FURTHER ADVANCES IN PRODUCED WATER DE-OILING UTILIZING A TECHNOLOGY THAT REMOVES AND RECOVERS DISPERSED OIL IN PRODUCED WATER 2 MICRONS AND LARGER

M.J. Plebon, Marc Saad, Serge Fraser
EARTH (Canada) Corporation
Montreal, Quebec Canada

ABSTRACT

In upstream oil and gas operations, saline water is co-produced with the crude oil. On a global spectrum, it is estimated that 3 barrels of water is produced for every barrel of crude oil [1]. As the asset matures, the ratio of water produced vs. crude oil begins to increase. In North America, the ratio is approaching 10:1. Treatment and disposal of produced water is becoming a leading economic factor in the viability assessment of the asset. This is especially so with offshore platforms where produced water must meet and exceed environmental regulations.

EARTH (Canada) Corporation have developed and validated a technology, Total Oil Remediation and Recovery (TORR™) [2], [3], [4], [5] to remove and recover dispersed oil in water 2 microns and larger. The technology is a combination of filtration, coalescence and gravity separation. Solutions for several challenging aspects of produced water properties have been developed and tested, through both field trials (onshore and offshore) and laboratory experimental simulations. Results obtained have been measured with an advanced video imaging particle size-distribution apparatus that measures samples on line and in real time. The results show that the technology has been successful in polishing produced water to oil-in-water concentrations of less than 10 mg/L without the need for chemicals or additional heat. The theory behind the technology will be explained and laboratory and offshore field results will be presented to support the technology's claims.

KEYWORDS – Produced Water Polishing, dispersed oil recovery, oil/water separators, oil recovery, de-oiling.

TECHNOLOGY OVERVIEW

The technology is a multi-stage adsorption and separation system having the capacity of multi-phase separation of large and small oil droplets (free-floating and emulsified) present in produced water. This is done by means of an adsorbent media, the Reusable Petroleum Adsorbent (RPA®, the media) [6], [7], and [8]. This material is a polyurethane-based, oleophilic, hydrophobic, non-toxic, media coalescing agent. The technology is also available in axial flow version.

The technology's separation process consists of routing the oily water to its inlet. The oily water passes through multiple vessels containing media cartridges and a recovery chamber. The media continuously adsorbs the oil emulsions, coalesces and desorbs them into larger oil droplets. In the recovery chamber, oil droplets desorbed by the media float to the top of the chamber in accordance with Stoke's Law. Inside the top of the vessel, the final separation occurs between the oil, gas and the water. The oil and gas are retrieved for re-use. The effluent water from the technology is treated to the customer's requirements. The third vessel is a standby for redundancy. (See Fig. 1)

Technology Operation Parameters

Although upstream oil and gas production and produced water characteristics can vary from one operation to the other, the technology has reached a stage in produced water treatment where it is developed and tested to operate within the following parameters: (See Fig. 2)

- Oil Densities: API° 15 and above.
- Fluid Temperature: up to 100 °C
- Solids management capability
- Oil concentrations up to 2000 mg/L
- Oil droplet and oil emulsion diameters down to 2 µm
- Flow rates up to 60,000 BWPD

Additionally, depending on the characteristics of the produced water to be treated, the efficiency of the system can be enhanced by providing optimized solutions on a case-by-case basis. This implies optimizing the two basic principles behind the technology: oil coalescence and gravity separation.

Measurement Methods

The major measurement method used to evaluate the performance of the process is the Visual Process Analyzer (ViPA) [9]. This combines a high-resolution video microscope with an image analysis system. It captures images of the particles in a process flow and allows the monitoring and analysis of those particles in real time (See Fig. 3 & 4). Information on the shape, size, optical density and fourteen other parameters are recorded for each particle in the image before the data is saved and the next image is captured. Up to eight particle types – or sub-populations – can be stored. Approximately fifteen images are analyzed each second.

Oil in water emulsions - as all liquid in liquid emulsions - is characterized by their almost perfectly spherical shape. In sharp contrast, sand particles are crystalline and therefore very different in shape to the oil droplets. The analyzer can differentiate such geometries and organize them in a database.

This measuring device can plot recorded parameters as an overall distribution for each or all sub-populations. The graphs are reported on screen and on the optional 4-20 mA output. The analyzer is also equipped with a comprehensive suite of trend analysis software. It determines the trends and trigger alarms. This provides vital time, especially on the field, before a process goes out of specifications, to take corrective action and prevent process upsets.

This measurement tool allowed recording findings both in the laboratory and in the field. It monitored oil and sand size distribution and concentration between the stages, based on particles sizes within the volume of produced water.

Basic Separation Theory

The removal of oil and grease from produced waters can be accomplished by the use of several well-known and widely accepted techniques. However, the performance of any given separation technique will depend entirely on the condition of the oil-water mixture. Present techniques for the separation of oil from water are based on their difference of density. Stoke's Law states that rising velocity (V_r) is a function of the square of the oil droplets' diameter.

Equation (1) $$V_r = g\, d^2 (\rho_w - \rho_o) / 18\, \eta$$

Where
V_r = rise velocity of oil droplet
g = acceleration due to gravity
ρ_w = density of water
ρ_o = density of oil
d = oil particle diameter
η = viscosity of water

From Stoke's Law, it can be seen that droplet size has the largest impact on the rising velocity rate. Consequently, the bigger the droplet size, the less time it takes for the droplet to rise to a collection surface and thus the easier it is to treat the water. The oil in the produced water can be present as free-oil, and/or emulsified, and/or dissolved states in different proportions. This oil droplet size distribution is one of the most important factors affecting the design of oil-water separators.

Free-oil is defined as an oil droplet of 150 microns, which will float immediately to the surface due to its large size and high rise velocity. An emulsion is defined as oil which is dispersed in the water in a stable fashion due to its small diameter and thus to its low rise velocity.

Emulsions can be classified into two categories: mechanical and chemical emulsions. Mechanical emulsions are created through the process of pumping, large pressure drops through chokes and control valves. Chemical emulsions are sometimes intentionally formed using chemicals to stabilize the emulsions for an industrial process need or other use. Gravity separation is the mechanism most commonly used for the removal of oil from wastewaters. This process primarily affects free oil. Tight oil emulsions and dissolved oil will not be removed by gravity separation alone. The objective in treatment of wastewater containing emulsified oils is to destabilize the emulsion so that the oil will separate by gravity or flotation. Essentially what is done is to promote inter-droplet contact with the purpose of developing larger droplets that will be easier to remove. Once the emulsion is broken, the same removal techniques applicable to free oil can be utilized. Small oil droplets are always difficult to separate. The smaller the droplets, the lower their rising velocity will be. A prerequisite for efficient separation is, therefore, that oil droplets coalesce (become larger and rise more rapidly).

A large number of simple gravity oil separation devices are available, varying from API (American Petroleum Institute) separators to Parallel Plate Interceptor (PPI) and Corrugated Plate Interceptor (CPI). The API gravity separator removes oil globules of 150 microns or greater where PPI and CPI separators can remove oil droplets down to 30 microns.

The second common method of oil and grease removal is through induced (IGF) or dissolved (DGF) gas flotation. Gas is introduced (either at atmospheric pressure or dissolved under pressure) to produce bubbles, which tend to attach to the oil droplet, decrease its specific gravity and float it quickly to the surface. Rapid oil removal is achieved when compared to gravity separation alone. Finally, it is often necessary to use chemical coagulants with flotation units. Chemicals such demulsifiers, alum, ferric chloride and cationic polyelectrolytes are used to improve the efficiency of oil and grease removal.

Another factor that affects the rise velocity of an oil droplet is the acceleration force (see Stoke's Law). Hydrocyclones are mainly governed by the centrifugal (g-force) applied to a spherical droplet in a centrifugal separation field. A liquid-liquid hydrocyclone separates free and dispersed oil from wastewaters with an applied centrifugal force many orders of magnitude greater than gravity (usually between 2000 to 3000 g). Centrifugal force causes the heavier water phase to migrate to the vessel wall while the lighter oil phase forms a central, low-pressure core from where it is recovered. Treatment chemicals may enhance hydrocyclone performance by facilitating emulsion breaking and droplet coalescence. Field applications showed that emulsions larger than 15 to 20 microns are removed efficiently by hydrocyclones.

The centrifuge is another enhanced gravity separation process, which combines high acceleration forces (5000 to 10,000 g-force) and a large settling area to simultaneously separate dispersed oil down to 3 to 7 microns droplets from oily-waters.

Filtration, another category of the oil separation process, is used but in limited applications due to its high maintenance cost requirements. In filtration, oily water is passed through a porous medium with or without the addition of treatment chemicals.

Applied pressure is used to overcome the flow resistance of the filter medium. Oil is usually retained and removed in the medium. The end of the filtration run is indicated when the filter medium becomes excessively contaminated with oil, at which point the medium must be cleaned or replaced. A single or multi-bed media material can be used as filtration medium. The most commonly used are sand, anthracite, crushed walnut and pecan shells, which can be used as a single-media or a combination of those. All of these materials must be backwashed or replaced when saturated which will create subsequent treatment and disposal problems (frequency of backwashing depends on service but 24 hour cycles are not uncommon). Performances vary widely depending on the type of filter, the operating conditions and the oily water's unique characteristics.

