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Treatment of Seawater With Cartridge Filtration—A Field Trial

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Abstract

In offshore operations, seawater is often injected to maintain reservoir pressure for enhanced oil recovery. A sulfate reducing membrane (SRM) is typically used to reduce the sulfate content in the seawater from 2900 mg/l to less than 50 mg/l to prevent souring of the reservoir by sulfate reducing bacteria and formation of barium and strontium sulfate scale when seawater is mixed with formation water. A two cartridge in series filtration pilot unit installed on a deepwater platform in the Gulf of Mexico has demonstrated that cartridge filtration can be used upstream of the SRM to pretreat seawater to meet the SRM feed seawater specification of SDI<5 and NTU<1. Scanning Electron Microscopy/Energy Dispersive Spectroscopy (SEM/EDS) was used to determine the composition of the material deposited on the surface of a used cartridge filter. From the SEM/EDS results, it was concluded that the filters were blocked predominantly by coccoliths (calcium compounds), diatoms (silicon compounds), iron oxide corrosion products, and broken, crushed marine debris, that formed a fine grained membrane cake on the filters. It was found that a two filter in series configuration is a better seawater filtration system than just using one single filter if seawater with an SDI < 3.5 is required. With the installation of a 50 micron nominal filter upstream of a 10 micron absolute filter, the service life of a 10 micron filter was increased by 20 times.

Introduction and Background

Selecting a filtration system for a Gulf of Mexico deepwater waterflood system is a significant challenge[1]. While deepbed multimedia filtration will likely deliver acceptable water quality to maintain injectivity, such filtration is heavy, particularly when liquid full, and occupies a great deal of space compared to alternatives such as cartridge filtration. If deep bed filtration is installed and it is not needed, it is a waste of space and weight. If it is not installed, and it turns out that it is needed, then retrofitting a system is almost impossible and the success of the waterflood may be seriously jeopardized. Therefore, the system selection regarding waterflood filtration must be made with great care. In this paper we describe a pilot study done on-site at a deepwater GoM TLP in order to assess the suitability of alternative systems to multimedia filtration.

Pilot Testing Objectives

The primary objectives for the pilot test were to:

- Demonstrate that cartridge filtration can be used to pretreat seawater to meet SRM filter feed specifications (SDI<5 and NTU<1).
- Determine the optimal cartridge filter micron rating and configurations (single stage or two stages) to provide a seawater quality of SDI<5 and NTU<1.
- Determine cartridge filter change out frequency. This information will be used for comparing the operating cost and capital costs of the cartridge filters process with a micro filtration membrane process for the pretreatment of seawater ahead of an SRM filtration system.

The secondary objectives were to

- Study the effect of seasonal algae bloom on feed seawater quality by measuring SDI and NTU over the six month testing period
- Determine the composition of the material deposited on the surface of a used cartridge filter using SEM/EDS instrument.

Pilot Skid Description

The pilot skid sketch is shown in Fig. 1. Fig. 2 shows the photograph of the pilot skid. The water is fed by the platform's submersible pump through a pressure regulator to the cartridge filtration skid. Sodium hypochlorite was injected at the inlet to the pilot skid to obtain about 3 ppm of chlorine in the feed water stream. A globe valve at the inlet controls the seawater flow rate at 6 gpm to the downstream cartridge filters. The first cartridge filter is a 50 micron nominal pore size filter. The second filter is a 10 micron absolute filter. Each cartridge filter is 2.5" OD by 19.5" long. The material of construction of the cartridge filters was polypropylene. The cartridge filter skid (39" by 60") is equipped with a chemical injection pump, a pressure relief valve, a pressure regulator, a pressure recorder, two differential pressure recorders, and a flow totalizer to record process conditions. This information was retrieved and NTU and SDI measurements[2] made on the platform on a weekly basis.

