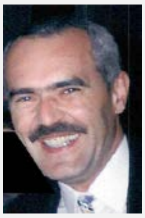
Impact of groundwater quality on heat pump operation



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It is not enough to determine the abundance and depth of the well as a source, but it is also necessary to perform a chemical water analysis at the project design stage in order to avoid possible exploitation problems. It is a misconception that only mechanical groundwater impurities can affect the operation of a heat pump; even greater problems are caused by bacteria that may appear in the environment of increased concentrations of some chemical elements. How to find a solution? This paper is based on practical example.

Key words: groundwater, heat pumps performance, chemical analysis, bacteria impact

The application of heat pumps in the field of heating and cooling of residential and business buildings in the Republic of Serbia has become significant. The use of renewable energy sources is a global trend and also an international obligation to reduce the use of conventional, depleted, energy sources and preserve a cleaner living environment. In this paper, the emphasis will be placed on the thermal use of groundwater as a renewable energy resource.

Legal regulation

There is no legal regulation for the use of air and earth as energy resources in the Republic of Serbia, while the Ministry of Energy once issued instructions and recommendations for the use of groundwater, which in practice were at the level of legal regulations. The given recommendations were very rigorous and complicated, as if the settlement was supplied with drinking water, not taking into account that groundwater is used exclusively as technical water, which is returned to nature in the same amount, without changing the chemical composition and with a slight temperature change allowed.

Certainly, in the near future, the rules and procedures for the use of all forms of renewable energy sources must be clearly and realistically defined through legislation in order to avoid problems in practice, so that all users of renewable energy sources should be registered and the Republic of Serbia will reach the prescribed percentage of renewable energy sources. in total energy consumption, prescribed by the European Union Directive 2018/2001[4]

Case study

In the current practice when using water-to-water heat pumps, the main focus was on the secondary part of the air conditioning installation and the heat pump itself as a device: proper calculation of energy needs, proper sizing of equipment and access to groundwater as an energy resource was superficial, based on experience of others or pre-letting someone else to solve. The only criteria for excavating the well was the natural static groundwater level, the depth of the well and the dynamic level of groundwater during exploitation (well yield).

Many papers have been published on the impact of groundwater quality on heat pump operation and capacity [6], the impact of heat pump operation on the environment, the impact of chemical composition and groundwater temperature on heat pump operation [5], but only few papers have focused on the impact of bacteria on optimal heat pump operation and on the environment [2] which in practice can arise as a major problem.

Some basic facts have been neglected: that in general the waters in the Republic of Serbia are slightly alkaline and hard and that precipitation and air temperature have the greatest impact on groundwater recharge and quality, especially on free-level and shallow horizons, where water was mostly used. The chemical composition of groundwater has been completely neglected and it turned out that it is very important in the correct determination of the location and other parameters of the well. **Figure 1** shows the characteristic profiles of well in the vicinity of Pecinci, and **Figure 2** shows well in Pancevo.

The picture shows all aquifers potentially suitable for exploitation, but the exploitation of groundwater is carried out from three horizons: 56–61.5 m, 67–76 m and 82–84.5 m due to the water quality where the suction screens are placed. The purpose of this well with a diameter of Ø450 mm is for irrigating seedlings with technical water by pumping with a submersible pump and free outflow of water through a perforated pipe network. The achieved water flow is 12 ℓ/s, with a depression of 4.5 m.

It can be seen that groundwater is exploited from two horizons: 30–40.5 m and 48.5–57.5 m, where suction screens are installed. The purpose of this well with a diameter of Ø323 mm is to supply the heat pump of the water-water system with technical water by pumping with two cascaded submersible pumps placed each on one exploitation horizon and pouring water into an open channel for collecting and draining groundwater and atmospheric water. The achieved water flow is 7 ℓl/s.

It is noticeable that in both wells, which are located on the territory of Vojvodina, the layers below 40 m have approximately the same composition, while in the upper layers the composition looks different due to surface influences and microclimate (precipitation, aeolian sediments, soil leaching, etc.). There were no problems during the exploitation of the well in Pecinci because the submersible pump freely discharged water into the irrigation system, while during the exploitation of the well in Pancevo for the purpose of supplying the heat pump, serious problems appeared.

