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PRACTICAL CONSIDERATIONS IN ENSURING COST MINIMIZATION IN THE DESIGN AND OPERATION OF SULFATE REMOVAL SYSTEMS

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Abstract

The removal of sulfate from injected seawater for waterflood and pressure maintenance operations has become widely accepted for reservoirs with sulfate scaling potential. The technology has been found to be exceptionally useful in deep water and subsea operations where scale control using scale inhibition squeeze treatments become prohibitively costly. Twenty five sulfate removal facilities are now operating or being built off the coast of West Africa, Brazil, and in the North Sea. Experience with these existing facilities has identified methods to minimize the size of the sulfate removal facility with accompanying weight and space savings which often exceed the capital cost of the sulfate removal system itself. Similar savings and trends have been identified by the availability and success of auxiliary pre-filtration equipment. Operational cost reduction and improved reliability have been achieved by selecting raw seawater intake locations and the re-design of sulfate removal membrane module, the key separation component in the sulfate removal system. The careful selection and evaluation of sulfate removal system components, including fine filtration and deaerators, have resulted in significant savings by extending membrane life up to twice the warranty period and by reducing operational costs of 25% than originally projected.

Resumo

A remoção de sulfatos da água do mar utilizada para operações de manutenção com sobre-injeção de água e pressão está se tornando amplamente empregada em reservatórios com potencial de incrustação de sulfatos. A tecnologia é excepcionalmente aplicável em águas profundas e operações submarinas, onde o controle de incrustação pelo uso de tratamentos com inibidores de incrustação torna-se proibitivamente custoso. Vinte e cinco instalações para remoção de sulfatos estão em operação ou em construção nas áreas costeiras da África Ocidental, Brasil e no Mar do Norte. As experiências nestas instalações existentes, possibilitou a identificação de métodos para minimizar as dimensões das unidades de remoção de sulfato, resultando na redução do peso e espaço necessários, que normalmente excedem as verbas requeridas para o sistema de remoção de sulfatos em si. Tendências e economias semelhantes foram identificadas através da disponibilidade e o sucesso de equipamentos auxiliares de pré-filtragem. A redução dos custos operacionais e melhor confiabilidade foram atingidas pela seleção dos pontos de tomada de água do mar sem tratamento prévio e pelo redimensionamento dos módulos das membranas de remoção de sulfatos, elementos chave dos componentes de separação no sistema de remoção de sulfatos. A seleção cuidadosa e a avaliação dos componentes do sistema de remoção de sulfatos, incluindo filtragem fina e desareadores, resultaram em economias significativas, aumentando o período de garantia em até duas vezes a vida útil das membranas e pela redução de 25% dos custos operacionais em ralação aos custos do projeto original.

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1. Introduction

The key component of a sulfate removal membrane process is a sulfate removal membrane module or element, the component of the process which performs the removal of sulfate from the incoming seawater. The membrane process, within the membrane module, is depicted in Figure 1 where sulfate ions are selectively repelled off a membrane surface while allowing most of the remaining components of seawater to pass through the membrane.

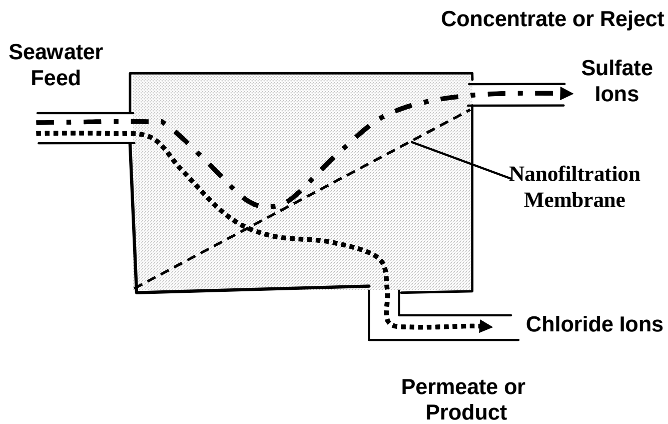

Figure 1. Nanofiltration Membrane Process

This membrane separation is achieved by placing the sulfate removal membrane in a "spiral wound configuration" which provides 400 + ft^2 of membrane area to be placed in a module or cylinder 8" in diameter and 40" in length. As shown in Figure 2, the seawater passes from one end of the membrane element to the other end through "feed channel spacers". As the seawater passes *over* the membrane, the sulfate ions are rejected or repelled off the surface and discarded. The remaining seawater, containing predominantly sodium chloride, necessary to maintain stable reservoir clays, passes through the membrane itself and is transported to a product water tube by the permeate or product water channel spacer. The sulfate free seawater is then collected and used for injection into the reservoir.

