}. Taking into account other pollutants contained in the water, which are also subject to the oxygenation, the oxygen flow was increased up to 0.4 dm^3 h^{-1} = 0.54 g
O_2h^{-1} = 0.45 $mgdm^{-3}$;
Test was performed for three oxygen doses:
- 0.4 dm^3h^{-1}= 0.54 g O_2/h = 0.45 $mgdm^{-3}$

- dm^3h^{-1}= 1.35 g O_2/h = 1.13 $mgdm^{-3}$
- dm^3h^{-1}= 2.7 g O_2/h = 2.25 $mgdm^{-3}$

BED DEEPNESS, FILTRATION MATERIAL

In the first experiment phase (filtration cycles: I, II, III) was kept the same bed deepness as is in the existing filters of ZPW Arkonka i.e. l m. During the next three filtering cycles the bed was deepened up to 1.3 m.
As the bed was used the quartzite sand coming from the filters of ZPW Arkonka.

DIAGRAMS AND TABLES

Results achieved from the determinations have been specified in tables (Table 3, Table 4, Table 5, Table 6, Table 7, Table 8). Each filtration cycle was presented in a separate table.

COMPARISON OF THE AERATION COSTS WITH THE OXYGENATION COSTS AERATION COSTS

They are composed mainly of the costs of electric energy consumption by the compressor. Other costs are the possible repairs of the equipment. We assume that it is within the warranty period i.e. the repair costs are covered by the manufacturer.
Daily water production at ZPW Arkonka amounts to 4000 m^3d^{-1}, for the aeration needs is used there the compressor with the delivery of 80 $m3h^{-1}$ and engine power 11 kW. The cost of l kWh: 0,20 PLN
Annual energy consumption amounts to:
11 kW * 24 h * 30 days * 12 months * 0.20 PLN/ kWh = **19 008 PLN**

OXYGENATION COSTS

They are composed of the tank lease costs and the oxygen consumption costs. The costs of the annual lease of the tank amounts to 12 000 PLN.
Oxygen consumption for the daily water production amounting to 4000 m^3d^{-1}:
4000 m^3d^{-1}* 0.45 gm^{-3} =1800 g = 1.8 kg O_2day^{-1}
Price of l kg O_2 : 0.30 PLN
Cost of the annual oxygen consumption:
1.8 kg * 30 days * 12 months * 0.30 PLN kg^{-1} O_2 = 195 PLN

Total oxygenation costs:
12 000 PLN + 195 PLN = **12 195 PLN**
As results from the above cost analysis, the aeration price is considerably higher than the oxygenation costs. The attention should be pay to the fact, that the majority of

Table 3

FILTRATION CYCLE I AT THE OXYGEN O_2 FLOW = 0.4 dm^3h^{-1} = 0.42 $mgdm^{-3}$
BED DEEPNESS 1 m

FILTRATION CYCLE HOUR	IRON Fe			MANGANESE Mn			OXYGEN IN TREATED WATER ($mgdm^{-3}$)	ph Reaction
	% REDUCTION	RAW WATER ($mgdm^{-3}$)	TREATED WATER ($mgdm^{-3}$)	% REDUCTION	RAW WATER ($mgdm^{-3}$)	TREATED WATER ($mgdm^{-3}$)		
0 h	1.41	0.1	92.91	0.41	0.26	36.59	0.04	7.5
4 h	1.49	0.06	95.97	0.41	0.26	36.59	0.04	7.5
8 h	1.51	0.08	94.70	0.38	0.28	26.32	0.06	7.5
24 h	1.46	0.1	93.15	0.4	0.3	25.00	0.06	7.5
32 h	1.51	0.12	92.05	0.39	0.32	17.95	0.08	7.6
48 h	1.5	0.12	92.00	0.39	0.32	17.95	0.06	7.6
72 h	1.49	0.22	85.23	0.4	0.34	15.00	0.06	7.6

Table 4

FILTRATION CYCLE II AT THE OXYGEN O_2 FLOW= 1.0 dm^3h^{-1} = 1.04 $mgdm^{-3}$
BED DEEPNESS 1 m

FILTRATION CYCLE HOUR	IRON Fe			MANGANESE Mn			OXYGEN IN TREATED WATER ($mgdm^{-3}$)	ph Reaction
	% REDUCTION	RAW WATER ($mgdm^{-3}$)	TREATED WATER ($mgdm^{-3}$)	% REDUCTION	RAW WATER ($mgdm^{-3}$)	TREATED WATER ($mgdm^{-3}$)		
0 h	1.48	0.1	93.24	0.41	0.28	31.71	0.71	7.5
4 h	1.49	0.08	94.63	0.39	0.28	28.21	0.74	7.5
8 h	1.51	0.08	94.70	0.4	0.3	25.00	0.71	7.5
24 h	1.46	0.1	93.15	0.4	0.3	25.00	0.72	7.6
32 h	1.5	0.1	93.33	0.38	0.3	21.05	0.7	7.5
48 h	1.5	0.14	90.67	0.42	0.32	23.81	0.73	7.5
72 h	1.51	0.22	85.43	0.4	0.34	15.00	0.73	7.6