System description

For the needs of hot and cold water production used in the air conditioning system in the building, a heat pump of the water-water system with a heating capacity of 142 kW with four cascaded compressors is provided. A detachable lamellar heat exchanger is installed to protect the heat pump. For pumping groundwater, two submersible pumps were installed in a cascade, at the depths of groundwater exploitation. The pumps are switched on depending on the required flow, i.e. the engaged capacity of the heat pump.

During the exploitation, a reddish colour of groundwater was noticed, which carried with it a certain dense mass resembling mud (**Figure 3**). This mass was deposited in the pre-exchanger, reducing the flow to such an extent that the compressors were switched off one by one until the moment of cessation of operation. The pre-exchanger was disassembled and cleaned every 10 days, which caused a delay in the operation of the air conditioning system, costs and, in the end, the nonsense of installing such a system.

In some other, smaller facilities, an identical situation occurred: the heat pump heat exchanger was clogged, the pre-filter was changed every 7 days, and the submersible pump itself was covered with a reddish mass resembling mud that absolutely prevented groundwater suction and shutdown. system. By rinsing the heat exchanger with chemical agents, replacing the filter and removing and cleaning the submersible pump, the problems were solved for a short time, and some of them gave up the use of the heat pump.

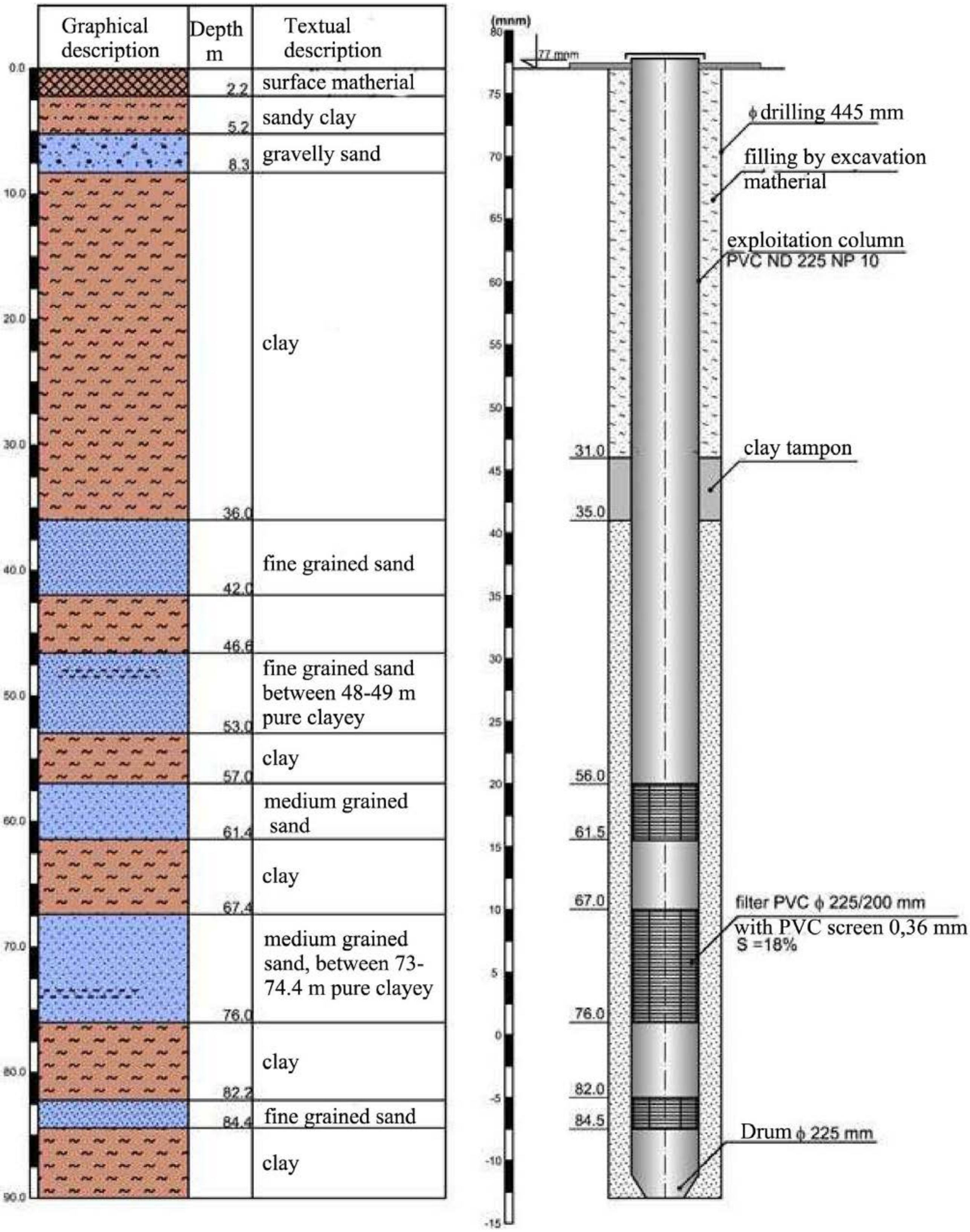

Figure 1. Vertical profile of a well in the vicinity of Pecinci.

Laboratory analyses

It has long been thought that "red mud" is the result of some mechanical impurities, siltation of wells or some kind of oxidation. However, laboratory testing of groundwater samples and analysis of the results led to a completely different finding. Namely, "red mud" are nothing but a type of anaerobic bacteria, called. ferro bacteria, which live in the depths, in waters rich in iron and feed on iron! Ferro bacteria usually manifest as brown, red or white sticky, slimy substances suspended in water. They are harmless to health but dangerous to installations. By pumping groundwater with pumps, these bacteria are also captured, and by transporting such water through pipelines, they are deposited on the walls, fittings and flow meters. The problem is that they can be optionally anaerobic, i.e. they can live and reproduce in environments with and without the presence of air.

Figure 3. Appearance of the pre-exchanger.

