skat Swiss Resource Centre and Consultancies for Development   ApaSan Proiectul Elveției de Apă și Sanitație în Moldova

Experience with In-Situ Groundwater Treatment for Removal of Iron and Manganese in Moldova

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The document is based on contributions from the multi-disciplinary ApaSan team and has been compiled by Matthieu Amos.

ABSTRACT

In-situ iron and manganese removal consists of bringing oxygen directly into an aquifer through the injection of aerated water. In some cases, the process has been proven to be easier and cheaper to implement and operate than the more common ex-situ removal. For this reason, Skat Consulting Ltd. installed two pilot plants in rural Moldova to explore the suitability and sustainability of in-situ removal in this context. Despite a few issues due to the lack of skilled maintenance companies in the country and a lack of funds for maintenance, the implemented systems were able to remove iron and manganese from the water efficiently. Moreover, the technology has been shown to be easy enough to be operated by local operators having only a low skill level.

Keywords: in-situ removal, iron, manganese, water, water treatment, Moldova, developing country

1. Iron and Manganese in Groundwater

Groundwater is one of the most commonly used water source, including for drinking water. Due to natural filtration of the water in an aquifer, groundwater generally has much lower needs for treatment prior to use than does surface water. However, groundwater, under certain conditions, contains substances that need removal prior to general distribution. Iron (in the form Fe(II)) and manganese (in the form Mn(II)) are frequently present substances in groundwater, therefore iron and manganese removal is one of the most common types of groundwater treatment. While neither of these represents a health risk if consumed, both do pose aesthetic and technical issues.

When groundwater containing iron and manganese comes into contact with oxygen, an oxidation reaction occurs that precipitates the soluble Fe(II) and Mn(II) into solid Fe(III) and Mn(IV). In practical terms, this results in the formation of rusty or black deposits in water piping, reservoirs and containers, which can end up damaging pumps, clogging pipes and consumer complaints due to colored water. For these reasons, it is important that iron and manganese concentrations are lowered to unproblematic levels.

While the World Health Organization (WHO) does not have any health-based targets for iron and manganese concentration levels in drinking water, it does state that concentration below 0.3 mg/l for iron and 0.1 mg/l for manganese are generally acceptable for consumers. Additionally, most countries around the world have drinking water standards that stipulate maximum acceptable concentration levels for both. Germany, for example, sets a limit of 0.2 mg/l for iron and 0.05 mg/l for manganese (TrinkwV 2001). Moldovan standards are currently set at 0.3 mg/l for iron and 0.05 mg/l for manganese (Government Decision nr. 934, 2007).

2. Iron and Manganese Removal from Groundwater

2.1 Functioning Principles

A range of techniques exists for the removal of iron and manganese from groundwater and are applied throughout the world. Typically, these techniques consist of above-ground (ex-situ) techniques that introduce oxygen (and sometimes chemicals) into the water with the aim of transforming the dissolved Fe(II) and Mn(II) ions into solid Fe(III) and Mn(IV). This allows the Fe(III) and Mn(IV) to be easily-separated from the water via one or more of a number of water-filtering techniques. Regardless of which ex-situ method is used, sludge is produced that needs to be both managed and disposed of properly. This sludge, obviously, has high levels of iron and manganese but may also include high levels of other substances such as arsenic, copper, nickel, phosphate and zinc (DVGW W223-1, 2005).

Subterranean (in-situ) techniques can also be used in the removal of iron and manganese from groundwater as an alternative to the above-described ex-situ techniques. In-situ techniques are also based on introducing oxygen to oxidize Fe(II) and Mn(II) into Fe(III) and Mn(IV). As opposed to having this process above ground, in-situ techniques instead use the aquifer itself as part of the process by enriching part of the extracted groundwater with oxygen and reintroducing it into the aquifer. This has the effect of increasing the redox potential for the groundwater around the well, causing dissolved Fe(II) and Mn(II) to change into Fe(III) and Mn(IV). In addition to the purely chemical oxidation reaction, dissolved iron and manganese ions also are adsorbed into the soil matrix and already-present oxidation products of microbiological processes, which removes them from the water. All these processes are the same as in conventional filtration technologies.

For continuous operation, in-situ systems usually use at least two wells, with part of the water extracted from a well set to extraction mode (referred to as an extraction well) being enriched with oxygen and then reintroduced into the aquifer via another well (referred to as the infiltration well), as shown in Figure 1. The role for each well is usually alternated, meaning that each well works sometimes as an extraction well and sometimes as an infiltration well.