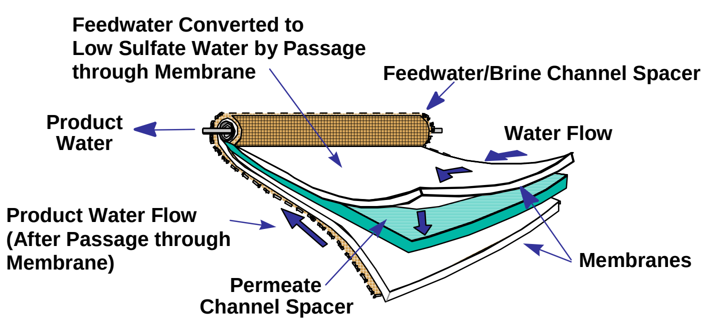

Figure 2. Configuration of a Nanofiltration Membrane Module

By optimizing the design and operation of the sulfate removal unit, one can have maximum impact in assuring operation cost minimization by maintaining the cleanliness of the feedwater/brine channel spacer and of the membrane area on both sides of this spacer. The two basic challenges to overcome in maintaining the cleanliness within the feed water spacer and the membrane surface are the minimization of: a) particles inherent in the seawater and b) biofilms or microorganisms that become deposited on the surface of the membrane as the sulfate free seawater passes through. These challenges are met by the proper design and operation of the auxiliary processes before the seawater reaches the sulfate removal system.

1.1 INCORPORATION OF THE SULFATE REMOVAL PROCESS INTO THE TOTAL WATER TREATMENT INJECTION SYSTEM

Conventional waterflood processing equipment requires the need to remove particles and microorganisms from the seawater to prevent skin damage of the reservoir rock in the injection well. Oxygen is also removed to prevent corrosion of the downhole injection piping. A sulfate removal unit requires the same water treatment. However, instead of focusing on the blocking of reservoir rock, one must focus on the blocking of the membrane surface within the sulfate removal membrane module. Once the seawater passes through the membrane, all particles greater than 0.001 μ are removed, thus removing nearly all possibilities of downhole deposition of foulants or materials on the sand face of the reservoir rock receiving the injection water. Consequently, initial reservoir injection pressures are more likely to be maintained throughout the life of the waterflood.

The sulfate removal system can be inserted into a conventional water treatment injection system as shown in Figure 3.

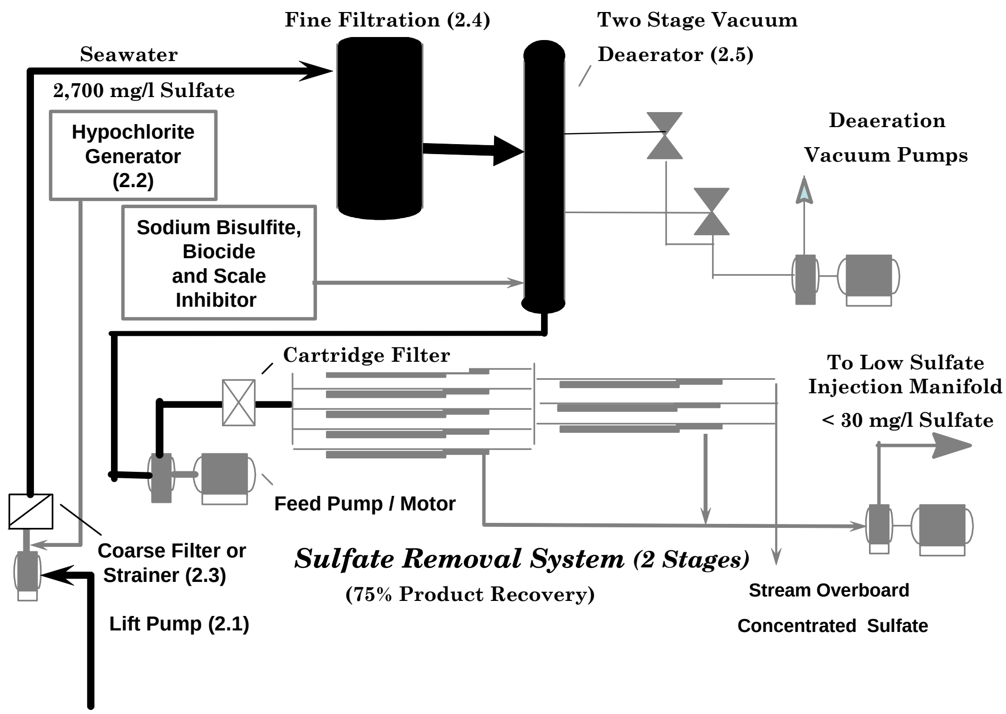

Figure 3. Seawater Injection Treatment System Incorporating Sulphate Removal

Attention to the particular design features or processes within this overall system will ensure fouling minimization and resultant cost minimization of the sulfate removal system. These design features are discussed as follows.

