EXPERIENCE FROM WORLD'S LARGEST SEAWATER FILTRATION PLANT FOR OIL RESERVOIR INJECTION

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ABSTRACT

Oil reservoir injection water should be non-corrosive, non-scaling, disinfected and free of particulate matter to minimize reservoir damage. Plant # 1 – a Saudi Aramco facility – with a present design capacity of 9.5 million barrels per day, is the world's largest seawater filtration treatment plant for oil reservoir injection. The design capacity is to be further increased to 14 million barrels per day in 2008. The present filtration system consists of 76 horizontal deep bed pressure filters using granular filter media. These downflow pressure filters are the largest of this type that have ever been built. Each filter is capable of handling 125,000 barrels of water per day. The filters are designed so that suspended solids in treated water should not exceed 0.2 mg/l, with no more that 10% of the solids exceeding the 2 micron size.

The objective of this paper is to give an overall overview of this unique seawater filtration facility and to share some of the challenges encountered, as well as the improvements done to this system.

KEYWORDS

Seawater, Filtration, Filter Media, Deep Bed Filtration, Reservoir Injection

1. Introduction

Plant # 1 – a Saudi Aramco facility in the Arabian Gulf is the world's largest seawater filtration treatment plant for oil reservoir injection. It has present design capacity of 9.5 million barrels per day of treated seawater which is presently being expanded to 14 million barrels per day. The treated water is injected into producing reservoirs in order to support oil production and to obtain optimum oil recovery. As a rule of thumb one barrel of oil is produced for every barrel of water injected.

To minimize any formation damage to the reservoir, the seawater is filtered at Plant # 1 prior to reservoir injection using granular deep bed filters. These downflow horizontal pressure filters are the largest of this type that have ever been built. The latest filters installed at this facility are of 11 feet (3.35 m) diameter x 40 feet (12.19 m) length.

The injection of water into the reservoir rock is necessary to maintain oil production from oil reservoirs. This method is called water-flooding. Water-flooding increases the oil production in two ways:

1. Water injected at the outer edges of the reservoir pushes the oil toward the producing wells located within the reservoir.

2. Reservoir pressure can be held constant by injecting a barrel of water for each barrel of oil produced. This helps to maintain the oil production rate because the reservoir pressure is maintained.

Seawater is the preferred source of injection water as compared to aquifer water because it is widely available and cheap. Seawater is usually relatively clean and of a general uniform composition. In addition, the seawater salinity is such that clay swelling is avoided. The general disadvantages of seawater are that it requires de-aeration to reduce corrosion related problems, disinfection for bacterial control and perhaps the greatest drawback of seawater being its scaling tendency. For the injected water to do its job it must move through the tiny pores of the reservoir rock to displace the oil. To ensure constant supply of water into the reservoir rock over a period of time it is critical that the water be non-corrosive, non-scale forming, disinfected and free of particulate matter. Any appreciable levels of corrosion products, scale, suspended solids, microorganisms, and other impurities could result in plugging of the small pores of the reservoir rock. This will cause a reduction in oil production. Therefore, the filtered water must meet stringent water quality requirements. Table 1 details the major contaminants of seawater that require treatment as well as the final treated seawater quality specifications used at Plant #1 of Saudi Aramco filtration facility.

Impurity	Symbol	Untreated Seawater	Treated Seawater
Total dissolved solids, (mg/l)	TDS	57,000	57,000
Total suspended solids (mg/l)	TSS	2 - 3	<0.2
pH, (standard units)	pH	8.1 - 8.2	7.2 - 7.3
Oxygen, (mg/l)	O_2	6.0 - 8.0	0.0
Sulfur dioxide, (mg/l)	SO_2	----	3.0 - 5.0
Residual chlorine, (mg/l)	Cl_2	----	0.0
Particle size (microns)			Less than 10% of the particles shall be larger than 2.0 microns

Table 1. Injection water specifications produced by Saudi Aramco Plant #1

Suspended solids at Plant #1 are removed by screening and media filtration. Growth of microorganisms is controlled by injecting sodium hypochlorite generated by on-site hypo-chlorinators and periodic use of non-oxidizing biocides. Oxygen is removed by nitrogen stripping and the residual oxygen is scavenged using sulfurous acid. Both nitrogen and sulfurous acid are manufactured on site. Removal of oxygen minimizes contamination of the water with corrosion products. The sulfurous acid injection causes the seawater pH to decrease slightly and this prevents calcium carbonate scale formation. However, a side effect of the sulfurous acid addition is the removal of the chlorine and therefore, periodically other biocides are injected into the system.