Fig. 1 Pilot Skid Layout

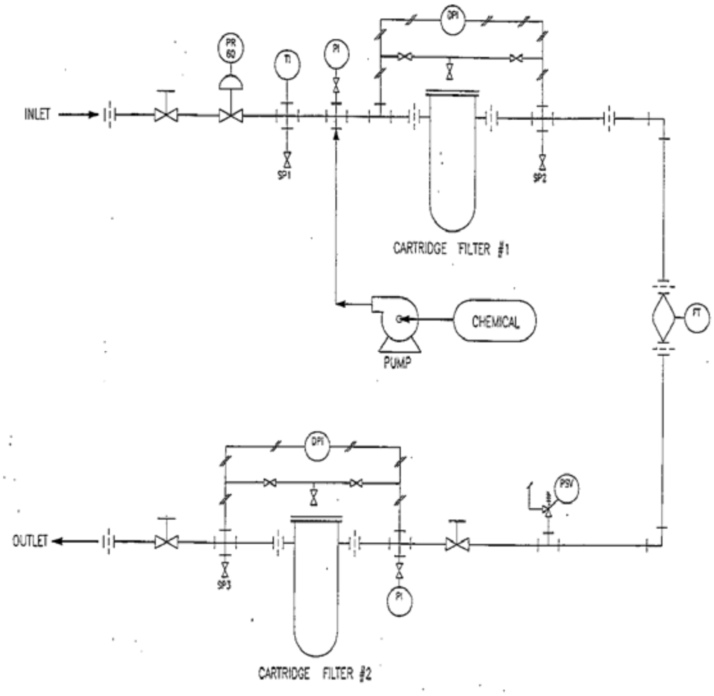
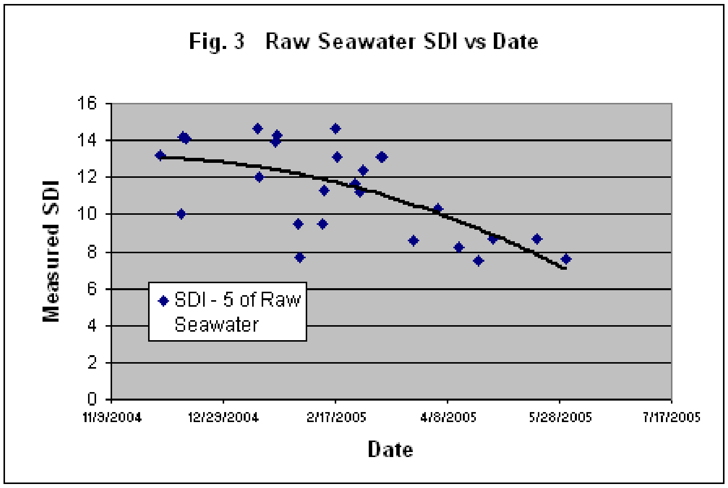


Fig. 2 Pilot Skid Photograph

Seasonal Effect of Algae Bloom on Seawater Quality

The pilot testing started in December 2004 and was completed in May 2005. The seasonal effect of algae bloom on the feed seawater quality was monitored by measuring the SDI of feed seawater. As shown in Fig. 3, the measured SDI during the algae blooming season was about 13 from December 2004 to the end of January 2005 based on the SDI-5 measurement procedure. It then reduced gradually from 13 to about 9 from the month of February to the end of May 2005.

Fig. 3 Measured Feed Seawater SDI vs. Run Date



Pressure Drop vs. Run Hours for the Two Cartridge Filters in Series Process

The original pilot skid was modified from a one strainer and one cartridge filter system to a two cartridge in series filtration system on February 12, 2005. The modified system was used to measure the pressure drop rate through the filters and to determine the filter service life. The first filter was a 50 micron nominal depth filter followed by a 10 micron absolute depth filter. The flow rate used for the pilot test was 6 gpm. The surface area for the 2.5" OD x 19.5" depth filter is 1 square ft. The flux was maintained at 6 gpm (gallons/minute) per ft^2 of filter surface area during the entire depth filter test period. It was found that the filter lasted for three to four weeks before the pressure drop across the first filter reached about 30 psi and the second filter pressure drop reached 20 psi. The filters were changed out when the pressure drop for the first filter reached 30 psi.