The Challenge of Removing Small Oil Droplets

Even under favourable conditions, oil droplets smaller than about 30 μm in water are known to be quite difficult to separate. Oily water with small droplets < 30 μm may then represent such a high proportion of the oil content that it is impossible to achieve discharge specifications with conventional equipment. It is important to fully understand the characteristics of the produced water. The size distribution curve for the dispersed oil in water must be measured in order to effectively address the issues and meet and exceed the set discharge targets.

Fine Emulsion Coalescence and Recovery

The uniqueness of the technology is in its ability to remove and recover dispersed oil droplets 2 microns and larger thus covering the broadest spectrum of the hydrocarbon size distribution curve. Laboratory measurements were conducted and analysis of the performance of the two-stage radial technology design system was monitored. Special emphasis was placed on observing the technology's ability to address the handling and recovery of small oil emulsions (in the ranges 2 – 5 µm and 2 – 10 µm). (See Table 1 & 2) The visual process analyzer was utilized to measure the performance results. (See Fig. 5)

The oil injected in this process had an API density of 20. The technology was treating the water at a rate of approximately 600 BWPD (equivalent to 3.8 m^3/hr, the design flow rate for the unit) and a water temperature of 23 ºC. The above measurements were taken when the unit had treated 641m^3 (4031 bbls) with continuous inlet oil concentration of 800 – 1000 ppm. Total inlet concentration into the technology was approximately 800-1000 ppm. Oil emulsions having diameters in the range 2 – 5 µm constituted 7.5 ppm of the overall concentration, while oil emulsions in the range 2 – 10 µm constituted 30ppm of that same overall value. Treatment of these emulsions in the two-stage technology shows that it is capable of removing up to 90% of oil emulsion having diameters in the range of 2 – 10 µm and up to 70% of oil emulsions in the range of 2 – 5 µm.

The nature of the tests (heavy-oil, low temperature, high inlet oil concentration…) contributes to lowering the efficiency of the unit in small oil emulsion handling. It is expected that this performance be enhanced in favourable field conditions (higher operating temperatures, lower concentrations…).

OFFSHORE FIELD TRIAL RESULTS - NORTH SEA

Trial A

Context of Field Trial

A field trial for the testing of the performance of the technology in treating the produced water (PW) on a FPSO (Floating Production, Supply and Offloading) vessel was recently conducted in the North Sea. Seven days were allocated for the offshore trial that was divided upon three test locations. These locations were slipstreams off the PW line downstream of two separate hydrocyclones (HC-1 and HC-2), and downstream of a degasser unit. The trial allowed for the demonstration of the performance of the technology's process in terms of oil recovery and lowering the PW oil concentrations to levels meeting the OSPAR 2006 legislation requirements and a target of 6mg/Liter.

Field Trial Unit

The field trial unit consisted of a two-stage 10.7bar rated system. The unit had a nominal flow rate capacity of 300 BWPD and maximum operating pressure and temperature of 10bar and 100ºC respectively. A twin-set of bag filters (5 micron filters) was installed upstream of the technology's process to capture any solid particles in the fluid. Four sample points on the unit allowed for sampling at the inlet of the bag filters, inlet of the first process stage, inlet of the second process stage and outlet of the whole technology's process unit. (See Fig. 18, Table #3)

Analysis Method

Oil-in-water (Total) analysis was performed on water samples from the inlet and outlet of the technology's field unit using a DTI approved infrared (IR) method in the chemical lab on board the FPSO. Oil concentration results are presented in parts-per-million for total (soluble, free-floating and emulsified) oil.

Field Trial Results

Oil concentration measurements at the inlet (after the bag filters) and at the outlet of the technology's field trial unit are reported for the three test locations. Sampling was done after approximately 2m³ intervals of PW treated. A new set of bag filters upstream of the field trial unit was used at the beginning of individual tests at the three locations. The bag filters had minimal pressure drop throughout the duration of each trial and did not require replacement. The fluid temperature was around 60 - 70ºC.

Test Location # 1 - Downstream of Hydro-Cyclone 1

The technology's field trial unit was first tested downstream of Hydro-Cyclone 1 (HC-1). The produced water from this stream had a temperature of 65ºC and a crude oil APIº density of 42.2. Chemicals injected upstream in the process included a demulsifier, a scale inhibitor, a corrosion inhibitor and low amounts of a defoamer. The average flow rate through the technology process was 1.36 m³/hr. Samples analyzed yielded the results displayed in Figure 6. Average oil concentrations downstream of the HC-1and at the inlet of the technology's process had a value of 98.2 ppm, while the effluent from the technology had an average oil concentration of 2.9 ppm.

Test Location # 2 - Downstream of Hydro-Cyclone 2

The technology's field trial unit was then tested downstream of Hydro-Cyclone 2 (HC-2) without replacing the media cartridges from the previous trial. The produced water from this stream also had a temperature of 65ºC and a crude oil APIº density of 31.8. Chemicals injected upstream in this process line included a demulsifier, a scale inhibitor, a corrosion inhibitor, a defoamer, and polymers. The average flow rate into the technology's process unit was 1.21 m^3/hr with large amounts of gas separated and recovered through the trial.

Average oil concentrations downstream of the HC-2 had a value of 313.4 ppm, while the effluent from the technology had an average oil concentration of 4.2 ppm. It was observed that the oil concentrations downstream of HC-2 fluctuated between 100 ppm and 850 ppm. The technology maintained a steady performance with an effluent oil concentration not exceeding 5.6 ppm. This showed that the performance of the technology is dependent on the specific particle size distribution of oil droplets in the tested produced water stream, rather than on the concentration (within ranges less than 5000 ppm). Figure 7 shows values of oil concentration at the inlet and outlet of the technology unit for the described test. Mentioned surges in oil concentration values can be observed along with the corresponding effluent concentrations.

Test Location # 3 - Downstream of Degasser Unit

The third location of the technology's trial was downstream of the Degasser unit joining the two produced water treatment streams described above. The fluid temperature was 60ºC and the injected chemicals' composition was the residual mix of the connecting two streams. Average flow rate through the technology's process unit was 1.54 m^3/hr. Results of analyzed produced water samples at the inlet and outlet of the technology are displayed in Figure 8. Inlet concentration values fed to the technology from downstream of the degasser unit were steady at around 44 ppm, while outlet concentration values had an average of 2.6 ppm.

Trial B

Context of Field Trial

A field trial for the testing of the performance of the technology in treating the produced water (PW) on the semi submersible platform was conducted at the request of the facility owner and operator. The offshore trial was to be conducted at two different locations. These locations were slipstreams off the PW line downstream Hydrocyclone fed pumps (directly upstream of the overboard (O/B) discharge point) and downstream of the separator.

The trial allowed for the demonstration of the performance of the technology in terms of oil recovery and lowering the PW oil concentrations to levels meeting the trial target of 15 mg/Litre OIW or below. Department of Trade and Industry (DTI) approved methods of oil-in-water analysis were conducted as a primary method for measuring the inlet and outlet oil concentrations from the technology. Results showed that the oil concentration removal efficiency across the technology was maintained at levels around 93%.

The offshore platform produces an approximate 6500 BBL of oil (API° Gravity 37.6) and 65,000 BBL of water per day. Production fluids come from several wells through the production platform. Through the first part of the trial, the technology was to treat the PW downstream of the hydrocyclone feed pumps (directly upstream of the overboard (O/B) discharge point). The OIW concentration at that location is expected to be around an average of 30 mg/L. The second part of the trial was to be performed downstream of the separator (and upstream of the hydrocyclones), where the PW effluent that is discharged overboard has an average OIW of 80 mg/L.

The production chemicals existent in the fluid stream entering the technology included:

- Corrosion inhibitors injected at approximately 12 ppm.
- Scale inhibitors injected at approximately 60 ppm.
- Demulsifiers injected at approximately 10 ppm.

Field Trial Unit

See Fig. 18 & Table #3

Analysis Method

Oil-in-water (Total) analysis was performed on water samples from the inlet and outlet of the technology using a DTI approved infrared (IR) method and the operations procedures in the chemical lab on board the platform. Oil concentration results are presented in mg/L for total (soluble, free-floating and emulsified) oil. Samples were consistently taken at the inlet and outlet of the technology. Volume of samples was 500 ml each. Inlet samples were taken at the corresponding sample points upstream of the technology. Outlet samples were taken from the discharge hose of the technology.

Oil concentration measurements are presented below separately for the two parts of the trial. OIW removal efficiency is determined across the two stages of the technology. That is; measured inlet and outlet oil concentration values are used to calculate the efficiency. The technology was preceded by a set of 25µm bag filters. These filters were replaced at the start of each trial. The pressure drop across the bag filters never reached the 15 psig value required for replacement.