Table 5

FILTRATION CYCLE III AT THE OXYGEN O_2 FLOW= 2.0 dm^3h^{-1} = 2.08 $mgdm^{-3}$
BED DEEPNESS 1 m

FILTRATION CYCLE HOUR	IRON Fe			MANGANESE Mn			OXYGEN IN TREATED WATER ($mgdm^{-3}$)	ph Reaction
	% REDUCTION	RAW WATER ($mgdm^{-3}$)	TREATED WATER ($mgdm^{-3}$)	% REDUCTION	RAW WATER ($mgdm^{-3}$)	TREATED WATER ($mgdm^{-3}$)		
0 h	1.5	0.1	93.33	0.42	0.24	42.86	1.64	7.6
4 h	1.45	0.08	94.48	0.4	0.26	35.00	1.7	7.6
8 h	1.5	0.08	94.67	0.4	0.28	30.00	1.68	7.5
24 h	1.48	0.1	93.24	0.41	0.3	26.83	1.68	7.5
32 h	1.48	0.1	93.24	0.38	0.32	15.79	1.66	7.5
48 h	1.5	0.12	92.00	0.38	0.32	15.79	1.7	7.5
72 h	1.49	0.22	85.23	0.4	0.34	15.00	1.66	7.5

Table 6

FILTRATION CYCLE IV AT THE OXYGEN O_2 FLOW = 0.4 dm^3h^{-1} = 0.42 $mgdm^{-3}$
BED DEEPNESS 1 m

FILTRATION CYCLE HOUR	IRON Fe			MANGANESE Mn			OXYGEN IN TREATED WATER ($mgdm^{-3}$)	ph Reaction
	% REDUCTION	RAW WATER ($mgdm^{-3}$)	TREATED WATER ($mgdm^{-3}$)	% REDUCTION	RAW WATER ($mgdm^{-3}$)	TREATED WATER ($mgdm^{-3}$)		
0 h	1.5	0.1	93.33	0.42	0.24	42.86	1.64	7.6
4 h	1.45	0.08	94.48	0.4	0.26	35.00	1.7	7.6
8 h	1.5	0.08	94.67	0.4	0.28	30.00	1.68	7.5
24 h	1.48	0.1	93.24	0.41	0.3	26.83	1.68	7.5
32 h	1.48	0.1	93.24	0.38	0.32	15.79	1.66	7.5
48 h	1.5	0.12	92.00	0.38	0.32	15.79	1.7	7.5
72 h	1.49	0.22	85.23	0.4	0.34	15.00	1.66	7.5

Table 7

FILTRATION CYCLE V AT THE OXYGEN O_2 FLOW = 1.0 dm^3h^{-1} = 1.04 $mgdm^{-3}$
BED DEEPNESS 1 m

FILTRATION CYCLE HOUR	IRON Fe			MANGANESE Mn			OXYGEN IN TREATED WATER ($mgdm^{-3}$)	ph Reaction
	% REDUCTION	RAW WATER ($mgdm^{-3}$)	TREATED WATER ($mgdm^{-3}$)	% REDUCTION	RAW WATER ($mgdm^{-3}$)	TREATED WATER ($mgdm^{-3}$)		
0 h	1.51	0.12	92.05	0.41	0.27	34.15	0.66	7.5
4 h	1.47	0.1	93.20	0.38	0.24	36.84	0.7	7.5
8 h	1.48	0.08	94.59	0.38	0.28	26.32	0.68	7.5
24 h	1.5	0.12	92.00	0.4	0.28	30.00	0.68	7.6
32 h	1.5	0.12	92.00	0.41	0.3	26.83	0.72	7.6
48 h	1.48	0.14	90.54	0.4	0.32	20.00	0.7	7.6
72 h	1.5	0.22	85.33	0.42	0.34	19.05	0.72	7.6

