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BEHEIRA GOVERNORATE, EGYPT**

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BURMAN, UNDERGROUND REMOVAL OF MANGANESE FROM GROUNDWATER IN BEHEIRA GOVERNORATE, EGYPT

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1- Introduction

Beheira Water and Drainage Company (BWADC) is responsible for the supply of drinking water in the whole of Beheira Governorate. Surface water is used as the main source, but people in the south of the governorate depend largely on groundwater.

The first wells were drilled in 1953. Today, the total groundwater production amounts to around 20 million m³, about 12% of the total production of BWADC. Currently, the groundwater is extracted on almost 100 sites. These sites mostly have 2 wells operating and sometimes 3 or 4.

The groundwater extracted from the Nile Delta aquifer generally contains iron (Fe²⁺) and manganese (Mn²⁺). See for instance RIGW, 1998. In the Kom Hamada and Itay al Barud areas the average concentration is 0.41 and 1.1 mg/l respectively. Since chlorination started in 1990, problems began to arise due to precipitation of especially manganese oxides in the distribution systems. It became necessary to set up a program to flush the system on a monthly basis. In summer even bimonthly flushing is executed on some places in order to maintain bacteriologic quality and guarantee a minimum chlorine concentration at the tap.

BWADC studies the possibilities to solve this so-called manganese problem. Next to groundwater treatment, it was investigated to what extent iron and manganese can be removed from the groundwater in the subsoil itself, using natural processes. To this end, a test was carried out on the groundwater extraction site of Kom Hamada. Because of its success the method was named BURMAN, "Beheira Underground Removal of Manganese" and is now being tested and implemented on other sites as well.

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2- Description of the site

The Kom Hamada treatment plant is situated in the Nile Delta at 35 km to the south-east of Damanhur, ($30^{\circ} 45' 50''$ N and $30^{\circ} 42' 30''$ E). The site has 4 production wells in a layout that is shown in Figure 1.

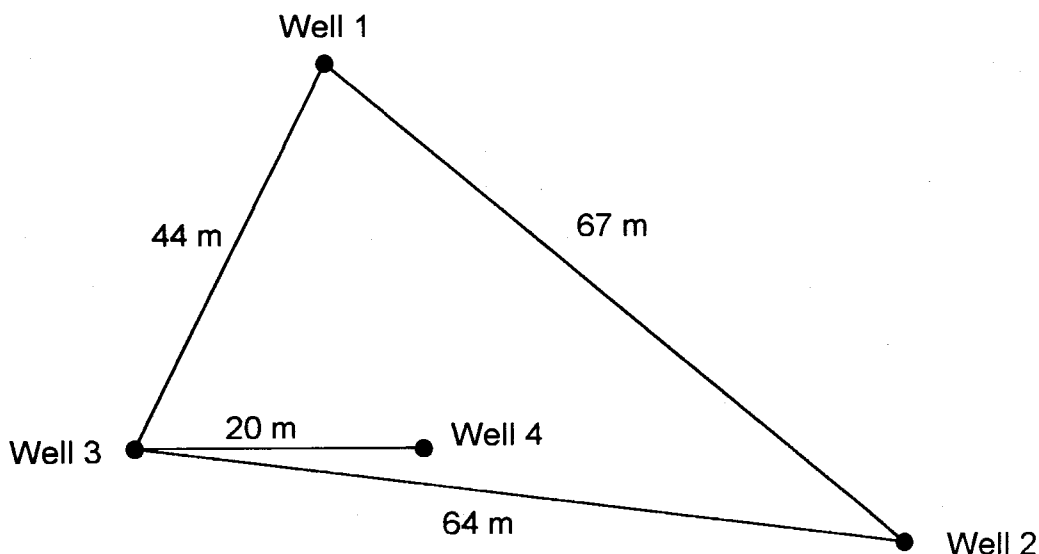


Figure 1: Layout of the wells at Kom Hamada site

Wells No. 1 and No. 2 were drilled in 1987. Both are 50m deep. Wells No. 3 and No. 4 were drilled in 1958. These wells are 55m deep. All wells have a screen of around 20 m.

The wells tap the Nile Delta aquifer, which, in Kom Hamada, reaches down to 350 m below mean sea level. It consists of sands and gravels with embedded clay layers of different composition. Pumping tests on the site revealed a high transmissivity of about $7500 \text{ m}^2/\text{d}$. From this high figure, it is concluded that the entire Nile Delta aquifer functions as a single unit and so these clayey intercalations have only a limited influence on the heads and the groundwater flow.