2. Design Features to Minimize Operation Cost

2.1 LOCATION OF SEAWATER LIFT PUMP OR FEED TO SEAWATER LIFT PUMP

Starting with clean cold seawater often obtained at deeper intake depths is perhaps the easiest and least costly measure in affecting the overall performance of the water treatment system. As mentioned earlier, biological and particle fouling is the key obstacle that must be overcome. By locating a feed water source with a low biological content and particle count, one immediately begins with a high quality feed water whose benefits cascade throughout the injection water treatment system. With a high quality feed water with reduced particle content, one can reduce the workload on the fine filtration, allowing it to perform at optimum performance and with minimum backwashing or regeneration. This, in turn, provides a higher quality feed water to the membranes which provides reduced fouling and the resultant decrease need for cleaning, downtime, and other system maintenance. In addition to water quality, water intake at a lower depth results in a lower temperature of the feed water. Since microorganism growth is reduced at lower temperatures, microbial growth on the downstream membranes is minimized.

2.2 HYPOCHLORITE GENERATORS AND SUBSEQUENT DECLORINATION PRIOR TO THE MEMBRANE SYSTEM

Hypochlorite generators are used in conventional injection water treatment systems to destroy microorganisms that could foul and block the sand face of the reservoir in the injection well. Likewise, the hypochlorite generator provides a source of chorine that destroys the microorganisms that will foul the membranes. However, the free chlorine must be removed prior to the membranes themselves as they will oxidize the surface of the membrane causing it to no longer reject or repel the sulfate ions off the surface. This is achieved by the addition of sodium bisulfite, a reducing agent which oxidizes and destroys the free chlorine upon contact. As soon as the hypochlorite is no longer present, renewed microbial growth can begin again. Consequently, by maximizing the time and subsequent fluid flow within the water treatment system with free chlorine, any microbial growth that can be started and deposited on the membrane, is minimized. Since all microorganisms are removed in the membrane process, the only microorganisms that can be deposited on the reservoir rock are those generated downstream of the sulfate removal system.

2.3 COARSE FILTRATION

Coarse filters of approximately 80 µ are used to remove seawater debris. They are not considered for the filtration of particles that result in the fouling of the membrane elements

2.4 FINE FILTRATION

The function of fine filtration is to remove all particles and microbial decomposition products due to the upstream process of the chlorination and subsequent destruction of microorganisms. Fine filtration also protects or reduces the workload of the 5 µ (nominal or 10 µ absolute) cartridge or guard filter required by the membrane element manufacturer to protect the membrane element. The cartridge or guard filters are a secondary "back-up" to capture any particles that could escape through the fine filters and would subsequently plug the feed channel spacer of the membrane element. It is important to note, that these guard filters are not able to be regenerated or cleaned. Consequently, any particles that ARE NOT removed by upstream fine filtration processing the raw seawater will need to be removed by the guard filter just upstream of the membrane system. All recommended fine filters can be regenerated or backwashed due to the relative large bulk of the particles and other materials in the raw seawater. Consequently, they are simply process equipment whose cost is encountered in the design and subsequent construction of the initial operation. The fine filtration used in nearly all of the sulfate removal systems in operation to date are the multimedia, dual media or sand filters. Pleated cartridge filters that can be regenerated by the drying / dehydration and subsequent removal of the particles on the feed side of the filter, feature a smaller space requirement and a significant reduced weight requirement. These pleated cartridge filters have been used very successfully in two water treatment systems incorporating sulfate removal. They, however, use a high dirt capacity pleated cartridge filter that needs to be replaced every two or three years. Both the multimedia and pleated cartridge filters have extended the replacement rate of the guard filter from 40 to 80 days. Without fine filtration, the guard filter replacement rate is reduced to approximately 3 days. In "the blooms" of the North Sea, the replacement rate is as low as 6 hours. The cost impact of the overall operational cost based on the frequency of replacement of the guard filter is shown in Figure 4.