The in-situ technique can also be applied with only one well; however, this requires a sufficiently-sized reservoir to store oxygen-enriched water until it can be reintroduced into the aquifer and operates in batch mode.

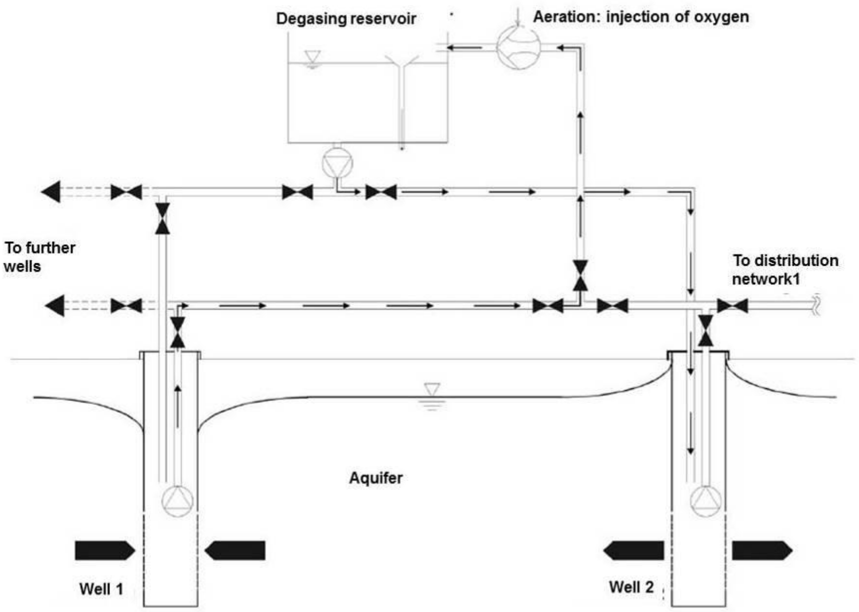

Figure 1: Simplified drawing of a 2-well in-situ system for iron and manganese removal, with Well 2 acting as the infiltration well (adapted from http://www.h2-pro.eu)

The in-situ technique requires a start-up period before being able to efficiently remove iron and manganese from the aquifer (see chapter 4.3 for an example). This period is needed to build up the aerobic microbiological flora (responsible for most of the manganese removal) in the subterranean reactor volume and takes up to six month. The volume of water that can then be extracted is a multiple of the volume that needs to be infiltrated. The efficiency of the process is described with the ratio of extraction volume to infiltration volume. Depending on the characteristics of the aquifer, the raw water quality and the operating mode, this ratio can range from 2 to 12 (DVGW W223-3, 2005).

2.4 Longevity of In-Situ Wells

Ex-situ techniques for iron and manganese removal from groundwater require that filters be backwashed periodically as deposits of oxidized compounds build up in the filter pores and lead to clogging issues. While one might naturally think that a similar process is needed with the use of in-situ techniques, the opposite is actually true. As the in-situ removal process takes place in the aquifer itself, in-situ treatment does not risk any clogging to the aquifer as a whole, greatly increasing the lifetime of in-situ systems as compared to ex-situ systems.

Although there is some sedimentation of oxidized compounds that does lead to some reduction in the well pores, this is entirely compensated by the extension of the volume of water around the well that reacts to the introduction of oxygen-enriched water. Additionally, the pore volume on the wells are quite large, meaning that any reduction in pore volume is relatively small. Moreover, compound deposits tend to settle in pores that are not hydraulically-active, thereby having no real negative impact on the process.

In the end, ex-situ systems regularly suffer from clogging issues as groundwater comes into contact with oxygen in wells, pumps and pipes. In-situ systems avoid this problem as iron and manganese are removed before the groundwater reaches any potential place where it might come into contact with oxygen. It is also important to note that numerous studies have confirmed that in-situ removal of iron and manganese does not increase clogging risks of aquifers, wells or other installations. As an example of this, the Rheindalen Water Works (Germany) has been running without any signs of a problem for more than 30 years (Fiedle, 1998).