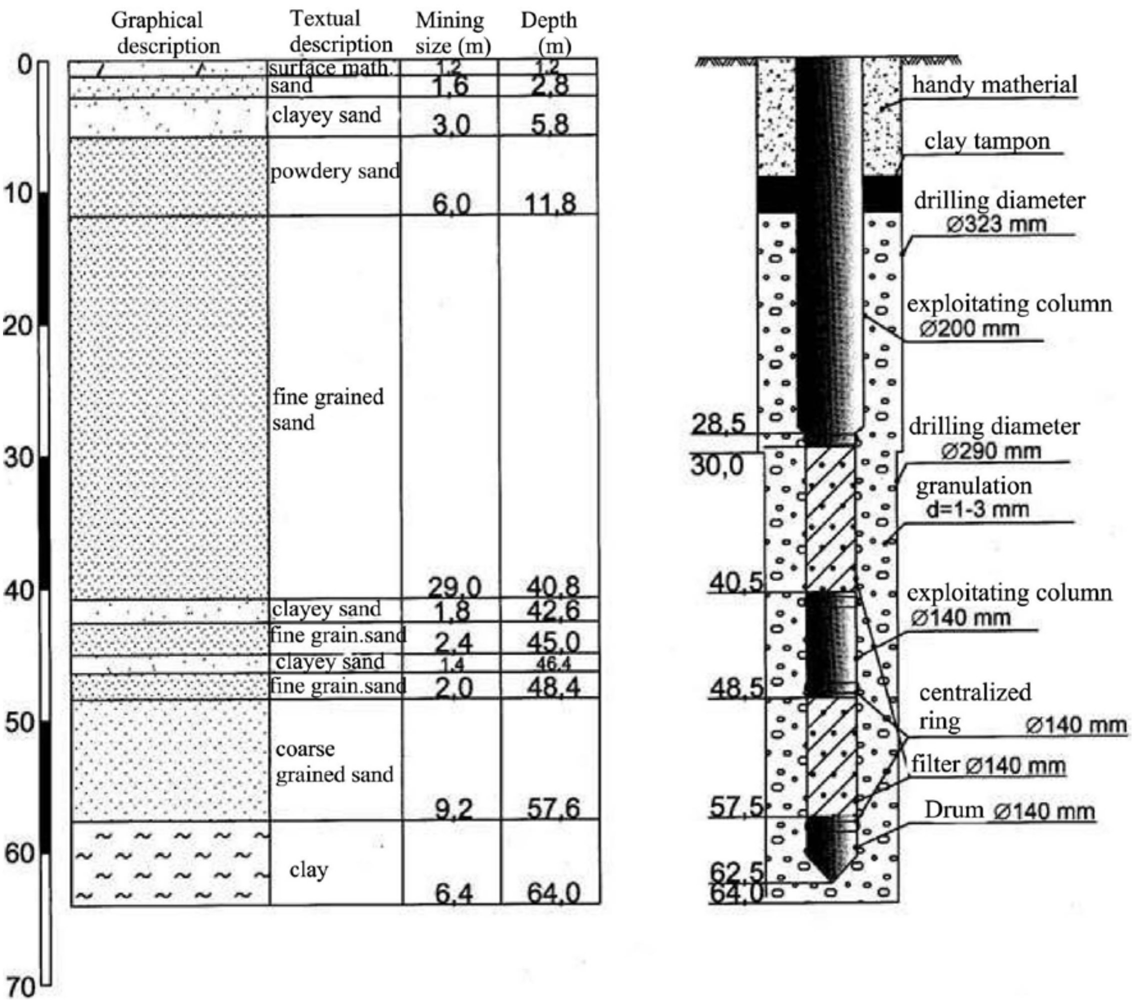

Figure 2. Vertical profile of a well in Pancevo.

Groundwater characteristics at the global level are:

- Waters from the first issue (depth up to about 18 m) are usually rich in calcium and magnesium salts, ie they are waters of increased total hardness, with a slightly increased content of ammonia, iron and manganese, as well as low concentrations of natrium
- Groundwater of the second released (depth up to about 80 m) is softer with higher concentrations of ammonia, iron and manganese, slightly increased content of arsenic and chloride, as well as low concentrations of natrium
- The waters of the third edition, which have been trapped in underground reservoirs for tens of thousands of years, are extremely soft, with an increased content of natrium, ammonia, arsenic and orthophosphate. Definitely during the passage of water on the way from the first to the third issue a natural softening process takes place on zeolite materials

Table 1 shows the maximum permitted concentrations of metals, non-metals, cations, anions and other water pollutants in different water categories. In addition to the total hardness, calcium content, special attention should be paid to the content of iron (Fe) in water because the increased concentration of iron is a suitable substrate for the appearance of anaerobic bacteria that can cause serious problems in heat pumps of water-water systems.