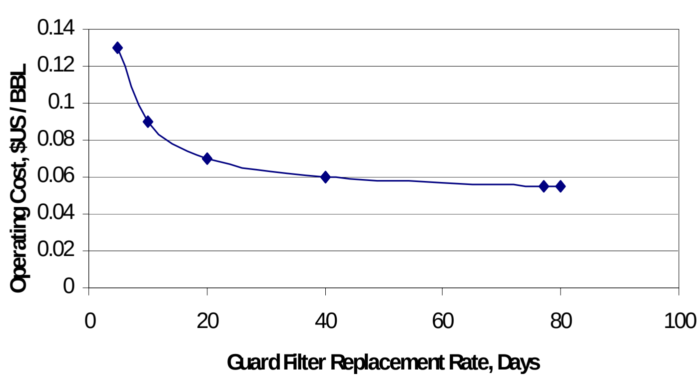

Figure 4. Operating Cost vs. Guard Filter Replacement Rate

2.5 DEAERATION

Oxygen must be removed from seawater prior to its injection into a reservoir primarily to prevent corrosion and to inhibit aerobic bacteria growth on the sand face of the reservoir rock in the injection well. With the incorporation of a sulfate removal system, there are two options for its location: a) upstream of the sulfate removal unit or b) downstream of the sulfate removal unit. In observing the biofouling potential on the sulfate removal systems in operation, it is important to note that good performance has occurred with both the upstream and downstream deaeration. However, with systems with the longest membrane life and least downtime due to cleaning, it is observed that removing the oxygen prior to the membrane system reduces the potential of biological growth and subsequent fouling on the membrane surface. An explanation for this is that aerobic bacteria exist in the fully oxygenated seawater as it enters into the water injection treatment process. Consequently, if oxygen, a key ingredient for the growth of these aerobic bacteria is removed, then the propagation and /or the probability of aerobic biological growth on the membrane is likewise reduced. The lack of oxygen simply causes the aerobic bacteria to attempt to propagate in a hostile (oxygen free) environment.

This biofouling limiting advantage comes at an equipment cost. By removing the oxygen from the seawater prior to the membrane system, the deaerator must be designed for the *feed* to the system. For a 100M BWPD (Barrel Water per Day) sulfate free water injection, the deaerator must be sized at 133M BWPD as the yield of the sulfate removal unit is 75%. By removing the oxygen after the sulfate has been removed, the deaerator can be designed for the *output* of the sulfate removal system, i.e.100 M BWPD.

By eliminating the biological growth on the membrane surface, cleaning frequency is decreased. The result is an improvement in on-line capacity. Reduced cleaning frequency also extends the life of the membrane by approximately 50%.

2.6 THE MEMBRANE ELEMENTS WITHIN THE SULFATE REMOVAL UNIT

The aging and subsequent fouling of the membrane is directly related to the relative workload or output of each membrane element. Ideally, all the membrane elements would carry the same workload and age or foul simultaneously.

There are design features that are common to all membrane systems and are directed towards adjusting flows and output of each membrane element to help achieve this goal. These are "built-in" features that are part of the sulfate removal system that can not and need not be changed and are of value mainly for an overall understanding and intellectual curiosity. However, there are design features *within* an individual membrane element that are vitally important in extending the useful life of the element.

A fundamental principal of membrane technology is that fouling (particle deposition, membrane compression, etc.) is directly related to output. Membrane output and fouling are related to pressure as illustrated in Figure 5.

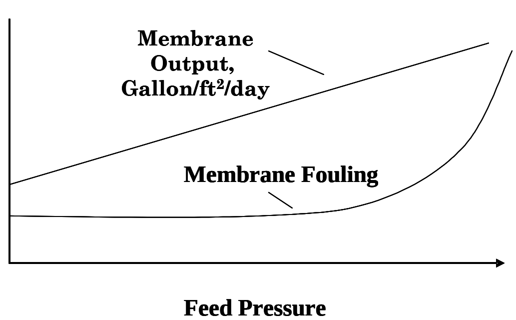

Figure 5. Impact of Feed Pressure on Membrane Output (gfd) And Fouling / Aging Potential.

Referring back to Figure 2, the spiral wound configuration is illustrated with individual membrane leaves attached to a central product water tube. A subtlety not readily recognized is that the output of the leaf – from that membrane area close to the product water tube versus the membrane area at the end of the leaf (and most distant from the product water tube) is not uniform. This is due to the pressure drop in the product water spacer between the two membrane layers. As shown in Figure 6, the feed pressure against a particular portion of the membrane area is negated by the back pressure within the feed channel spacer. Consequently, the output of the membrane area closest to the product water tube is much greater than the output of the membrane at the end of the leaf. Likewise, the fouling potential (wear) of the membrane nearest the product water tube is greater.