2.5. In-Situ Limitations

In-situ systems can, in principle, work as an alternative to ex-situ techniques without any limitation. However, the efficiency of in-situ removal is affected by certain conditions, including:

- A high level of easily-oxidizable materials and/or iron sulphate in the aquifer
- Oxidizable contents (especially methane) being in the water
- Iron and manganese bound with humic matter (which is not easily-oxidized)
- A heterogenic aquifer structure
- Strong groundwater gradients near the in-situ wells
- Low pH and/or low buffering capacity of the groundwater (DVGW W223-1, 2005)

It should be noted that the presence of one or more these factors does not automatically exclude the possibility of in-situ removal but does indicate that in-situ efficiency will be reduced.

The geologic composition of the area should also be considered as it can limit the success of an in-situ system. The underground area should be porous and homogeneous enough to ensure an efficient and even diffusion of oxygen (Appelo et al., 1999) as well as sufficient water productivity. In order to assess the applicability and expected efficiency of an in-situ system, a thorough investigation of the groundwater, the aquifer and surrounding geology is required.

2.6. In-Situ Advantages

In-situ systems require much less in terms of facilities than ex-situ systems, significantly reducing investment and operational costs. In fact, an in-situ system really only requires pumps, pipes, a degassing tank and an electronic steering unit. Operationally, in-situ systems, beyond the initial start-up period, can be run automatically according to pre-set cycles, without much operator input as there are no chemicals to be added to the system, no filter to be backwashed and no filter sludge to be managed. Energy consumption of in-situ systems is also much lower.

In short, in-situ systems, in the appropriate circumstances, are as effective as ex-situ systems and significantly cheaper to install, operate and maintain.

3. Application in Europe

While the in-situ concept of iron and manganese removal from groundwater is nothing new (German engineers patented the process more than 100 years ago), its practical application began in the 1970s in Scandinavia (Winkelnkemper, 2015). The first applications used a circle of infiltration wells around the main extraction well(s), but the real breakthrough came with the idea of alternating the wells' usages (with each well sometimes serving as an extraction well and sometimes serving as an infiltration well). This breakthrough was bolstered when extensive research conducted by German professor Ulrich Rott (University of Stuttgart) significantly contributed to the understanding of the in-situ process and helped popularize it among many authorities and engineers.

Today, in-situ technology is state-of-the-art and is described in great detail by the technical norms of the DVGW, the German Technical and Scientific Association for Gas and Water (DVGW W223-3, 2005). In fact, it is now applied for a wide range of applications, including for drinking water, irrigation, swimming pools, industry and geothermic applications.

Sinsheim (Germany) Example

Sinsheim, a small German town of 10,000 people, implemented an in-situ system to treat its groundwater due to the low investment, operational and maintenance costs. Following a relatively long planning and investigation period (including several months of field testing for in-situ efficiency), the system began operating in 2005. It uses two alternating wells and can bring up to 700,000 m^3 of water per year up to German standards.

When the system began working, the groundwater in the area had iron concentrations of up to 0.62 mg/l and manganese concentrations of up to 0.23 mg/l. After two months, iron concentration had stabilized at 0.02 mg/l. After one year, manganese concentrations had stabilized at 0.1 mg/l. The system has been operating consistently, without any issues, since then (as confirmed by an interview with the operating staff in 2013).

The German company FERMANOX has been the main pioneer in the use of in-situ systems for more than 30 years. The company began by providing small installations for agricultural use and gradually expanded from there. Today, it is a market leader in supplying in-situ equipment and supplies ready-to-install equipment for both small and large facilities. In total, more than 10,000 facilities supplied by FERMANOX are in operation today, mostly in Germany and the Netherlands (FERMANOX website).

Other countries in which the use of in-situ systems have become more popular are: Austria, Finland, Hungary, Russia, Sweden and the United States (Kazak, 2010). The largest in-situ system in the world (with a capacity of treating 200,000 m^3 of groundwater per day) is located in Khabarovsk, Russia (Arcadis, 2012).

Despite the obvious advantages, numerous successful examples and strong documentation, the actual application of in-situ systems is still far below its real potential, with iron and manganese in most areas of the world still being removed using traditional ex-situ systems. The main reason for this is that the technology is still not widely-known among most authorities and engineering companies.

An important obstacle for wider implementation may also be the fact that thorough investigations need to be carried out as part of the planning and design of such systems and that operators dislike having little influence on a process that happens underground. If in-situ systems are to gain more usage throughout the world, their low cost (when compared to ex-situ systems) needs to be emphasized.

4. Application in Moldova

Moldova (officially: The Republic of Moldova) is a small landlocked former Soviet state in Eastern Europe with a population of approximately 3.35 million people. Today, it is the poorest country in Europe, with poverty being especially marked in the rural areas.