In this paper, we will focus only on the iron content in groundwater. From the table we can see that for the needs of water supply (technical water) the maximum allowed concentration of iron is 0.3 mg/ℓ. If this concentration is higher than the maximum allowed, the presence of anaerobic bacteria can be expected, which can cause problems in the operation of the heat pump. That is why the laboratory analysis of groundwater is very important for the correct selection of the location and depth of the well, i.e. the level from which the groundwater will be exploited.

***Table 1.** Maximum permitted concentrations of elements in water.*

Classification	Technical water MPC	Bottled water MPC	Natural mineral MPC	Spring water MPC
1. Basic physical-chemical values				
Temperature (°C)				
pH value	6.8–8.5	6.8–8.5		6.5–9.5
Turbidity (NTU)	1	0,6		
Colour (Pt-Co scale degree)	5	10		
Electrolytic conductivity (mS/cm)	1000	500		2500
Dry residue (mg/ℓ on 180°C)	-	500		
Total hardness of water	6.6			
Consumption $KMn0_4$ (mg/ℓ)	8	5		
2. Dissolved gases				
Oxygen	-			
Carbon dioxide (CO_2) (mg/ℓ)	-		250*	
Hydrogen Sulphide H_2S) (mg/ℓ)	without	without		
3. Macro components				
Cations	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ
Calcium (Ca)	200	100	150*	
Magnesium (Mg)	50	30	50*	
Natrium (Na)	150	20	200	200
Kalium (K)	12	10		
Anions	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ
Hydro carbonate (HCO_3)			600*	
Chlorides (Cl)	200	25	200*	250
Sulphates (SO_4)	250	25	200*	250
Nitrates (NO_3)	50	5	50	50