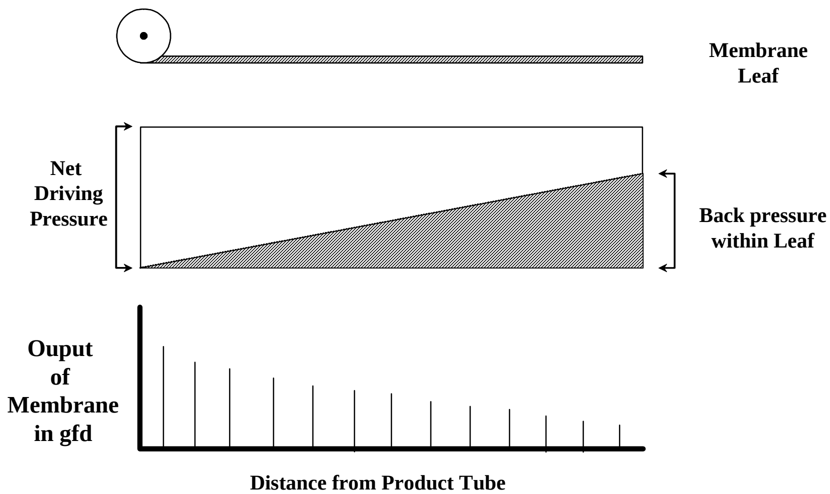

Figure 6. Variation of Water Production Within a Membrane Leaf

By shortening the membrane leaf and increasing the number of leaves to maintain the area within the membrane module, the work output, within the membrane element, is more evenly distributed. This is accomplished by the use automated membrane element construction which provides for: 1) the ability to attach a greater number of leaves on each product tube and 2) the precise application of glue lines which produces the envelopes and the resultant loss of membrane area due to glue spread.

By using automated membrane element construction, the effective membrane area is increased approximately 25%. By having more membrane area within each element, the number of vessels and accompanying weight and space could be reduced by a corresponding number.

3. Factors in Assuring Cost Minimization in the Design and Operation of Sulfate Removal Systems

Knowing the operating costs and how these costs are affected by a system design is the first step in prioritizing what measures will have the greatest impact on the operation costs of the sulfate removal unit. It is observed that much time and resources are often spent on individual cost items that result in inconsequential savings.

Table 1 is a listing of the estimated costs and assumptions cost basis of the operation of a sulfate removal unit. Table 1 can be modified by the end user into an Excel spreadsheet to better predict one's particular situation. For example, as indicated in the discussions on the replacement rate of cartridge filters based on upstream fine filtration, a 40 day replacement rate results in a cost of $0.0100 / BBL (Barrel). If the replacement rate is once every 5 days, the cost of the cartridge filter is $.0800 / BBL.

Table 1 - Operating Costs of a Sulfate Removal System

	$US/ BLL
Labor [1]	0.0150
Membrane Replacement [2]	0.0106
Cartridge (Guard) filter [3]	0.0100
Energy [4]	0.0150
Chemicals [5]	0.0067
Cleaning [6]	0.0024
Total	**0.0597**

(1) 12 hr./ 100M BWPD capacity at $US 125/hr.
(2) 5 year membrane element life for 400 ft^2 membrane element with installed cost of $US 2680
(3) Cartridge filter at $US 0.40 / BWPD capacity with replacement rate of 40 days
(4) 0.16 KW/BBL at $US 0.094/KW
(5)

Chemical	Dosage rate ppm	Recovery (Yield)	$/lb	$US/BBL product
Antiscalant	3	75	2.5	0.00349
Coagulant	1	75	2.36	0.00110
Bisulfite	3	75	0.45	0.00063
Biocide*	0.29	75	10.9	0.00147
Total				0.00670

* Biocide shock treatment 1/wk

(6) Cleaning chemicals ($US 0.037 /BBL) plus 24 hr. labor at $US 125/hr every 40 days

4. Summary

Based on systems in operation to date, deepwater intake, the removal of oxygen prior to the membranes, and the use of fine filtration, will result in guard filter replacement frequencies of 40+ days, a cleaning frequency of once every two months, and membrane replacement rates of 6+ years using the short leaf membrane element.

As in most systems, there is a capital cost / operating cost tradeoff. Operators are strongly encouraged to carefully examine: 1) the cost comparison of the deep and shallow water intake, the use of fine filtration, and upstream or downstream deaeration and 2) the corresponding difference in operating cost. Other factors include “on line” capacity and the loss of total capacity due to frequent cleaning.

5. Acknowledgements

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