Fig. 4 shows the test results from April 4th to April 27th. The filters lasted about 550 hours (23 days) before they were changed out. At about 400 run hours, both the first and the second filter pressure drop was about the same at 20 psi. Before 400 run hours, the pressure drop for the first stage filter was lower than that for the second stage filter. This was because the first stage filter has a larger pore size of 50 microns nominal versus the smaller pore size of 10 microns absolute for the second stage filter.

After 400 run hours, the pressure drop for the first stage filter became higher than that for the second stage filter. This is because a significant amount of biological solid materials had deposited on the first stage filter surface and as a result the effective pore size of the first stage filter became smaller over time, increasing the filtration efficiency of the first filter.

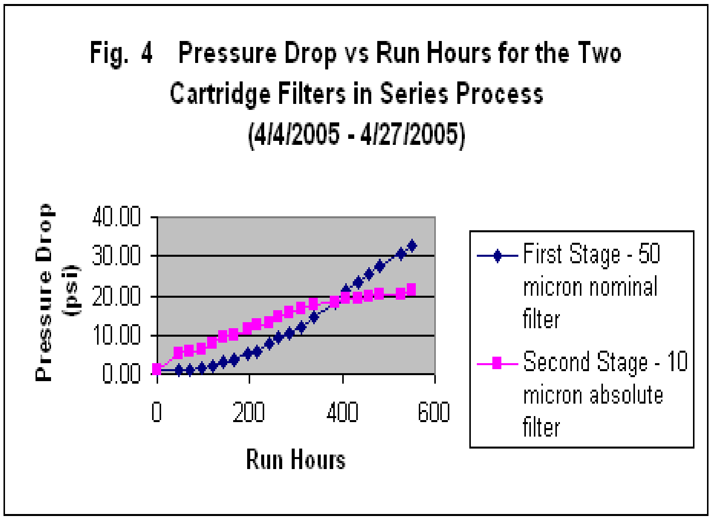


Fig. 4 Pressure Drop vs Run Hours for the Two Cartridge Filters in Series Process (4/4/2005 - 4/27/2005)

Once the pressure drops of the first stage filter reached greater then 30 psi, both the first and the second stage filters were changed out. The test was then repeated. The results of the next run from 4/27 to 5/18/2005 are shown in Fig. 5. The results of this run indicated that the pressure drop for both the filters are very similar to those for the previous results as shown in Fig. 4.

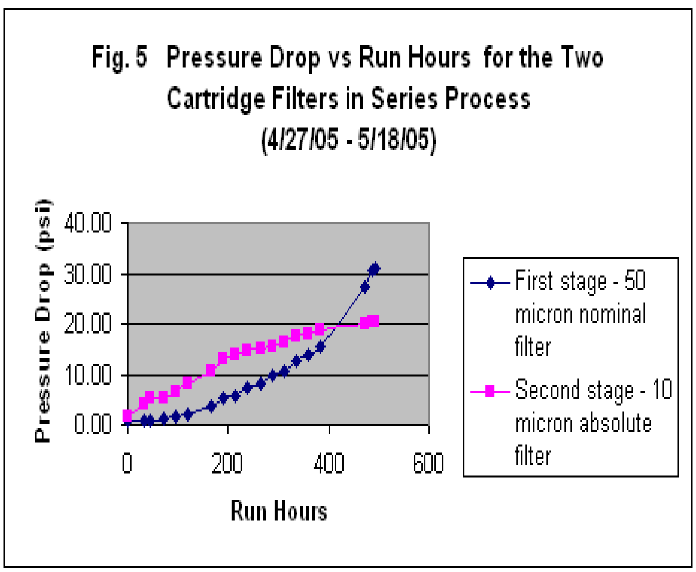


Fig. 5 Pressure Drop vs Run Hours for the Two Cartridge Filters in Series Process (4/27/05 - 5/18/05)

In this pilot project, both the filters were changed out when the first filter pressure drop reached 30 psi. For a commercial application, the second filter needs to be changed out only if its pressure drop rises to 30 psi.

Measured SDI vs Run Hours

The measured SDI versus run hours for the test period from April 4 to April 27 is shown in Fig. 6. At 1 hour of run time, the measured SDI at the inlet to the first stage filter was 10. The SDI was reduced to 4.6 and then to 3.6 after the first stage and second stage cartridge filters outlets. At 438 hours of run time, the measure SDI at the inlet to the first cartridge filter was about 8.0. It was reduced to 2.4 and 2.1 respectively after the first stage and second stage of filtration.