4. Micro components				
Metals	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ
Iron (Fe)	0.3	0.05	1*	0.2
Mangan (Mn)	0.05	0.02	0.5	0.05
Chrome total (Cr) II	0.05	0.05	0.05	0.05
Chrome total (Cr) II	0.05	0.10	0.05	0.05
Aluminium (Al)	0.2	0.05		0.2
Barium (Ba)		0.1	1	
Zinc (Zn)	3.0	0,1		
Cooper (Cu)	2.0	0.1	1	0.002
Lead (Pb)	0,01	0.05	0.01	0.01
Cadmium (Cd)	0.003	0.005	0.003	0.003
Arsenic (As)	0.010	0.05	0.010 tot	0.01
Antimony			0.0050	0.0050
Selenium (Se)		0.01	0.01	0.01
Quicksilver (Hg)	0.001	0.001	0.0010	0.001
Nickel (Ni)		0.01	0.020	0.02
Non-metals	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ
Ammonium ion (NH_4)	0.1 NH_3	0.01-		0.50 NH_3
NitritesfNOT)	0.03		0.1	0.0001
Phosphor (P)		0.03-phosphates		
Borates (BO_3)		1.0-borates	-	0.001
Fluorides (F)	1.2	1.0	1*	0.0015
Bromides (Br)	-			
5. Radioactivity				
Parameter - Activity	Bq/ℓ	Bq/ℓ	Bq/ℓ	Bq/ℓ
Total α - activity		0.1		
Total β - activity		1,0		
226 Ra				
6. Pollutants				
Parameter	mg/ℓ	mg/ℓ		
Cyanides	0.050		0.07	0.05
Total Phenol	0.001			
Detergents	0.1			
Total Grease and oils	0.100			
Organo-chlorine pesticides	0.5			
PAH				
7. Microbiology				
	Presence	Presence	Presence	Presence
Aerobic mesophilic bacteria in 1 mℓ	100		20	
Coliform bacteria of faecal origin in 100 mℓ	0			
Total coliform bacteria in 100 mℓ	0			
Streptococci group D in 100 mℓ	negative		0	
Proteus species in 100 mℓ	negative			
Sulphite-reducing clostridia in 100 mℓ	1		0	
Pseudomonas aeruginosa in 100 mℓ	negative		0	

Table 2 shows the results of laboratory analysis of raw groundwater from wells in Pancevo [3]. It is visible that the increased concentration of iron is significantly above the MDK and the fact is that “red mud” – anaerobic bacteria – appear in that water. The analysis does not include anaerobic ferro bacteria because the Laboratory is not equipped for that type of analysis, but there are Laboratories that do that as well. Ferro bacteria are not harmful to human health but only reflect the degree of purity of the water.

Thus, the analysis showed that natural well, unfiltered and untreated water from the subject site has a significantly increased concentration of iron (3.9 mg/ℓ) and manganese (0.15 mg/ℓ) and the water hardness is 27.2°dH. The presence of chloride is significantly below the MDK, 32.1 mg/ℓ, and mesophilic aerobic bacteria 83 CFU/mℓ. It is reasonable to assume that anaerobic ferro bacteria can appear in water of this composition.

Problem solution

After the cause of the “red mud” that clogged the heat pre-exchanger was determined, the method of destroying such bacteria by chlorination was started. A time chlorination system was installed on the suction pipeline of the well water in front of the heat pre-exchanger by injecting 12.5% natrium hypochlorite solution directly into the pipeline. The mentioned solution is normally used for disinfection of drinking water and pool water.

The result was unexpectedly good: more than a year passed without the need for cleaning and rinsing the pre-exchanger, and during that time the heat pump itself functioned properly and without problems.

Submersible drainage sump pumps were not removed from the wells because they were functioning properly. But in some other facilities of smaller capacity, the submersible pump was completely covered with “red mud” and did not give any flow. This can be caused by the amount of anaerobic bacteria in the environment of the pump suction basket or the suction power of the pump – in a facility with a water flow of about 2 m³/h the well pump was surrounded by “red mud” while in the facility with a water flow of about 25 m³/h for now there were no such problems.

Since the well water was discharged into an open drainage channel, the laboratory analysis was started again to determine the concentration of residual chlorine (Cl) in the water and to see whether the water pollutes the earth and the environment and whether there has been a change in chemical water composition. The results are shown in **Table 3**. [3].