Test Location # 1 – Oil Removal Results

The technology treated around 30 m^3 of produced water at an average flow rate of 1.83 m^3/hr (275 BWPD). New bag filters were installed at the beginning of the trial. At the start of the trial, upset conditions were observed (due to bringing online of the test separator) where inlet OIW values of 300 mg/L and 125 mg/L were observed. (See Fig. 9) The Inlet OIW then levelled at average OIW concentrations of around 26 mg/L while the overall average outlet OIW concentration was 2.7 mg/L from the technology throughout the whole trial. OIW Removal Efficiency calculated values give an average efficiency of 93% with the specific produced water characteristics from the O/B discharge location. These values are directly related to the mean oil droplet size in the influent (data on mean droplet size not available).

Pressure readings were logged throughout the trial. These provided values for pressure drop across each individual stage of the technology as well as across the bag filter elements. Pressure drop across the media cartridges is a function of inlet OIW concentration. Maximum operating pressure drop measured across both individual stages was 6 psi.

Test Location # 2 – Oil Removal Results

Second part of the trial was performed downstream of the separator and upstream of the PW hydrocyclones. Steady-state inlet OIW concentrations into the technology had an average of 76 mg/L with a maximum measured value of 235 mg/L. Effluent from the technology had an average OIW concentration of 7.2 mg/L, with a minimum measured value of 5mg/L and a maximum of 11 mg/L. All measured results are presented in Figure 10 below. The calculated OIW removal efficiency had values ranging up to 96% with an average of 92%. It is to be noted that the separator has no demulsifier or oil separation enhancing chemicals injected in it. This further shows the adaptability of the technology to treating the mentioned produced water with high levels of OIW removal efficiencies. Similar pressure readings to those in the first part of the trial were observed, where the pressure drop across every stage of the technology did not exceed 6 psig.

Trial C

Context of Field Trial

A field trial for the testing of the performance of the technology in treating the produced water (PW) on a platform was conducted at the request of the owner. The offshore trial was to be conducted at two different locations. These locations were slipstreams off the PW line downstream of the first stage B separator and downstream of the B-WEMCO unit.

The trial allowed for the demonstration of the performance of the technology in terms of oil recovery and lowering the PW oil concentrations to levels meeting the trial target of 15 mg/Liter OIW or below. Department of Trade and Industry (DTI) approved methods of oil-in-water analysis were conducted as a primary method for measuring the inlet and outlet oil concentrations from the technology. Results showed that the oil concentration removal efficiency across the technology was maintained at levels around 95%.

The platform produces an approximate 4000 BBL of oil (API° Gravity 39) and 100,000 BBL of water per day. Production fluids come from the platform pass through the production platform prior to the oil/water being routed to the onshore gathering facilities. Through the first part of the trial, the technology was to treat the PW downstream of the first stage separator (separator B) and upstream of the WEMCO separators. The OIW concentration downstream of the separator is expected to be around an average of 250 mg/L. The second part of the trial was to be performed downstream of the WEMCO separators, where the PW effluent that is discharged overboard has an average OIW varying between 40 to 50 mg/L.

The production chemicals existent in the fluid stream entering the technology included:

- Corrosion Inhibitor injected in the Bravo produced fluids at approximately 39 ppm.
- Scale Inhibitor injected in the Bravo produced water at approximately 15 ppm.
- Demulsifier injected in the Bravo produced fluids at approximately 15 ppm.
- Demulsifier injected in the Alpha produced water at approximately 4 ppm.
- Deoiler injected in the Alpha produced water prior to O/B discharge at approximately 4 ppm.

Field Trial Unit

See Fig. 18 & Table #3

Analysis Method

Oil-in-water (Total) analysis was performed on water samples from the inlet and outlet of the technology using a DTI approved infrared (IR) method and operator standard protocols and procedures in the chemical lab on board the platform. Oil concentration results are presented in mg/L for total (soluble, free-floating and emulsified) oil. Samples were consistently taken at the inlet and outlet of the technology. Volume of samples was 500 ml each. Inlet samples were taken downstream of the 25 µm bag filter elements located upstream of the technology (to capture any solid particles having a nominal size of 25 µm and above). Occasional samples were taken after the first stage of the technology.

Test Location # 1 – Oil Removal Results

The technology treated around 300 m^3 of produced water at an average flow rate of 1.8 m^3/hr (271 BWPD). Bag filters were changed four times during this part of the trial. Average inlet OIW concentrations were around 283 mg/L while the overall average outlet OIW concentration was 16.8 mg/L from the technology. Maximum inlet and outlet OIW concentrations measured were 610 mg/L and 38 mg/L respectively. Minimum outlet OIW concentration measured was 4.5 mg/L. The mean oil droplet size at inlet was 7µm (measurements provided by operator). (See Fig. 12 for Inlet/Outlet Visual Samples)

It is shown from the results in Figure 11 that as the inlet OIW concentration feeding the technology increases, the outlet OIW concentration increases. However, this increase in outlet OIW concentration takes place with a lower slope than that of the inlet OIW. This is due to the corresponding increase in droplet count of oil droplets having a mean diameter less than 10 µm in size. As the number of these droplets increases in the feed, their rate coalescence increases proportionally and thus resulting in a lower increasing slope of outlet OIW concentration.

The Oil Removal Efficiency of the two-stage technology for this part of the trial is presented in Figure 13. Lower efficiency values correspond to events when new bag filter elements were being installed and thus capturing a major part of the feed oil, resulting in a significant drop in inlet OIW values into the technology. These values were used in calculating the overall efficiency. OIW Removal Efficiency calculated values give an average efficiency of 93.5% with the specific produced water characteristics from the first stage separator. These values are directly related to the mean oil droplet size of 7µm in the influent.

Pressure readings were logged throughout the trial. These provided values for pressure drop across each individual stage of the technology as well as across the bag filter elements. Pressure drop across the media cartridges is a function of inlet OIW concentration. Maximum operating pressure drop measured across both individual stages was 6 psi. Results are presented in Figure 14 below.

Test Location # 2 – Oil Removal Results

The second part of the trial was performed downstream of the B WEMCO separator, just before the overboard discharge point. Inlet OIW concentrations into the technology ranged had an average 57 mg/L with a maximum measured value of 77 mg/L. Effluent from the technology system had an average OIW concentration 0f 10.9 mg/L, with a minimum measured value of 7 mg/L and a maximum of 14 mg/L. All measured results are presented in Figure 15. It is to be noted that a centrifugal pump was used to feed the unit. This might have further sheared the oil droplets in the feed water to the technology.

The calculated OIW Removal Efficiency is presented in Figure 16. As the larger oil droplets and emulsions have already been separated in the WEMCO, the oil droplet size distribution (made even smaller with the pump action) comprising the measured inlet OIW concentrations between 24 mg/L and 77 mg/L were recovered with an efficiency lower than that of the previous part of the trial. However, the calculated OIW removal efficiency had values ranging up to 90%. As for the pressure drop readings (Figure 17) for the second part of the trial, these cannot be interpreted with conclusive certainty. This was due to the fact that the pump was running at a lower capacity (than nominal for the technology in use).

CONCLUSIONS

The technology merits serious consideration for the applications of de-oiling produced water. Overall one can conclude the following:

- The technology can adsorb, coalesce, desorb and recover dispersed oil in water 2 microns and larger.
- The technology is effective in lowering the hydrocarbon concentrations of produced water especially for offshore facilities where strict discharge regulations must be adhered to.
- The technology has the capability of good performance even during upset inlet conditions.
- Chemicals are not needed to enhance the oil removal efficiency.
- Additional heat is not required to obtain favourable results.

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Table #1 – 2-5 Microns

2 – 5 µm range	Concentration (ppm)
Average at Inlet	7.48
Average at Outlet	2.38
% Removal (ppm)	68.22

Table #2 – 2-10 Microns

2 – 10 µm range	Concentration (ppm)
Average at Inlet	29.84
Average at Outlet	2.88
% Removal (ppm)	90.36

Table #3 – Field Demonstration Equipment Specifications

Design Parameters	Vessel Enclosure	Stainless Steel SS 316
	Design Pressure	ASME 150 psig (10.2 Barg)
	Design Temperature	110° C
	Class	Zone 1/ Division 2
Operating Parameters	Nominal Capacity	300 BWPD
	RPA® Stages	2 Radial
	Operating Pressure	Max 150 psig
	Operating Temperature	Max 95°C
	Inlet Oil Concentration	Max 2,000 PPM
	Inlet Suspended Solids	Max 50 mg/L
	Chemical Additives	N/A
	Bag Filters	1-25 µm
	Sample Points	1 per stage
Instrumentation	Flow Rate	Turbine Meter + Indicator
	Pressure	4 x Pressure Gauges
	Interface Indicators	N/A
	Control Valves	N/A
Safety	PSV	Set @ 135 psig
Dimensions	Overall Footprint	L 160 cm X W 85 cm X H 105 cm
	Estimated Dry Weight	530 kgs
	Estimated Wet Weight	600 kgs
Procedures	Turnover/Inspection	Inspection/Precommissioning Manual
	Pre-Commissioning	Inspection/Precommissioning Manual
	Start-up/Operation	Operating/Instructions Manual
	Emergency	Operating/Instructions Manual