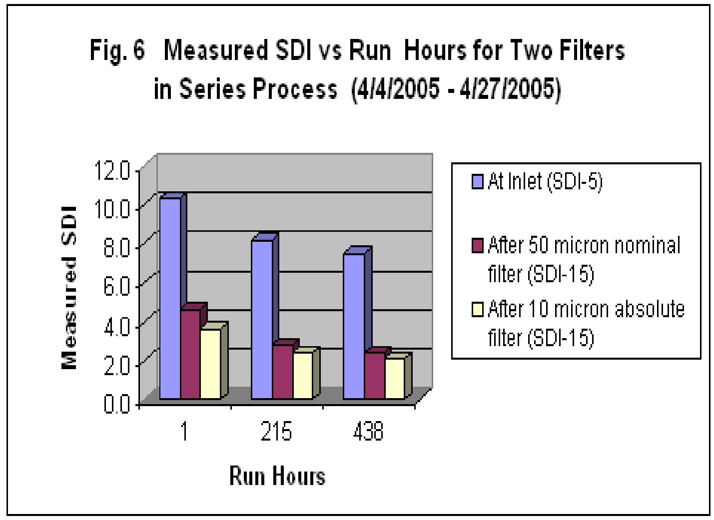


Fig. 6 Measured SDI vs Run Hours for Two Filters in Series Process (4/4/2005 - 4/27/2005)

The measured SDI for the test period from April 27 to May 18 is shown in Fig. 7. At 29 hours of run time, the measured SDI at the inlet to the first stage filter was 8.7. The SDI was reduced to 3.7 and then to 3.6 at the first stage and second stage cartridge filters outlets. At 494 hours of run time, the measure SDI at the inlet to the first cartridge filter was about 8.7. The SDI was reduced to 2.5 and 2.2 respectively after the first stage and second stage of filtration.

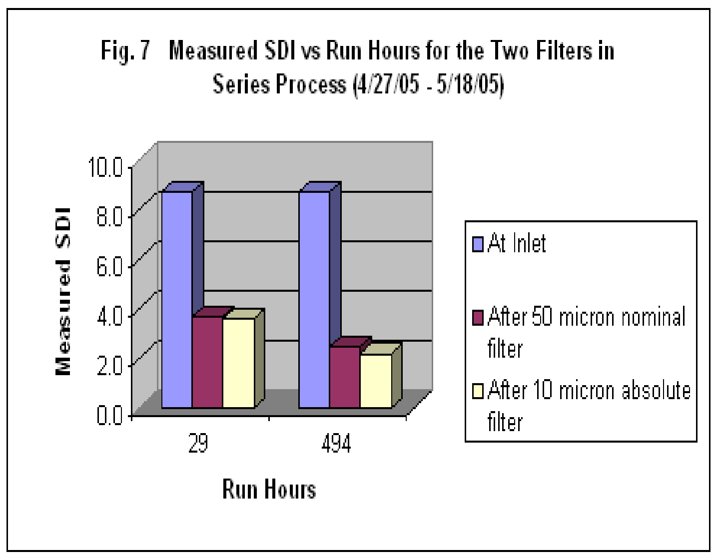
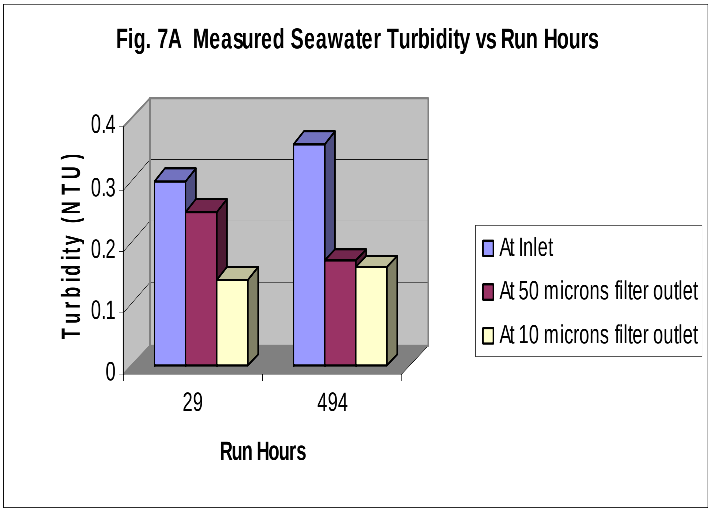