The objective of this paper is to give an overall overview of this unique facility, where the world's largest filtration process takes place, and to share some of the challenges and improvements done to this system.

2. Description of Saudi Aramco Plant #1

Plant #1 receives seawater from the Arabian Gulf with high salinity of approximately 57,000 mg/l in total dissolved solids (TDS). Arabian Gulf seawater contains an enormous amount of living organisms ranging from very small bacteria and plants to large fish. These species can cause fouling, plugging, and corrosion. Shellfish, barnacles, jellyfish, etc., can cause fouling of the intake structure, screens, pipes, and canal walls which can lead to the decrease in the flow capacity to the plant. Figure 1, which is the process flow diagram of Plant #1, shows that the first step is for the seawater to be disinfected by injecting sodium hypochlorite. Sodium hypochlorite is generated in-situ using the electrolytic cell process.

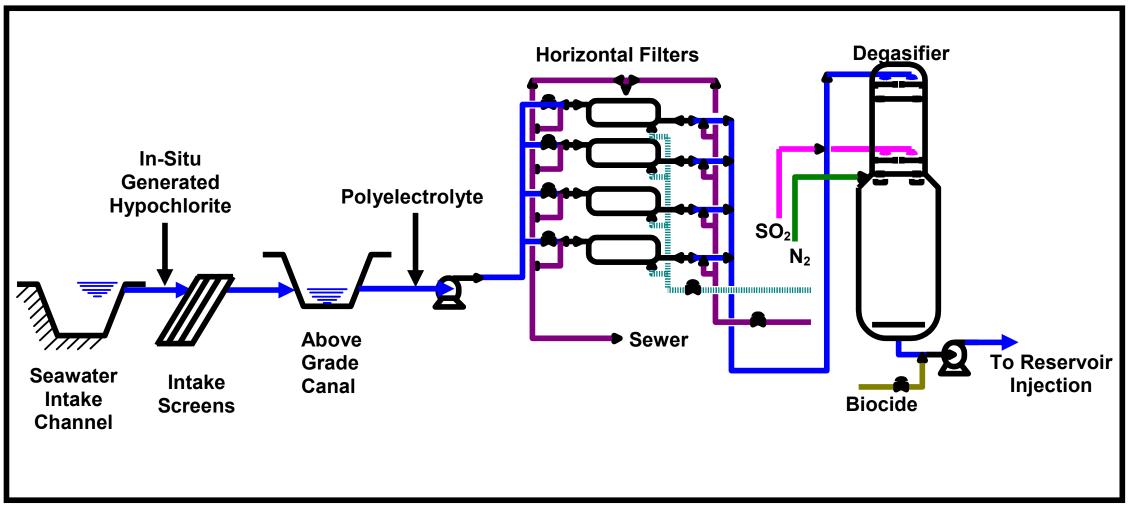

Figure 1. Saudi Aramco Plant #1 Process Flow Diagram

Sodium hypochlorite is added to the seawater at the intake structure to prevent larger fish from reaching the plant intake. All the marine organisms (large fish, plankton, and algae) are removed from the seawater by the use of mechanical screens, sodium hypochlorite, and filter media. Failure to remove the microorganisms from the system will cause problems such as:

- Fouling of the canal, piping, filters and de-aerators
- Fouling of the filters by the growth of plankton and algae in the filters
- Plugging of the injection wells downstream of the filters
- Corrosion of stainless steel piping and other system components
- Generation of hydrogen sulfide which in turn will cause corrosion and plugging problems

The seawater is then passed through bar and drum screens to remove any seaweed, marine organisms and other debris. The seawater is then pumped to an above grade canal and sent to 19 treatment modules. Each module has a design capacity of 0.5 million barrels per day and consists of four filters and a deaerator column for oxygen removal.

Filtration aid (polyelectrolyte) is added to agglomerate the seawater colloids and enhance the filtration performance. This chemical treatment is absolutely necessary to achieve the required high suspended solids removal efficiency.

The filter modules and the degasifiers are located on either site of a central canal from which they are fed. The filters are designed so that the residual suspended solids in treated water should not exceed 0.2 mg/l and no more that 10% of the suspended solids should be larger than 2 microns in size to avoid oil reservoir formation damage.