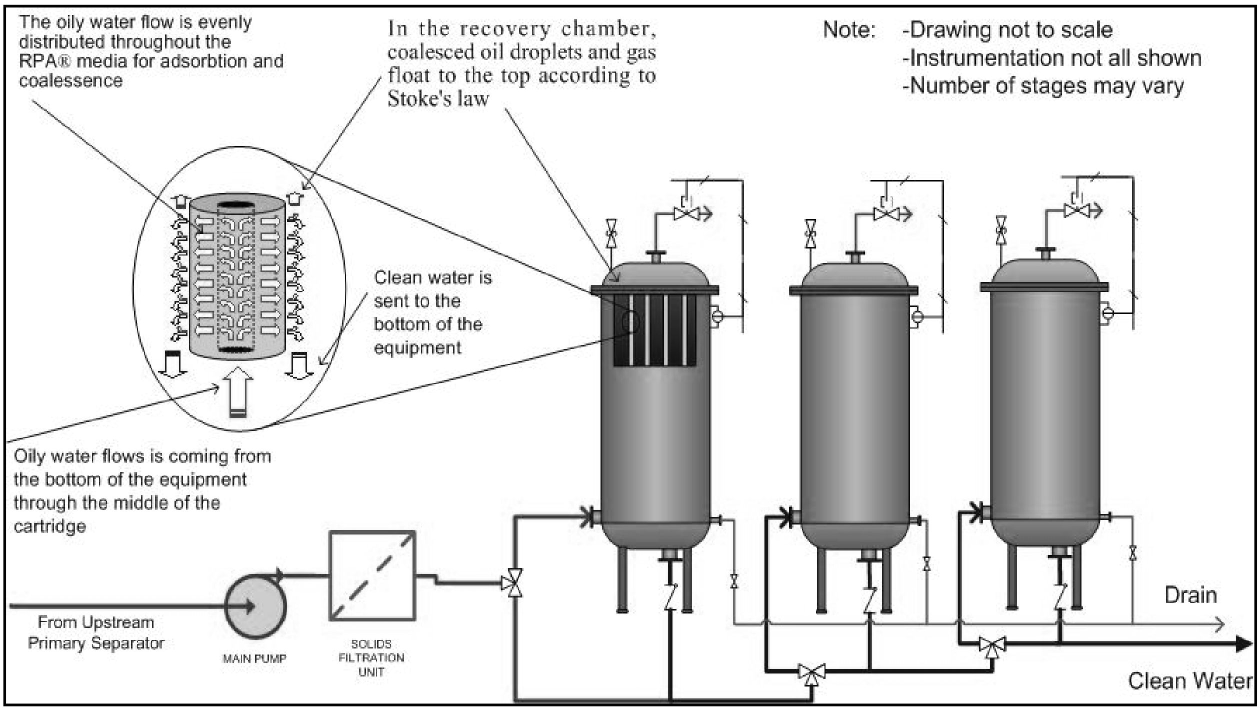

Figure 1. - Process Flow Diagram of the Technology

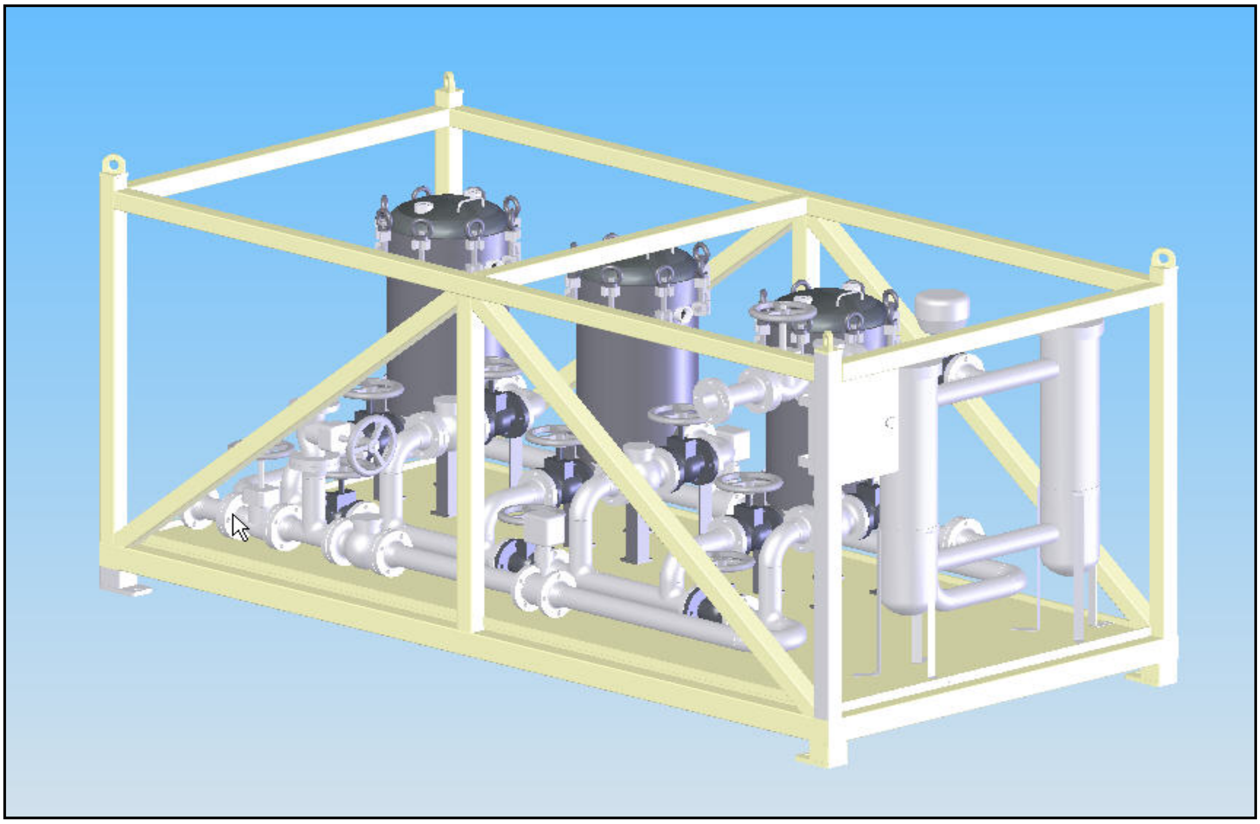

Figure 2. - Typical 3D Design of Technology

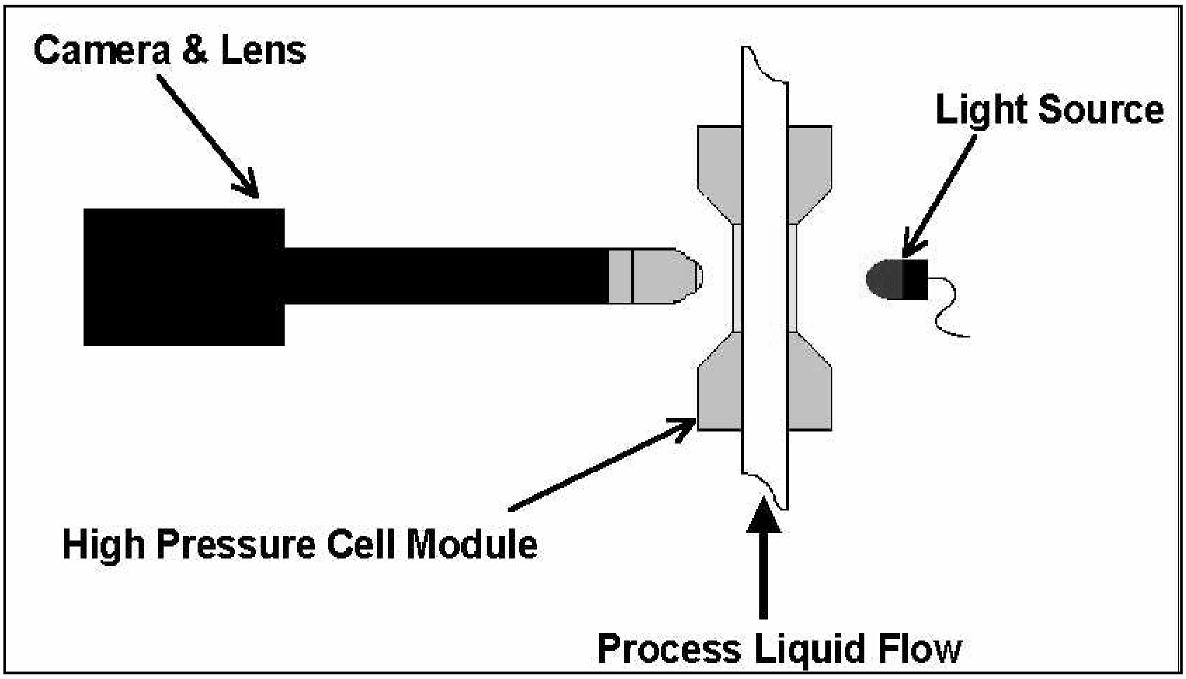

Figure 3. – Video Imaging Process Analyzer Operating Principle

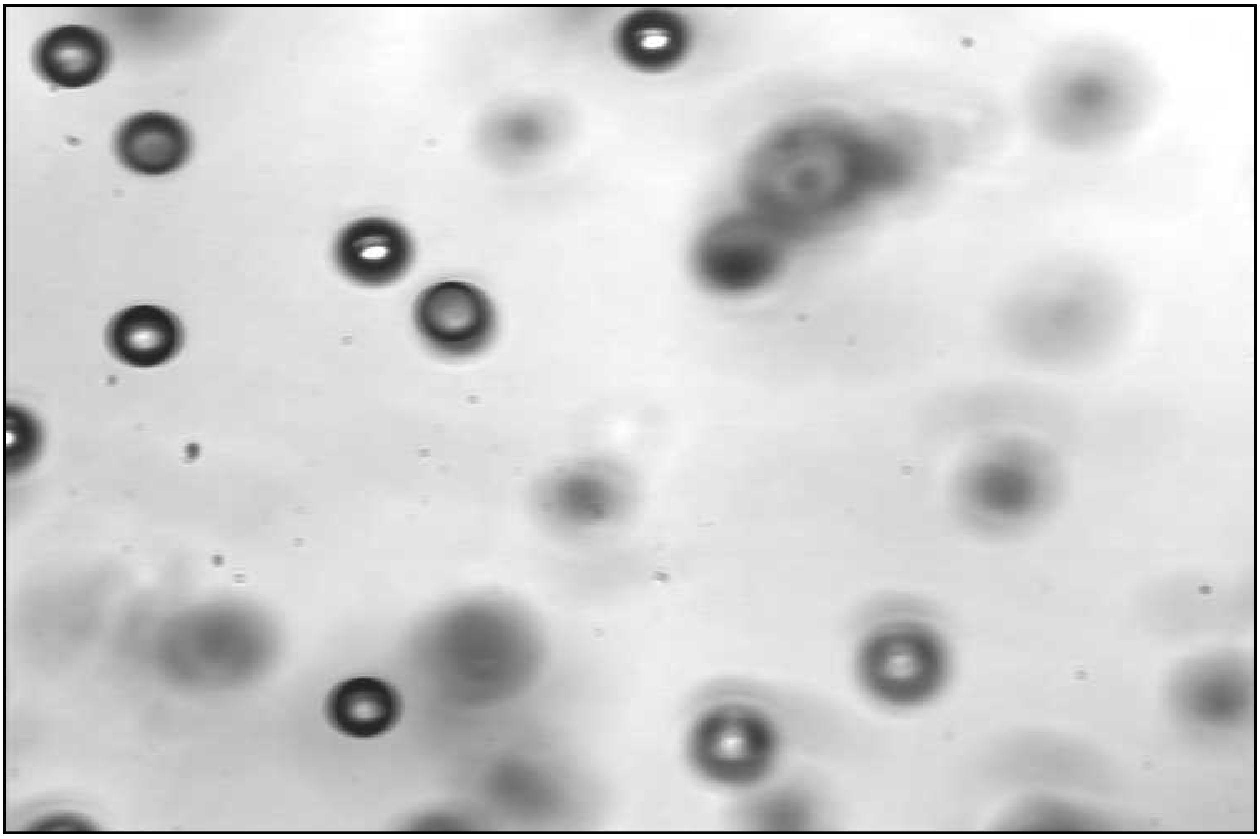