Fig. 7 Measured SDI vs Run Hours for the Two Filters in Series Process (4/27/05 - 5/18/05)

The measured seawater turbidity is shown in Fig. 7A. At 29 run hours, the NTU values for the seawater feed and downstream of the 50 micron and 10 micron filters were 0.3, 0.25 and 0.14 respectively. At 494 run hours, the measured NTU values were 0.35, 0.17 and 0.10 respectively.



Composition of Biological Materials Deposited on the Filter Surfaces

Scanning Electron Microscopy/Energy Dispersive Spectroscopy (SEM/EDS) was used to determine the composition of the material deposited on the surface of a used filter (tested in December 2004). From the SEM/EDS results, it was concluded that the filters become blocked predominantly by broken and crushed, undifferentiated marine debris, quartz spicules, coccoliths, diatoms, algae and bryozoans that formed a membrane cake over the filter surface. The presence of abundant marine debris is most likely due to an algal and coccolithic bloom in the seawater.

The shape of the microorganisms varied from the long needle type (quartz spicules) to the cylindrical type (diatoms) as shown in Fig. 8. The length of the spicules is about 30 microns and the length of the diatom is about 10 microns. Fig. 9 shows that coccoliths (round shape) also are present in the seawater. Fig. 10 shows the measured elements included silicon, calcium and iron. The iron in the seawater is probably due to steel corrosion products. A proper selection of materials of construction for the seawater injection system is potentially important in reducing the plugging of the filters and membranes by corrosion products.

Fig. 8 Shape of Quarts Spicules and Diatoms

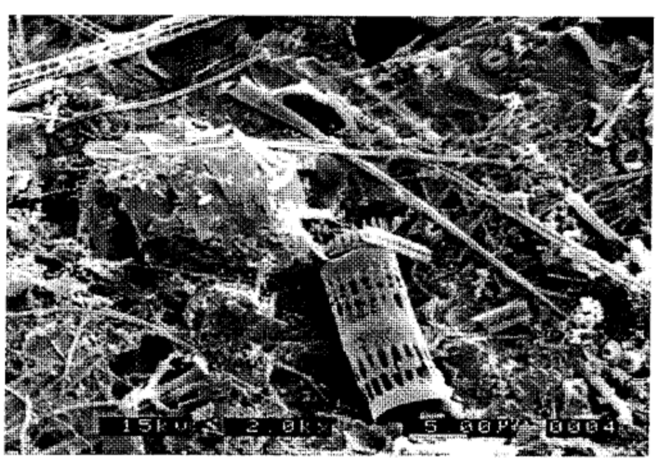


Fig. 9 Shape of Coccoliths (Round Shape)