The aquifer is covered by a top-layer consisting of clay, loam and sand, which is about 6 m thick at Kom Hamada. Its resistance against vertical flow has still to be determined by proper longer pumping tests with a larger number of observation wells.

The groundwater extraction at Kom Harnada was 1.2 million m^3 in 1999 and typical analyses of the groundwater in the area are given in Table 1.

Table 1: Typical groundwater quality analyses in the Kom Hamada Area

Well Name	NH ₄ mg/l	CO ₂ Mg/l	Cl mg/l	SO ₄ mg/l	Fe mg/l	Mn mg/l	Ca mg/l	Mg mg/l	EC mg/l	TDS mg/l	pH
Zawyet Mo	0.34	18.6	87	37	0.02	0.46	48	20	609	406	7.53
Ebioka	0.26	14.6	62	47	0.1	0.92	42.5	18.5	725	486	7.49
El Tod 2	0.19	22	82	60	0.1	0.36	295	36.5	1088	728	7.36
El Tod 1	0.25	17.2	67	108	0.12	0.73	36	?	678	453	7.34
K.Zeyada	0.17	17	37	60	0.66	0.25	325	17	510	340	7.37
K.Zeyada	0.23	17	27	25	1.3	0.25	48	7.5	540	361	7.34

As can be seen from Table 1, manganese concentrations in the order of 1 mg/l are found in (many) wells in the area. While in most places in the world iron concentrations tend to be higher, too much higher than those of manganese, the opposite is true in this area. From the nation wide monitoring by RIGW it is known that this is generally the situation throughout the Nile Delta.

3- Subsurface removal background

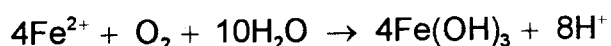
From the scientific literature it is known that iron and manganese may be removed from the groundwater by pre-injection of aerated water (Seyfried e.a., 1985, Dekov e.a., 1997, Jaudon e.a., 1989). During the injection ferric iron and two-valued manganese to the extent that it is adsorbed to the grains are oxidised by the oxygen in the injected water, changing the iron and manganese to its amorphous ferrous and manganate. These form fresh adsorption space for Fe²⁺ and Mn²⁺.

During subsequent extraction Fe²⁺ and Mn²⁺ are adsorbed to the freshly oxidised grain surfaces. This way these cations are extracted it from the groundwater. So, ideally, the process yields water virtually free of iron and manganese, until the adsorption space is used up again. This is the point at which the next injection cycle has to start.

This cyclic system will be beneficial if the volume of groundwater extracted before Fe and Mn concentrations rise again, is much larger than the volume of aerated water that is injected during each cycle. The maximum ratio between extracted and injected water is called the yield factor. At least its theoretical value can be computed by looking at the

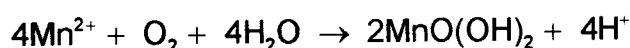
reactions taking place in the subsoil and neglecting for the time being the disturbing factors, to be described later.

The oxidation of iron can be described chemically by the reaction,



Implying that 1 mole of O_2 is needed for the subsurface oxidation of 4 moles of ferric iron adsorbed on the grains. Hence 0.14 mg of O_2 is needed per mg of Fe^{2+} .

Likewise the manganese oxidation can be described chemically as follows:



Consuming 1 mole of O_2 for each mole of Mn or 0.29 mg O_2 per mg of Mn^{2+} .

If we have an oxygen concentration in the injection water equal to o mg/l and in the groundwater an Fe^{2+} and Mn^{2+} of f and m mg/l respectively, the maximum yield factor may be computed from the volume of ground water having an amount of iron and manganese which can be exactly oxidised by the oxygen in the injection water. Therefore, the maximum possible yield factor becomes:

$$Y = o / (0.14 * f + 0.29 * m)$$

If we enter the average values found in the Kom Hamada and Itay al Barud area (0.41 mg Fe^{2+} /l and 1.1 mg Mn^{2+} respectively, we obtain a high yield factor of almost 30:

$$Y = 8 / (0.14 * 0.41 + 0.29 * 0.73) = 29.9$$

Even with the highest concentrations, currently found in Kafr el Bulien a very promising theoretical maximum yield factor is thus computed:

$$Y = 8 / (0.14 * 1.1 + 0.29 * 1.46) = 13.9$$

It is known from the literature that the pH is an important factor in the success of subsurface removal of iron and manganese. The values found in the area are all above 7 and therefore favourable.