Figure 4. – Image of Droplets as Seen by Analyzer

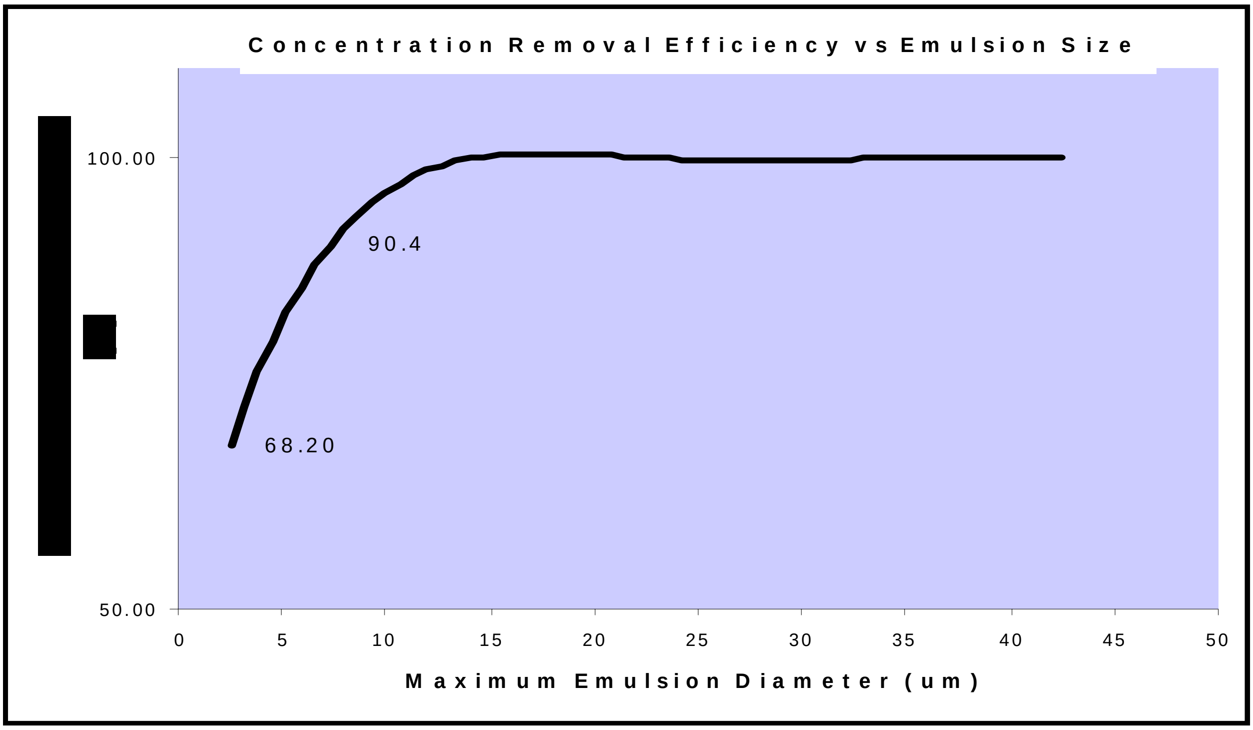

Figure 5. – Concentration Removal Efficiency vs. Emulsion Size

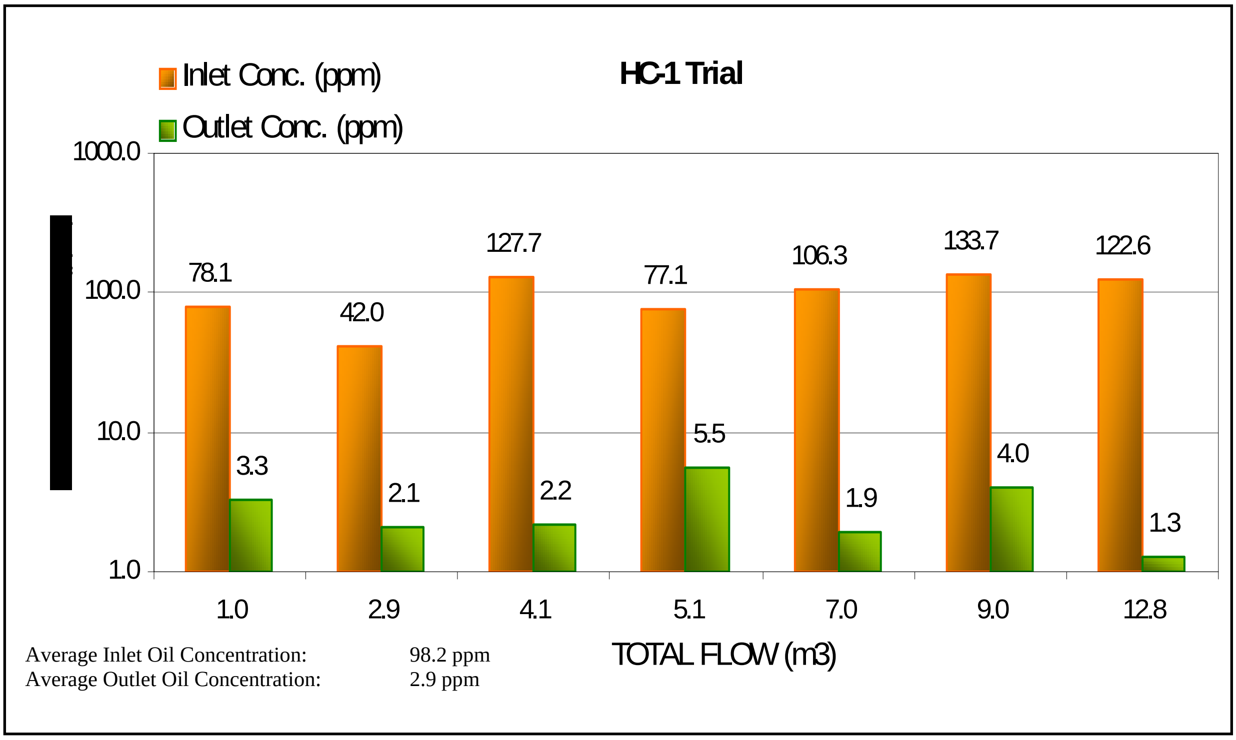

Figure 6. - Oil Concentration Values as Determined by Lab IR Method at Inlet and Outlet of the Technology's Field Trial Unit at Trial A, Location 1