Table 8

FILTRATION CYCLE VI AT THE OXYGEN O_2 FLOW = 2.0 dm^3h^{-1} = 2.08 $mgdm^{-3}$
BED DEEPNESS 1 m

FILTRATION CYCLE HOUR	IRON Fe			MANGANESE Mn			OXYGEN IN TREATED WATER ($mgdm^{-3}$)	ph Reaction
	% REDUCTION	RAW WATER ($mgdm^{-3}$)	TREATED WATER ($mgdm^{-3}$)	% REDUCTION	RAW WATER ($mgdm^{-3}$)	TREATED WATER ($mgdm^{-3}$)		
0 h	1.5	0.08	94.67	0.4	0.24	40.00	1.66	7.5
4 h	1.5	0.08	94.67	0.4	0.26	35.00	1.7	7.5
8 h	1.52	0.1	93.42	0.38	0.28	26.32	1.66	7.5
24 h	1.48	0.1	93.24	0.38	0.3	21.05	1.68	7.5
32 h	1.48	0.12	91.89	0.38	0.3	21.05	1.68	7.5
48 h	1.5	0.12	92.00	0.42	0.32	23.81	1.7	7.5
72 h	1.5	0.22	85.33	0.42	0.34	19.05	1.66	7.5

the oxygenation costs is the tank lease price. The oxygen consumption cost amounts only to 195 PLN.
Profitability of the oxygen utilisation is visible but its effectiveness in conditions prevailing at ZPW Arkonka is not convincing.

CONCLUSIONS

According to the tests performed we have stated that, keeping the existing working conditions of the filters operation, the change of the aeration-filtration technological line into the oxygenation-filtration technological line does not result in the quality improvement of the treated water. Manganese compounds contents in the water shall still remain on the level exceeding the permissible standard of 0.1 $mgdm^{-3}$. The best result achieved by now during the tests amounted to 0.24 $mgdm^{-3}$.
However we should not totally resign of the purposefulness of use of the oxygenation in water treatment processes. Further tests of that innovatory method are necessary in better working operations of the filters. Comparison of the aeration costs with the oxygenation costs, which resulted considerably in favour of the second one, induced us also to continue to perform them.
What might have the adverse effect on the results?

- pH of the raw water amounting to 7.5÷7.6 in case of the inactive bed (quartzite sand) is too low to secure the effective oxygenation of manganese,
- tests were performed at the high filtration rapidity $V_f = 9.2\ mh^{-1}$,
- rinsing process took place using the same water as result of which too low expansion of the bed was achieved, what made the effective rinsing impossible,
- as the bed was used the quartzite sand coming from the filters operating at Arkonka, this is the filling, which does not have any special properties concerning the manganese reduction.

To improve the quality of water coming from Arkonka it should be performed the modernisation of that intake basing on the economic aspects i.e. not to change the equipment working there, but to try to improve their operation through:

- reduction of filtration rapidity, what does not need any financial outlays,
- use water and air to rinsing, what does not require so big expansion of the bed as rinsing with the water only and brings considerably better effects,
- it should be made the attempt to activate the bed used in the intake (quartzite sand) using the potassium permanganate,
- change of a part of the bed i.e. use of the two-layers' filters, one of the layers would be the quartzite sand in use, and the second one battery manganese – manganese ore, the grains of which are coated by the manganese dioxide, application of such filling should result in the effective demanganisation of the water.

If the above modifications do not result in the quality improvement of the treated water, it should be decided to increase pH of the water, which would force the change of technology and as result the considerable costs.
During the tests the deepness of the bed was increased, what did not result in any effect, what should be remembered during the intake modernisation.

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USUWANIE ŻELAZA I MANGANU METODĄ NATLENIANIA I FILTRACJI NA PRZYKŁADZIE UJĘCIA WÓD PODZIEMNYCH ARKONKA

Streszczenie

Celem przeprowadzonych badań było stwierdzenie przydatności ciekłego tlenu i filtracji dla potrzeb uzdatniania wody. Badania przeprowadzono na ujęciach wód głębinowych Arkonka. Aby je wykonać zbudowano stację modelową składającą się z filtra grawitacyjnego zamkniętego, instalacji doprowadzającej tlen, instalacji doprowadzającej wodę i mieszacza. Dla potrzeb doświadczenia wyznaczono stopień redukcji żelaza, stopień redukcji manganu, oznaczenie pH, oznaczenie zawartości tlenu w wodzie uzdatnianej. Powyższe oznaczenia miały pomóc w analizie tej nowatorskiej technologii. Tłem porównawczym były wyniki powyższych oznaczeń dla ciągu technologicznego napowietrzenie – filtracja, którą stosuje się na ujęciu wody Arkona. W zakres tego porównania wchodziła analiza efektywności redukcyjnych poszczególnych metod wraz z porównaniem kosztów ich zastosowania na skalę przemysłową.