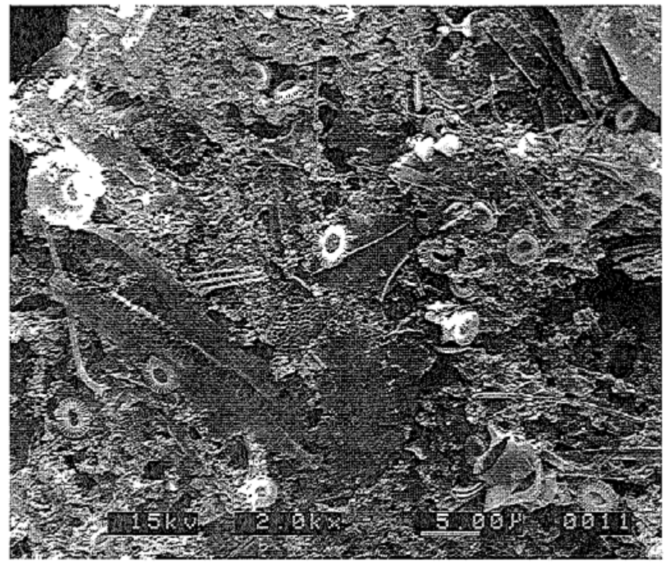
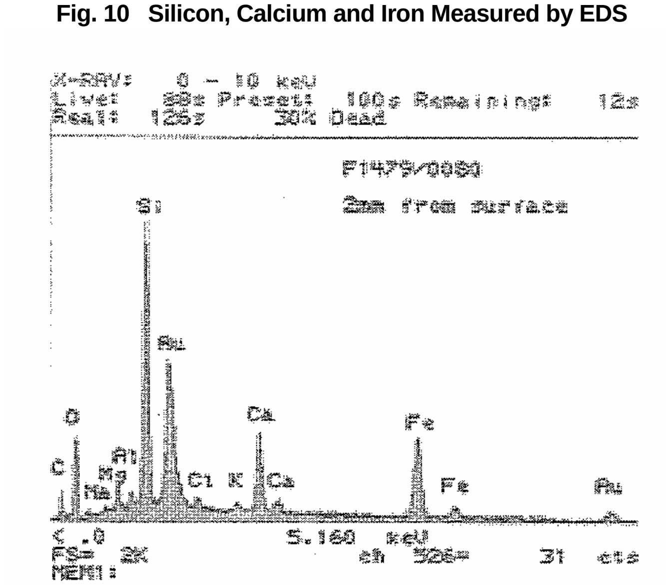


Fig. 10 Silicon, Calcium and Iron Measured by EDS



Attempts were made to measure the solids concentration in the seawater feed and at the filter outlet by a Millipore filtration method. Since the water content of microorganisms is at least 75% and the Millipore test data is reported on a dry basis, the total suspended solids concentration and the solid loading on filters based on the Millipore tests do not accurately represent what is present in the seawater. However, the measured results are shown in Table 1.

Table 1 Total Suspended Solids and Solid Loading Measured by Millipore Filtration Test

Date	Sample Location	Filter Pore Size	TSS Conc. (ppm)	Solid Loading (gram)
12/11/2004	Inlet	20 micron abs.	0.49	
12/11/2004	Outlet	20 micron abs.	0.25	12.5
12/11/2004	Inlet	40 micron abs.	0.36	
12/11/2004	Outlet	40 micron abs.	0.11	18.7
1/12/2005	Inlet	50 micron abs.	0.25	
1/12/2005	Outlet	50 micron abs.	0.17	23.9
Note: TSS and Solid Loading are based on dry basis.				

The use of the SEM/EDS to determine what types of biological materials were in the seawater was therefore a more useful tool than a Millipore Filtration Test for understanding the cartridge filter performance.

Measured NTU vs. Run Hours

The measured turbidity (NTU) for the feed seawater was quite low at < 0.5 NTU for the entire period of the testing. The results are shown in Fig. 11. This may be due to the fact that the color of the microorganism is light and does not change the apparent clarity of seawater. Also, the size of some of the micro-organisms is likely too small to effectively scatter visible light.

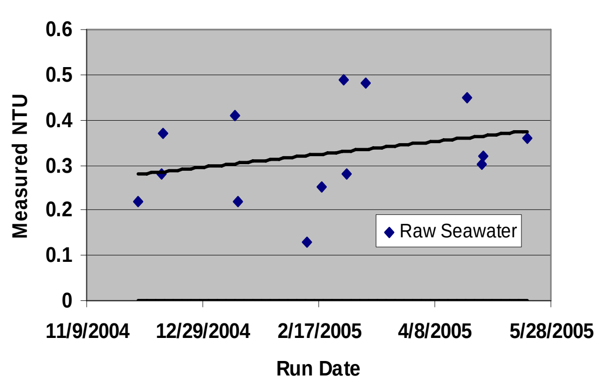
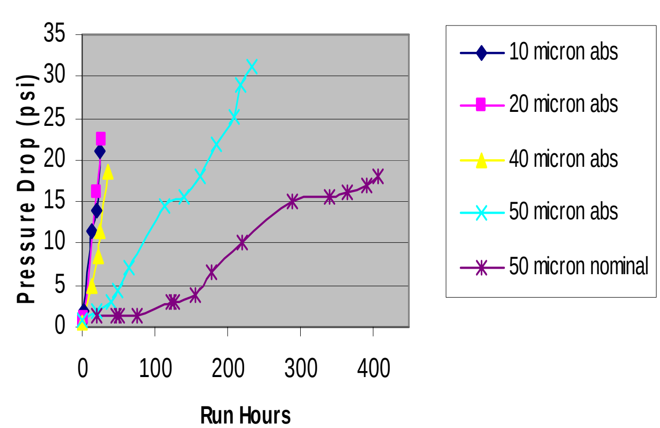