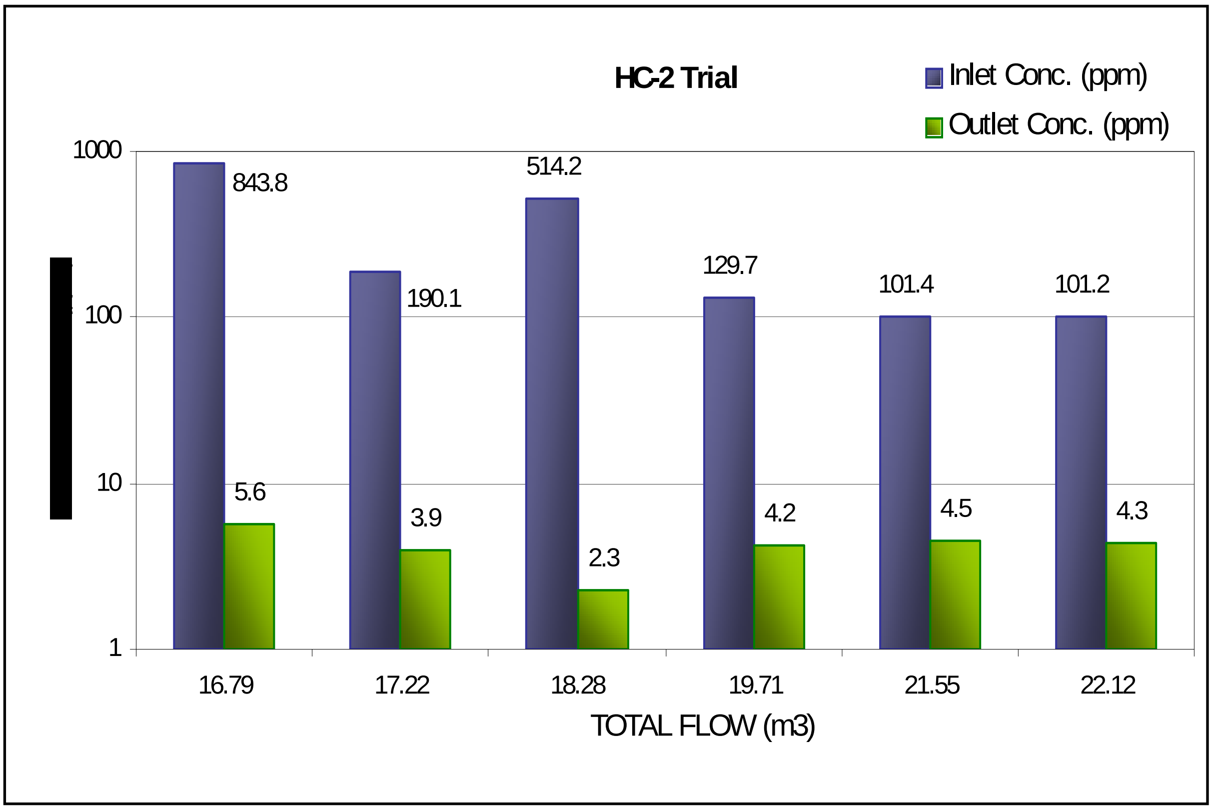

Figure 7. - Oil Concentration Values as Determined by Lab IR Method at Inlet and Outlet of the Technology's Field Trial Unit at Trial A, Location 2.

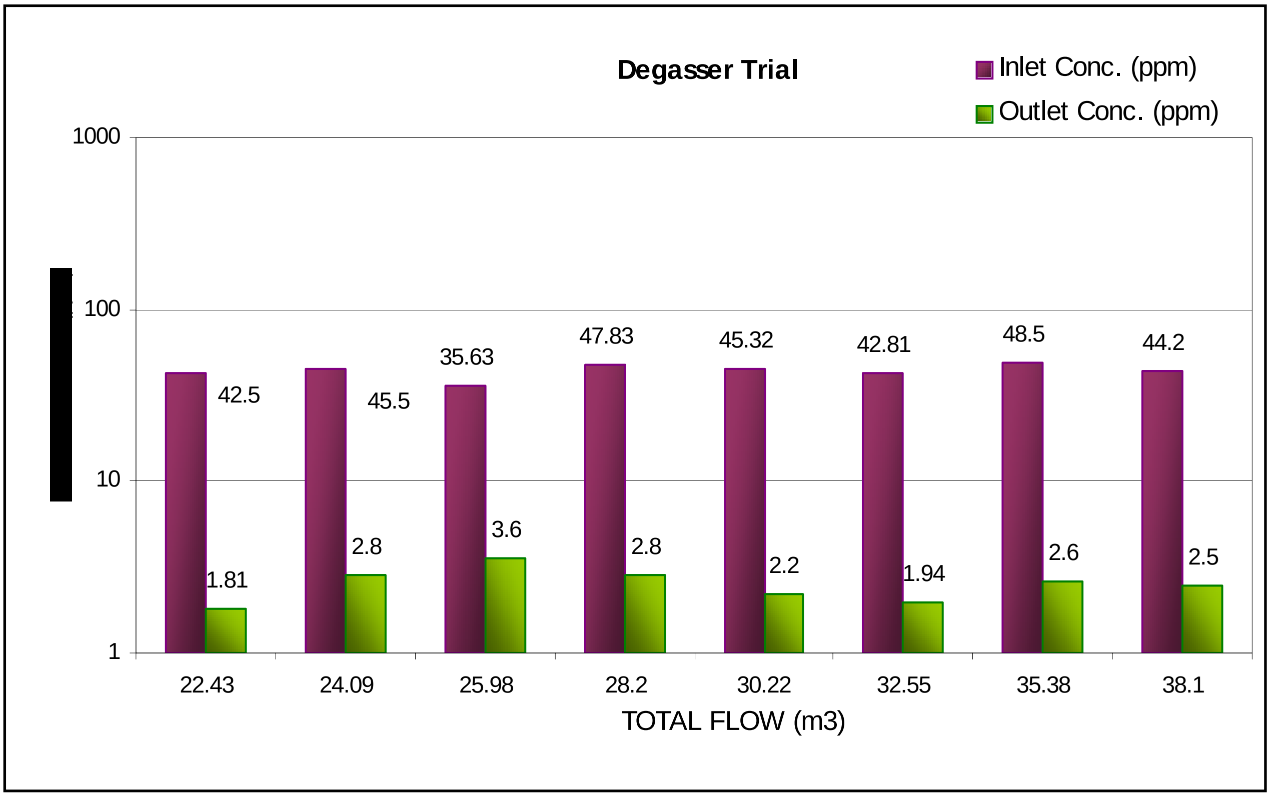

Figure 8. - Oil Concentration Values as Determined by Lab IR Method at Inlet and Outlet of the Technology's Field Trial Unit at Trial A, Location 3.