Based on this positive preliminary information, a test was made in January to March 2000 in Kom Hamada site.

4- Description of the Kom Hamada experiment

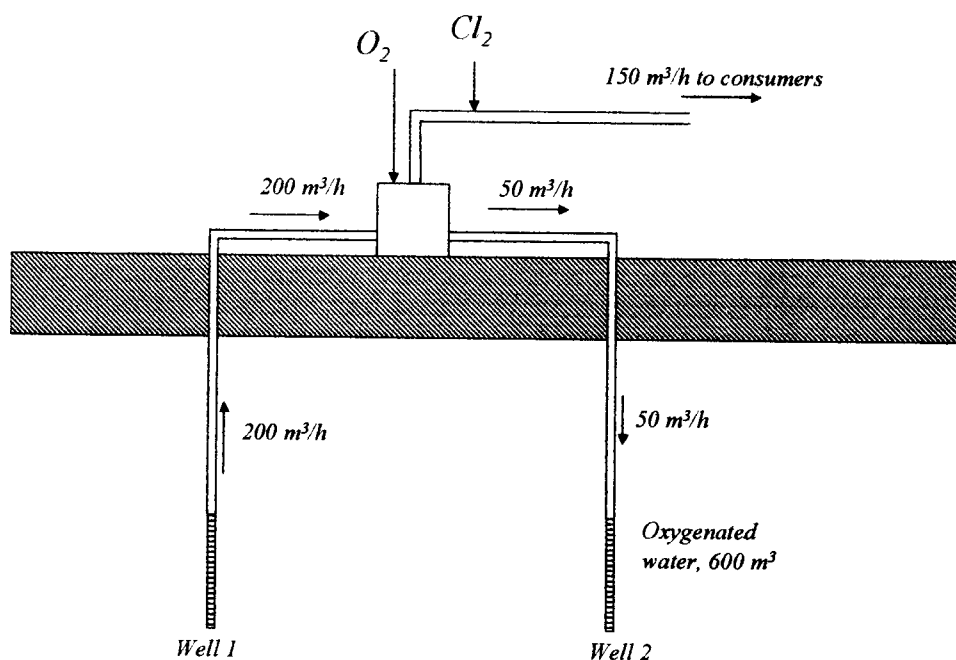


Figure 2: Layout of the setup at Kom Ramada site

Subsurface removal of (iron and) manganese seeks to oxidise the two cations Fe^{2+} and Mn^{2+} in the subsoil. This is done by injection of a fixed volume of aerated water into a well, after which extraction may start from this well and continue until the iron and or manganese concentration rises to some fixed norm. After that the cycle of injection and extraction is repeated. A schematic of the arrangement is shown in Fig. 4. One hopes that the volume of water without the two metals is much larger than the volume of injected aerated water.

The experiment was carried out using an old recovery well, Well No. 3 (Figure 1). It started on January 12, 2000, using aerated water from No. 1, which shows a Mn-concentration between 0.7 and 1.0 mg/l.

During the test a number of injection-extraction cycles were carried out. Each cycle consisted of an injection and a pumping phase with a resting period of several hours in between. In total about 13 cycles have been executed.

Injection takes place at a rate of 25 m³ /hour, infiltrating a total of 1000 m³ at each cycle. After a rest period of several hours, extraction starts at a rate of 50 m³ /hour. The

amount extracted from cycle to cycle, starting with 2000 m³. Cycles with up to 5000 m³ have been carried out already.