The filtrate from the horizontal filters is fed to degasifiers for de-aeration. Oxygen needs to be removed from seawater for corrosion control. The oxygen content in seawater is approximately 6 and 8 mg/l for summer and winter respectively. After oxygen removal in the degasifier by nitrogen stripping the residual oxygen level is of the order of 10 ppb. Sulfurous acid is then added to scavenge this residual oxygen and to achieve a complete oxygen removal. The residual chlorine is removed in the de-aerator by the sulfurous acid addition. Once the de-aerated water leaves the de-aerator, there is no residual biocidal capability in the treated water. It is therefore necessary to inject a second biocide into the treated water after the de-aerator. The injection of biocide is generally injected in one to three slugs per week rather than being added continuously. The treated water is pumped through pipelines as far as 300 km away for reservoir injection.

Sometimes, the desired injection water quality specifications are difficult to meet because of several challenges. The filters are operated at a high flux rate in order to cope with the high filtrate demand requirement, single chemical dosage may not be capable of consistently achieving the required specifications, and filter bed upsets occur due to inconsistent backwash practices. Furthermore, the filters are arranged in modules (each module consisting of 4 filters). A small number of large filters may be more convenient as less valves, actuators, connections etc are required, but can lead to operational control problems. The increase in flow rate when one filter is out of service (under backwash) is the factor n/n-1. Thus for a module of 4 filters the factor is 4/3, i.e. 1.33. Such an increase in flow rate can cause a spike of turbidity from the three filters still in service.

3. Plant #1 Filtration Improvements

Twenty (20) filters out of the 76 filters are new installed filters. Several modifications such as lowering of flux rate, change in filter media configuration, and change in chemical dosing were made to the new filters in order to improve their filtration efficiency.

Reduction of Flux Rate:

The flux rate (filtration velocity) is inversely proportional to the filtrate quality. To lower the flux rate, the size of filters installed was increased from 10 ft (3.05 m) diameter x 36 ft (10.97 m) tan-to-tan length to 11 ft (3.35 m) diameter x 40 ft (12.19 m) tan-to-tan length. This has caused decrease if flux rate while maintaining the same output of 125,000 barrels per filter per day. The decrease in flux rate improved the filtrate water quality as shown in figure 2.

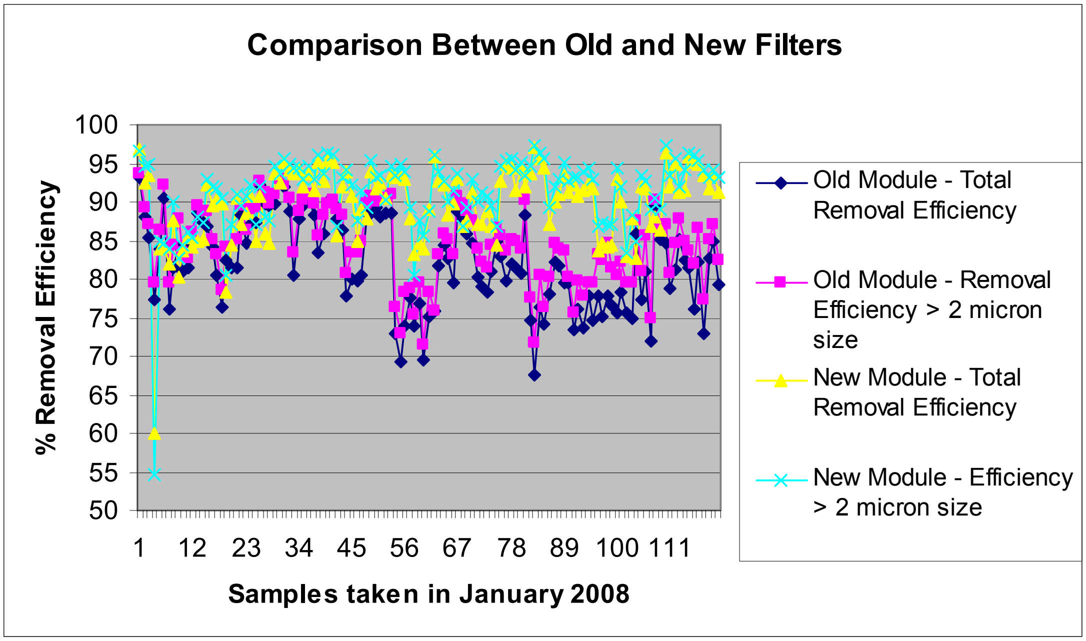

Figure 2. Comparison of filtration efficiency between old and new filters

Filter Media Configuration:

The old filter media configuration consisted of gravel support layers, coarse sand and fine sand on top. The new filter media configuration consists of fine sand and anthracite on top. The gravel support layers were removed and this has enabled the installation of deeper layers of fine sand and anthracite. The removal of the support layers was made possible by the installation of special wire wound laterals whose nozzles cannot be blocked by the sand medium. Anthracite was installed to enable the use of ferric sulfate $Fe_2 (SO_4)_3$ coagulant. Special care was taken in matching the filter media sand and anthracite in relation to their size and specific gravity to avoid intermixing and interpenetration. Filter media of narrow size distribution were used (uniformity coefficients of <1.3 and <1.5 for sand and anthracite respectively) to sustain long filter runs, avoid media interpenetration, be able to backwash the filter bed with the minimum of free board while avoiding media loses.

Chemical Dosing:

To further improve the filtration efficiency of the new filters apart from the flocculent addition it was also decided to add ferric sulfate coagulant. This change is presently in progress. Since ferric sulfate is anticipated to produce a voluminous floc anthracite layer has been installed on top of the sand to retain the voluminous floc and to achieve acceptable filter runs between back washings. Ferric sulfate coagulant was chosen instead of ferric chloride because ferric sulfate is expected to have a better performance at the natural pH of seawater of pH 8.1 - 8.2 than ferric chloride. The isoelectric point (zero point charge) of ferric sulfate floc is around pH 8.0 – 8.5 whereas the isoelectric point of ferric chloride floc is around pH 6.0.

Modification of Feed Water Distribution Showers:
Initially the feed to the horizontal filter was taking place through an assembly of showers. The nozzles of these showers were bigger in size than the size of the filter media, thus filter media were getting lost during backwashing upsets. This shower feed system has been replaced with a lateral type of assembly with opening sizes smaller than the media size. The new feed system helped to make the distribution of the feed water to the filter more uniform and have eliminated filter media loss during backwash upsets.

Siphon Arrangement (to enhance air scouring efficiency and water backwash):
The use of a coagulant such as ferric sulfate can result in the build up of a surface "cake" on the anthracite layer. This "cake" needs to be broken during air scouring and flushed out of the filter during water backwash. The filter is drained to about 3 inches above the filter media surface prior to commencing the air scour. This is very important in achieving the braking of the "cake" since most of the agitation during air scouring should take place where the "cake" is and not above or below the "cake" location. Failure to drain the water to the correct level prior to the start of the air scouring will result in insufficient breaking of the surface "cake" which can lead to mud-ball formation. The draining of the filter to the correct level prior to air scouring is accomplished by the installation of a siphon system instead of having to rely on drainage time which is a function of the filter's degree of blockage.

4. Conclusion

Plant # 1 is unique in terms of size and process. Treating large volumes of sea water is very challenging and meeting the water quality specifications for oil reservoir injection is even more challenging. Many design improvements such as filters' size, filtration media, filtration aids (flocculants and coagulants) feed water distribution lateral assembly, and siphon arrangement for filter water drainage prior to air scouring have led to significantly increasing the filtration efficiency.

5. References

1. Nicos P. Isaias, Ahmed S. Al-Rammah, Saudi Aramco Engineering Report (SAER #5606), March 1998

2. Degrémont, Water Treatment Handbook, Chapter 9, Filtration Through a Filter-Bed, 5th English ed; Published by Halsted Press, 1979, pp254-274.

3. Quaye B. A., Isaias N. P., "Contact Flocculation-Filtration of Low Turbidity, Highly Colored Acid Moorland Water" Journal of the Institution of Water Engineers and Scientists Vol. 39 N0. 4 August 1985 pp. 325-340.

4. Purchas, D. B., Wakeman, R.J., Solid/Liquid Separation Equipment Scale-Up, Uplands Press, London, 2nd Edition, 1986: pp. 497-508.

5. Saudi Aramco Materials System Specification (32-SAMSS-034) “Granular Filtering Materials”