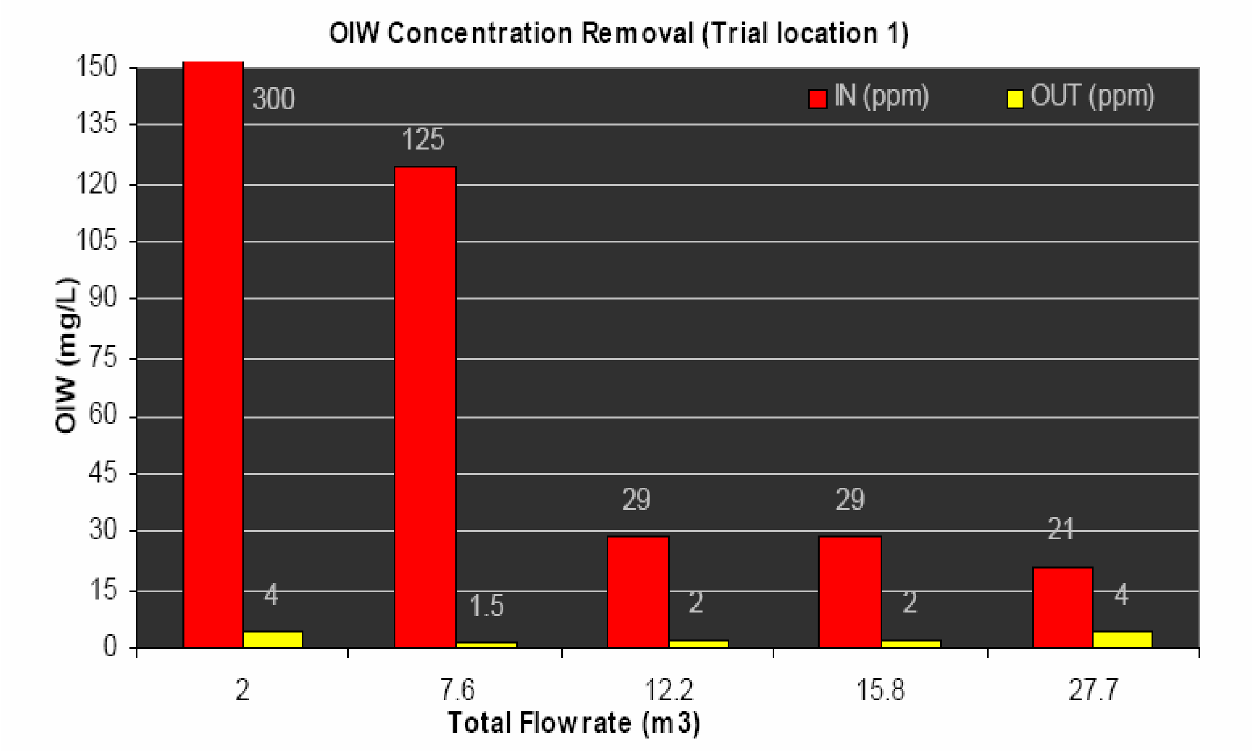

Figure 9. – Trial B, Location #1

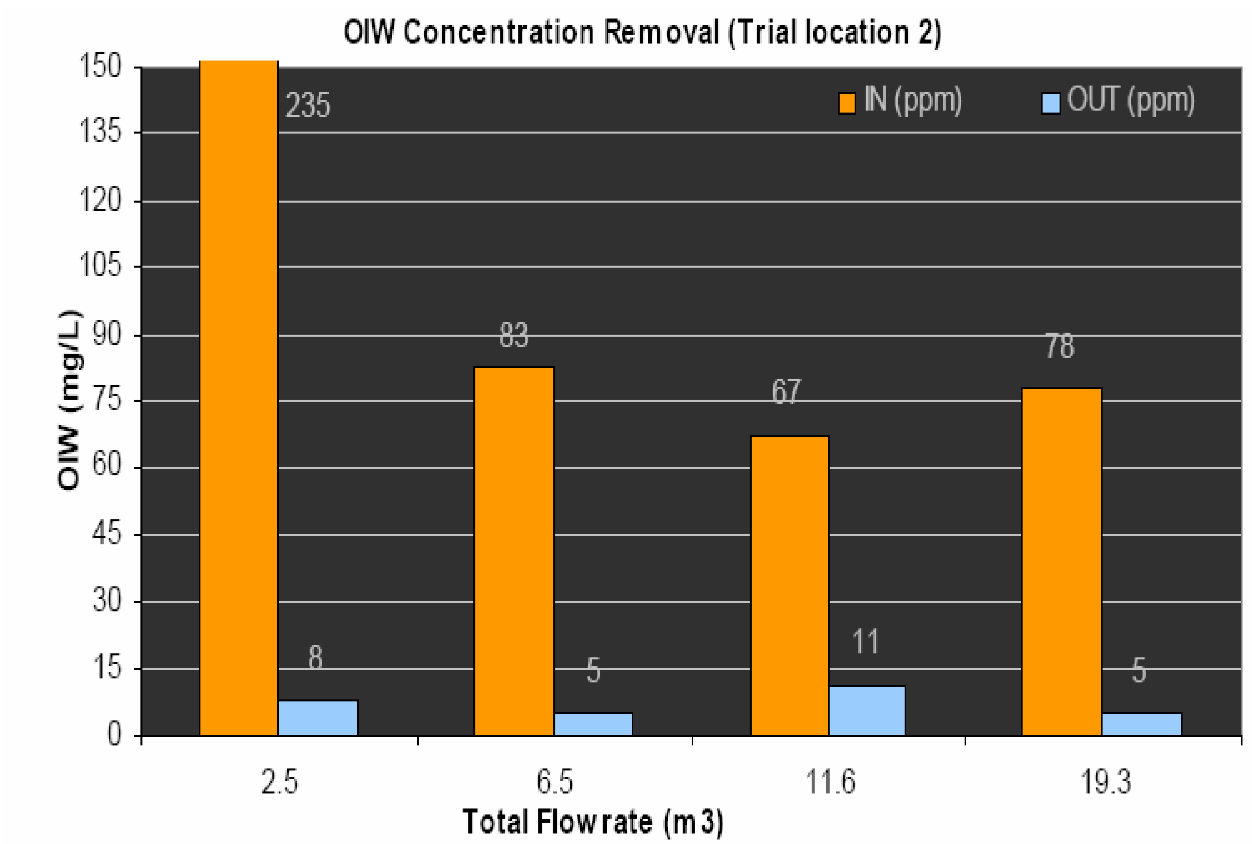

Figure 10. – Trial B, Location #2

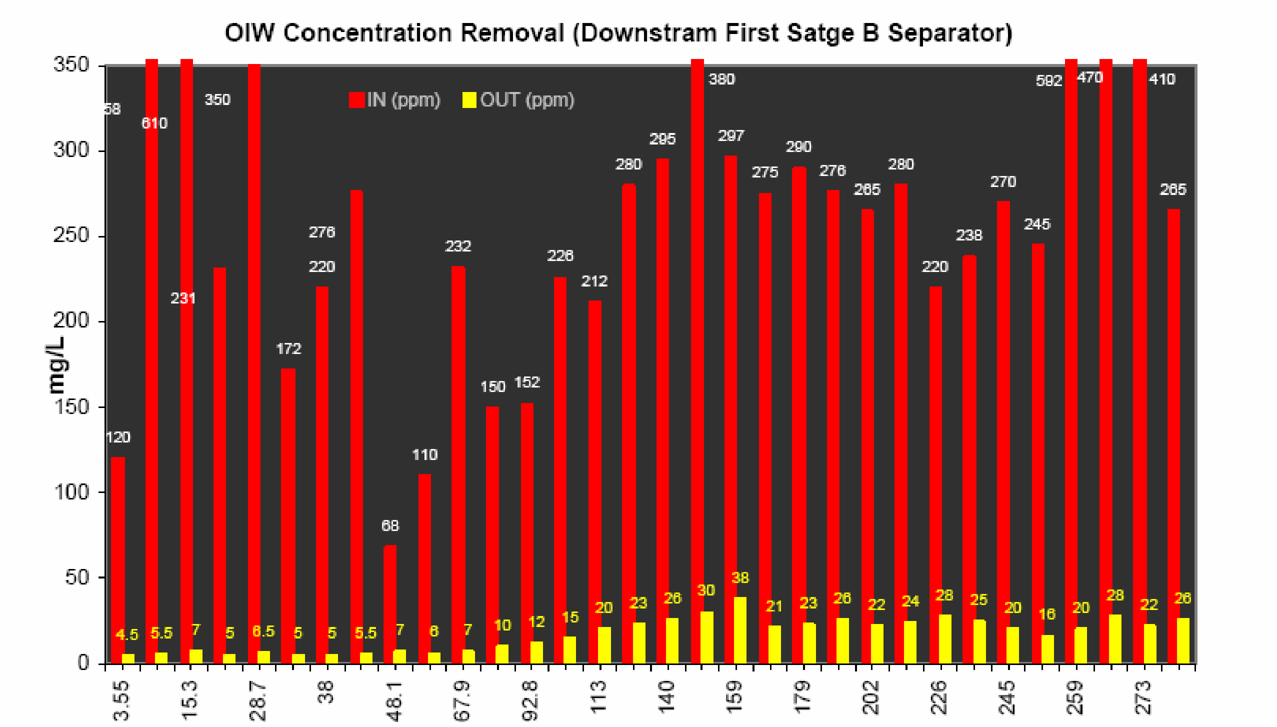

Figure 11. – Trail C, Location #1

Figure 12. – Trial C, Location #1 – Visual Samples of Outlet and Inlet from the Technology