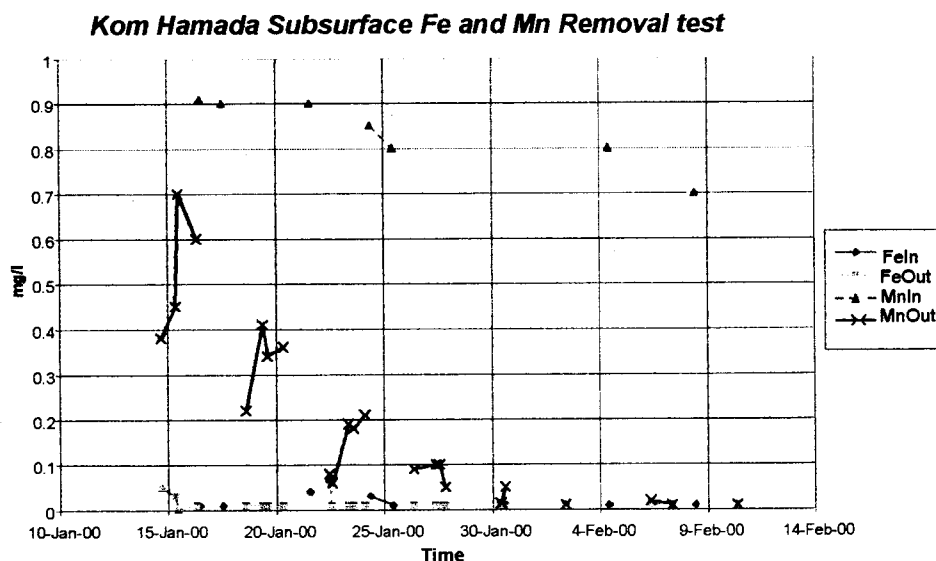


Figure 3: Results of the first 8 cycles of the Kom Hamada subsurface iron and manganese removal experiment

The results are shown in Figure 3, the injection water has a concentration of 0.7 to 0.9 mg Mn²⁺/l. Already after the first cycle a substantial reduction of the concentration was obtained. Clearly, Fe²⁺ also decreased, but due to the much lower concentration this is not very important at this site. As can be seen from the figure, the manganese concentration is reduced further with each cycle. After the four cycles it was almost completely removed, having become as low as 0.01 mg Mn²⁺/l, almost a hundred times lower than that of the natural groundwater.

5- Special features during the execution

During this particular test, water was taken after aeration from a sediment tank of the local groundwater treatment plant. This water coming from a regular well always contains high manganese concentrations. If the injection/extraction cycles are continuously switched between two wells, then the water from neither of these two wells contains iron and manganese, and hence the injection water will be virtually free of

these Fe and Mn and therefore clogging due to precipitates during injection is prevented.

6- Risks

Some risks may exist with this system. Obviously, the accumulation of iron and manganese hydroxides around the well could theoretically clog the formation. However, experience of several decades elsewhere in the world shows that this is not the case. It is believed that this is due to slow crystallization of the amorphous hydroxides. The oxides thus formed take far less space than do the hydroxides.

Ammonia in the groundwater may consume oxygen and thus reduce the theoretical yield. However, reaction between the oxygen in the injection water and the NH_4^+ in the groundwater can only take place at the interface between the two waters. This is a completely different mechanism and thus poses no real threat.

Organics in the groundwater might consume oxygen as well. This problem is unlikely to happen due to the same argument.

Soil organics adhering to the grains might be oxidised, especially if a bacterial population develops. However, the alternating redox environment during the injection extraction cycles is unhealthy for bacteria, and so the problem is unlikely to be serious. Furthermore, the amount of organics within the cylinder of soil around the well screen that is reached by the aerated water is limited and will be leached, so that such organic materials will gradually disappear from it.

Oxidation of pyrite (FeS_2) crystals may occur if pyrite is present. This would consume oxygen as well. No signs of this have occurred so far. More seriously with pyrite oxidation is, however, the potential dissolution of heavy metals embedded in the pyrite crystals, such as Zn, Sr, As. For this reason the water will be analysed for these metals (Appelo & Postma, 1993).

Introducing oxygen in steel casing and screens with the aerated water might increase corrosion. If this water is chlorinated, it might increase corrosion even further. Hence, when implementing this system with new wells, these should be constructed of non-corrosive materials such as PVC.

Finally, wells should be as far from each other as possible, so that the injected cylinder of aerated water is not displaced too much by wells operating in its vicinity.

7- Continuation

Because the test was yielded such a positive result the experiments are extended to other sites as well, notably to Itay al Barud and Ash-Shu'ayrah. As soon as enough experience is obtained the process may be integrated in the regular groundwater operations of BWADC.

8- Conclusions

Manganese is generally present in the groundwater of the Nile Delta aquifer. It causes problems in pipelines and discomfort with our consumers. It is very difficult to construct a groundwater treatment plant on all of the about 100 groundwater extraction sites. Subsurface removal of iron and manganese looks very promising as it is relatively cheap and uses no chemicals, nor does it need special chemical like permanganate or facilities like sedimentation tanks and filters. It applies natural processes triggered in the subsoil by injection of aerated water. The applied theory shows promising figures, as does the test done in Kom Hamada. After the experiments are fully evaluated they will enter into the regular groundwater operations of Beheira Water and Drainage Company to the benefit of the people. Hopefully this BURMAN method may help to solve this quite general groundwater manganese problem with the Nile Delta groundwater in general.

Acknowledgement

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