4.1 Technology Transfer to Moldova

The Swiss government has been providing support to the Moldovan government since 2001in areas designed to improve the quality of life in rural areas of the country, which includes access to safe drinking water. Recent Swiss support in the area of water safety, implemented by Skat Consulting Ltd. (Skat), has focused on the construction of water supply systems in villages as well as the introduction of community-based management in order to ensure the sustainable operation of the systems without additional support. For this reason, the water systems implemented by Skat use simple technologies that provide safe water to inhabitants, as these systems are more likely to be operated in a sustainable manner by the communities than systems that use more sophisticated treatment technology.

In two villages (Sculeni – 1,700 residents; and Şerpeni – 3,100 residents) in which Skat supported the construction of water supply systems, groundwater was found to contain too much iron and manganese for direct distribution. As more traditional (i.e. ex-situ) systems for treating the water would have required inputs and procedures that are more complex and expensive (e.g. chemical inputs, filter backwashing, desludging), they were determined to be inappropriate for implementation in these contexts (i.e. too much to be reliably-managed by a community-based operator). As such, Skat determined these two locations could be suitable as pilots for in-situ systems.

Following investigations into the groundwater, aquifers and surrounding areas, both villages were determined to, indeed, have suitable conditions for in-situ systems. The appropriate facilities were then purchased from FERMANOX and installed by the Moldovan company OPM Soluţii SRL (OPM). As part of the installation agreement, Skat required OPM to monitor the facilities during the start-up phase and make appropriate adjustments to the systems' cycles in order to achieve maximum efficiency.

Both systems are now operating automatically and require very little in the way of interventions. Figure 2 below illustrates how small and simple the in-situ systems installed in Sculeni and Şerpeni are. Skat is now in the process of establishing long-term service contracts between specialized company and the community-based operators so that skilled support is available for the proper maintenance of the systems as well as for any trouble-shooting required. As the technology is quite simple and the operation can be controlled by remote access, the costs of these service contracts are expected to be low and affordable to the community-based operators.

Figure 2: Housing for the in-situ system (left) and in-situ system equipment (steering unit, degassing tank and plumbing) (right) installed in Şerpeni, Moldova

Both pilots have shown that in-situ systems are viable and sustainable options for solving water treatment issues in rural Moldovan locations, especially when compared to more complex and expensive ex-situ systems. Due to this success, Skat intends on providing thorough documentation of the experiences to national authorities in order to raise awareness about the potential of such systems in a broader context, including its potential use for larger operations and industry.

4.2. Case Study: Şerpeni

Context

The in-situ system in Şerpeni (Anenii Noi district) was constructed in 2015 and consists of two wells that operate to provide the village with suitable drinking water. Initial measurements of dissolved iron and manganese in the Şerpeni groundwater measured 0.2 mg/l for both compounds, below the national limit for iron but well above the national limit for manganese.

Results and Discussion

Skat monitored the treatment efficiency of the Şerpeni in-situ system in 2015 and again in 2018. The 2015 results showed an average concentration of 0.09 mg/l for iron and 0.06 mg/l for manganese. The 2018 results showed a fluctuating efficiency over time, with iron concentration levels remaining the same but manganese concentration levels rising to 0.16 mg/l. Following these somewhat unexpected results, an inspection highlighted two main issues:

1. Communication between the wells and the reservoir had been disrupted due to network bills not being paid. As the extraction pumps could not be turned on and off remotely through the automation system anymore, this resulted in the system being operated manually for a period of at least 4 months (the exact timeframe for manual operation is unknown).
2. The water meter used for the operation of the in-situ system was in a highly-deteriorated state due to sand and small stones being pumped through it, resulting in pumping cycles being disturbed and reduced treatment efficiency. The most likely cause of this is that the water meter had not been cleaned as periodically as required.

Once the problems associated with manual operations were resolved, concentration levels of iron and manganese were remeasured, reaching 0.01 mg/l for iron and 0.04 mg/l for manganese.

Conclusion

The Şerpeni in-situ pilot demonstrates the enormous potential for a properly-operated in-situ system in many rural Moldovan areas. It also highlights the importance of proper operation and maintenance as a local operator who is unable or unwilling to contract for proper maintenance/replacement of non-functional equipment can greatly reduce system efficiency.

This is likely to remain a problem for Moldova in the short term as the market is not yet developed and there is a lack of skilled operators and/or maintenance companies, especially in rural areas. As of 2018, no suitable maintenance service provider for the Şerpeni system had been found.