Fig. 11 Measured NTU vs. Run Dates

One Stage Cartridge Filter vs Two Stage Cartridge Filters In-Series Process

At the beginning of the pilot test, several different pore sizes of filters were tested to determine the rate of change for pressure drop as a function of filter pore size. Fig. 12 shows the test results. For the 10, 20 and 40 micron absolute pore size filter, the pressure drop was very rapid. The 10 micron filter took only about 25 hrs to reach a pressure drop of 20 psi. For the 50 micron absolute and the 50 micron nominal size filter, the run time was increased to about 200 hrs and 450 hrs respectively before the filter pressure drop reached 20 psi. This is an indication that a significant amount of the biological solid material is less than 50 microns in size. A significant amount of the quartz spicules (length is in the 30 to 40 microns range as measured by the SEM method) and of the diatom (5 microns size) may have contributed to the high rate of increase for filter pressure drop when the filter pore sizes ranged from 10 to 40 micron absolute.

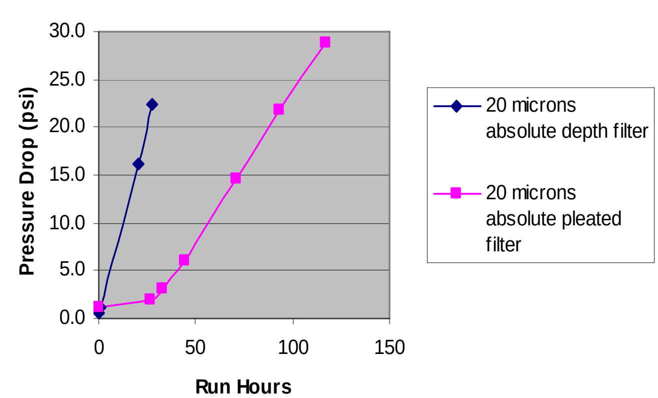
Fig. 12 Depth Cartridge Filter Pressure Drop vs Run Hours



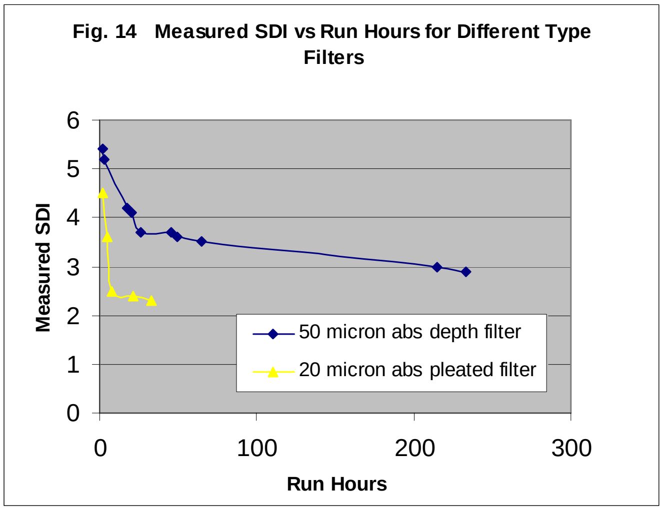
The pressure drop data for the two cartridge filters in series process was discussed earlier. The service life of the 10 micron absolute filter was increased to at least 500 hours if a 50 micron nominal filter was installed upstream to remove larger particles.