Repeated analysis of groundwater after chemical treatment by chlorination shows that the water got a more natural colour, that it is significantly clear, that a smaller drop in chloride and a drastic drop in the concentration of aerobic mesophilic bacteria were recorded. The observed decrease in the concentration of iron and manganese is not a consequence of water chlorination, but by natural process. The concentration of residual chlorine is below the permitted limit, the water is bacteriologically correct, so as such this water does not pollute the earth or the environment.

Table 2. *Laboratory analysis of raw groundwater in Pancevo [3].*

Parameter	Unit	Limiting value	Reference method	Result
Temperature	°C		Guide book P-IV-1	21,5
Colour	Pt-Co	5	SRPS ENISO 7887 2013	82,7
Odour	/	without	HDMI-002	backwater
Turbidity	NTU	5	HDMI-003	30,5
Iron	mg/L	0,3	HDMI-017	3,9
pH	/	6,8-8,5	HDMI-007	7,2
Consumption $KMn0_4$	mg/L	12	HDMI-009	6,3
Residue evaporation	mg/L	-	HDMI-012	515
Electrical conductivity	µS/cm	2500	HDMI-011	859
Ammonia	mg/L	1	HDMI-029	0,39
Chlorides	mg/L	250	SRPS ISO 9297:1997	32,1
Nitrites	mg/L	0,03	HDMI-004	<0,006
Nitrates	mg/L	50	HDMI-005	1,2
Manganese	mg/L	0,05	HDMI-018	0,15
Hardness of water	°dH	-	Rule book III/15	27,2
Aerobic mesophilic bacteria	CFU/mL	100	SRPS ENISO 6222:2010/37°C	83

Table 3. Laboratory analysis of chlorinated groundwater in Pancevo [3].

Parameter	Unit	Limiting value	Reference method	Result
Temperature	°C	-	Guide book P-IV-1	22,5
Colour	Pt-Co	5	SRPS ENISO 7887 2013	8,5
Odour	/	without	HDMI-002	without
Turbidity	NTU	5	HDMI-003	0,9
Iron	mg/L	0,3	HDMI-017	1
pH	/	6,8-8,5	HDMI-007	7,4
Consumption $KMn0_4$	mg/L	12	HDMI-009	4,6
Residue evaporation	mg/L	-	HDMI-012	415
Electrical conductivity	µS/cm	2500	HDMI-011	961
Ammonia	mg/L	1	HDMI-029	0,27
Chlorides	mg/L	250	SRPS ISO 9297:1997	19,2
Nitrites	mg/L	0,03	HDMI-004	<0,006
Nitrates	mg/L	50	HDMI-005	2,2
Manganese	mg/L	0,05	HDMI-018	0,08
Hardness of water	°dH	-	Rule book III/15	27,2
Aerobic mesophilic			SRPS ENISO	
Bacteria	CFU/mL	100	6222:2010/37°C	<1
Water temperature	°C	-	DMI-003	15,1
Air temperature	°C	-	DMI-003	24,9
Residual chlorine	mg/L	up to 0,5	DMI-004	0,2

Conclusion

1. "Red mud" that occurs during the exploitation of groundwater in water-water heat pump systems are anaerobic ferro bacteria that feed on iron in water.
2. Effective destruction of ferro bacteria as well as other bacteria is by chlorination of water by injecting 12.5% sodium hypochlorite solution directly into the feed pipeline. Controlled and measured chlorine injection does not endanger the earth or the environment into which the water is discharged.
3. The suction power of the well pump, ie the speed and flow of well water, are important for preventing the deposition of bacteria on the suction basket and preventing clogging of the pump itself.
4. Chlorination of groundwater significantly prolongs the period of need for regular cleaning of heat pre-exchangers or heat pump heat exchangers
5. It is necessary to perform test excavation of wells and laboratory analysis of groundwater from the exploitation level in the phase of design and selection of energy production systems in order to determine the yield of wells and the presence of iron (Fe) in the water.
6. Increased concentration of iron in water is not a condition for the obligatory appearance of anaerobic ferro bacteria, but it is a significant indicator that it will most likely happen.
7. Well maintenance and repairs are generally a very important prerequisite for optimal heat pump operation [1] [7]. ■

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