4.3 Case Study: Sculeni

Context

Sculeni (Ungheni district) constructed a new water system between 2009 and 2011. Shortly after it began working, however, a large number of consumer complaints were made due to high levels of iron and manganese in the water, prompting Skat to investigate possible solutions. In 2013, a water quality analysis determined that Sculeni water had very high concentration levels of both iron (1.2 mg/l) and manganese (0.5 mg/l). In 2014, the three wells servicing the village (all of which are located in the same general area) were connected to an in-situ system, and two new wells were built within the aerated zone (but not directly connected to the in-situ system) to help address the increasing water consumption.

Results and Discussion

Skat monitored the treatment efficacy in Sculeni in 2014 and again in 2018. A summary of those results is presented in Table 1 below.

Table 1: Sculeni water monitoring results (2014 and 2018)

	Fe(II) (mg/l)	**Mn(II) (mg/l)**
Pre-in-situ water quality (2013)	**1.20**	**0.50**
Moldovan quality standards	*0.30*	*0.05*
German quality standards	*0.20*	*0.05*
Post in-situ implementation monitoring results		
Start-up (average of June 2014)	0.40	0.83
After 1 week (2014)	0.20	0.58
After 5 weeks (2014)	0.13	0.49
August 3, 2018	0.01	0.08
September 5, 2018	0.07	0.18
September 18, 2018	0.01	0.08
October 11, 2018	0.02	0.08

As one can see, iron and manganese have been virtually eliminated from Sculeni's water supply, with concentration levels showing a continual decrease since the installation of the in-situ system. The spike observed on September 5, 2018 coincides with a 220-300 m^3 per day[1] spike in water consumption. This possible correlation between peak water consumption and peak concentration levels needs further exploration.

Operation and Maintenance

Since implementation, no major problems in the Sculeni in-situ system have appeared. The operator has, thus far, been able to execute all necessary actions and solve minor maintenance issues without outside assistance.

The fees collected from water consumers have been adequate to allow for proper maintenance and operation of the in-situ system thus far.

Conclusion

The pilot in-situ system in Sculeni has been successful. Despite the general lack of specialized knowledge in the area, the ease with which an in-situ system can be operated and maintained by a committed and attentive local operator has been demonstrated.

5. Potential for Further Application in Moldova

Relatively high iron and manganese concentration levels in the groundwater are common in Moldova (Danube Water Program, 2018); however, the potential for in-situ systems to resolve this is somewhat limited due to the geological conditions in many areas of the country, which do not always allow for a good mixing of oxygen in the aquifer. The most suitable areas for in-situ systems appear to be in areas around the banks of the Prut and Dniester rivers, especially upstream areas as they tend to have gravel deposits (downstream areas tend to have fine silt and clay that do not allow adequate mixing and create impervious layers).

In these areas (i.e. upstream areas of the Prut and Dniester rivers), in-situ solutions seem to be a feasible solution in Moldova. Regular follow-up is necessary within the first few years after implementation in order to ensure the automation system is calibrated properly and understood by the local operator. Once well-trained, local operators have demonstrated the capacity to resolve many issues by themselves but will likely need expert assistance for more specific issues. Unfortunately, such expertise is currently hard to find in Moldova and may not be affordable for small localities/operators. The Moldovan government and several projects, however, are now pushing for the regionalization of water services. This may well lead to the development of and support for innovative solutions in the coming years.

[1] Data obtained from the Sculeni Water Consumer Association

6. Conclusion

Despite many advantages (no significant above-ground facilities, no sludge management, automation, etc.), in-situ systems have not realized their full potential in many areas around the world, including in Moldova. It should be noted, however, that the application of in-situ systems is limited by the geology of each area, which must be porous enough to ensure proper oxygenation.

Nevertheless, the two pilot experiences in Moldova have demonstrated that, assuming proper geological conditions exist, in-situ systems are effective solutions that meet national standards for the removal of iron and manganese from groundwater. Moreover, the low investment, operational and maintenance costs of in-situ systems as well as the lack of a need for chemical inputs suits the Moldovan rural context well. The major obstacle for Moldova to overcome if in-situ systems are to become a viable solution is the lack of skilled and affordable maintenance solutions capable of servicing systems in rural areas. As with any technology, however, exposure and further implementation is likely to change this going forward, increasing in-situ systems potential to greatly improve water safety in many rural Moldovan areas.

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