The filter test results reported so far are for depth filters with a beta value of 1000. The depth filter was made up of alternate layers of plastic mesh and a fibrous layer with a depth of 0.75 inch. To increase filter service life, a 20 micron absolute pleated filter was tested to determine how much improvement the filter service life can be extended. Fig. 13 compares the filter pressure drop for the 20 microns absolute depth filter vs. the 20 microns absolute pleated filter. The pleated filter is a single layer filter with beta value of 5000.

Fig. 13 Pressure Drop for Depth Filter vs Pleated Filter



As shown in Fig. 13, it took about 25 run hours for the depth filter to reach 20 psi of pressure drop, whereas for the pleated filter it took about 90 hours to reach 20 psi. The measured SDI vs. run hours for the 50 micron absolute filter and the 20 micron absolute pleated filter are shown in Fig. 14. Because the micro-organisms deposited on the filter surface make the filter more efficient in removing the biological materials in seawater, the measured SDI is reduced as run hours are increased. It took about 215 hours for the SDI to be reduced to 3.0 for the 50 micron absolute depth filter, but it only took about 6 hours for the 20 micron absolute pleated filter to reduce the SDI to 3.0.



It is concluded that a proper combination of filters could lead to an optimized system for seawater filtration. The test results indicate that the use of two filters in series increases the filter service life significantly when compared to the single filter configuration. The use of pleated filters can also improve the filter life because it contains about 10 times filter surface area when compared to the same size (2.5" OD x 19.5" long) depth filter. The flux was maintained at 0.6 gpm/ft^2 since the flow rate is 6 gpm and surface area of the pleated filter is 10 square ft.

Conclusions

The measured SDI of seawater in the Gulf of Mexico during the algae blooming season was about 13 based on the SDI-5 measurement procedure. It then reduced gradually from 13 to about 9 from the month of February to the end of May, 2005. The measured turbidity of the feed seawater was quite low at < 0.5 NTU for the entire testing period.

The rate of change of pressure drop through a two cartridge in series filtration system was used to determine the service life of cartridge filters. The first filter was a 50 micron nominal filter followed by a 10 micron absolute filter. The flux was maintained at 6 gpm per ft^2 of depth filter surface area during the entire test period. It was found that the filter service life was three to four weeks before the pressure drop across the first filter reaches about 30 psi. The filters were changed out when the pressure drop of the first filter rose to about 30 psi.

The measured SDI-15 at the second filter outlet was about 3.6 at the start of the test run. It dropped to about 2.0 to 2.2 at the end of about 500 to 550 hours (21 to 23 days) of run time. This is because the deposited materials on the filters make the filters more efficient in removing the biological organisms from the seawater.

Scanning Electron Microscopy/Energy Dispersive Spectroscopy (SEM/EDS) was used to determine the composition of the material deposited on the surface of a used filter tested in December 2004. From the SEM/EDS test results, it was concluded that the filters were blocked predominantly by iron oxide corrosion products, coccoliths (calcium compounds), diatoms (silicone compounds), and broken, crushed, undifferentiated marine debris that formed a fine grained membrane cake over the filter.

It was found that the installation of a 50 micron nominal filter upstream of a 10 micron filter increased the 10 micron absolute filter service life by 20 times. The pressure drop for the 10 micron absolute filter reached 20 psi in only 25 hours without the upstream installation of the 50 micron nominal filter. With the installation of the 50 micron filter upstream of the 10 micron absolute filter, it took about 500 hours for the 10 micron filter pressure drop to reach 20 psi.

It is concluded that a two filters in series process is a better seawater filtration system than just using one single filter for filtering seawater if seawater with an SDI of <3.5 is required.

Nomenclature

GoM	Gulf of Mexico
TLP	Tension Leg Platform
SDI	Silt Density Index
NTU	Nephelometric Turbidity Unit
SEM/EDS	Scanning Electron Microscopy/Energy Dispersive Spectroscopy
SRM	Sulfate Reducing Membrane
mg/l	milligram per liter
gpm	gallon per minute
micron	10^{-6} meter
ppm	parts per million

Acknowledgements

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References

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2. Standard Test Method for Silt Density Index of Water, Applied Membrane Inc.