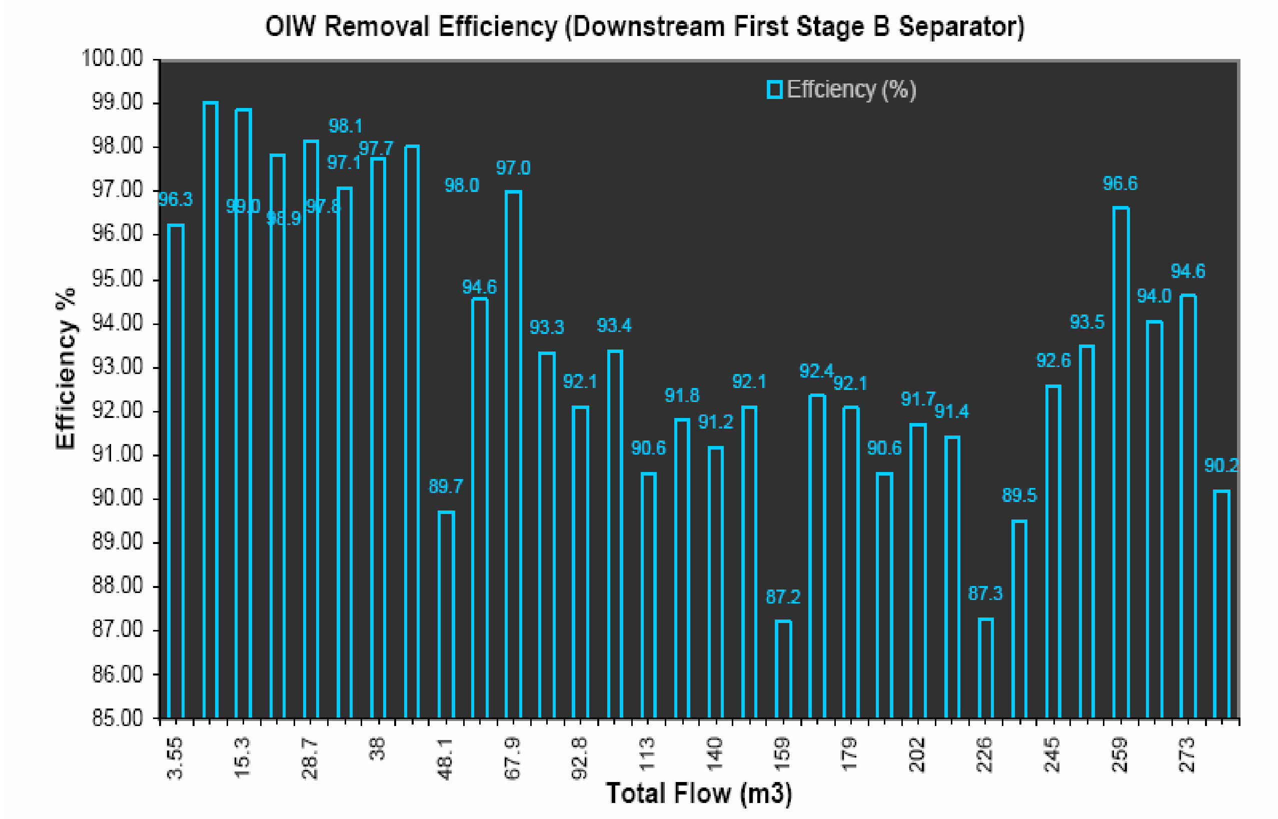

Figure 13. – Trail C, Location #1 – OIW Removal Efficiency

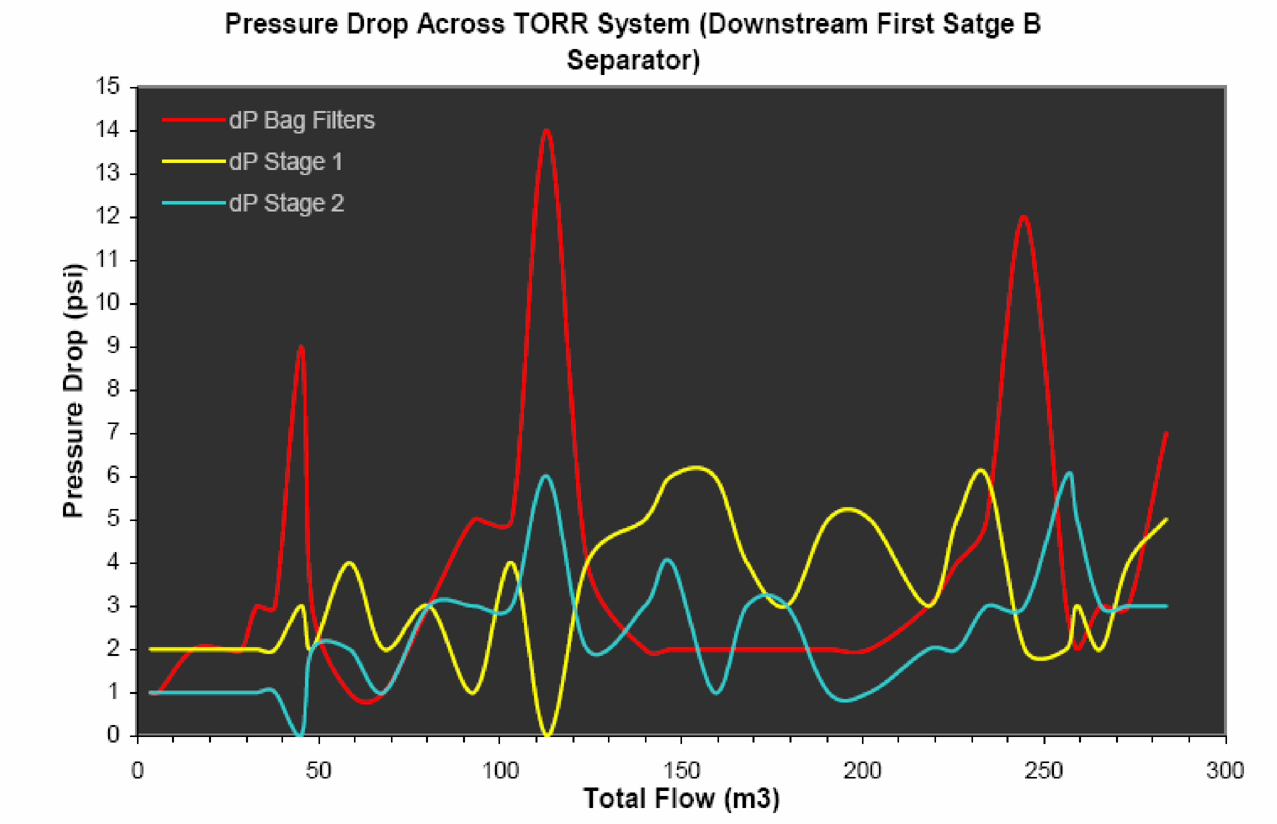

Figure 14. – Trial C, Location #1 – Pressure Drop Observations

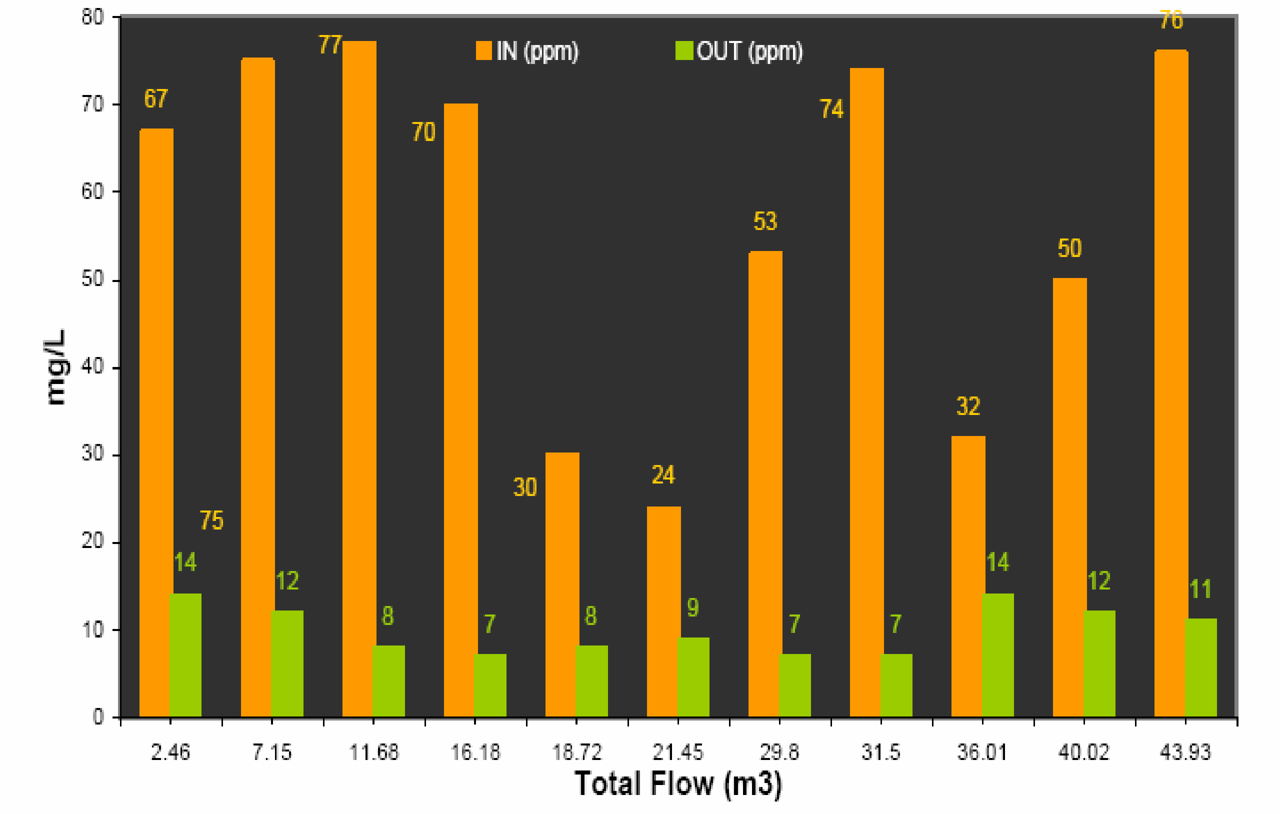

Figure 15. – Trial C, Location #2 OIW Inlet & Outlet Measurements

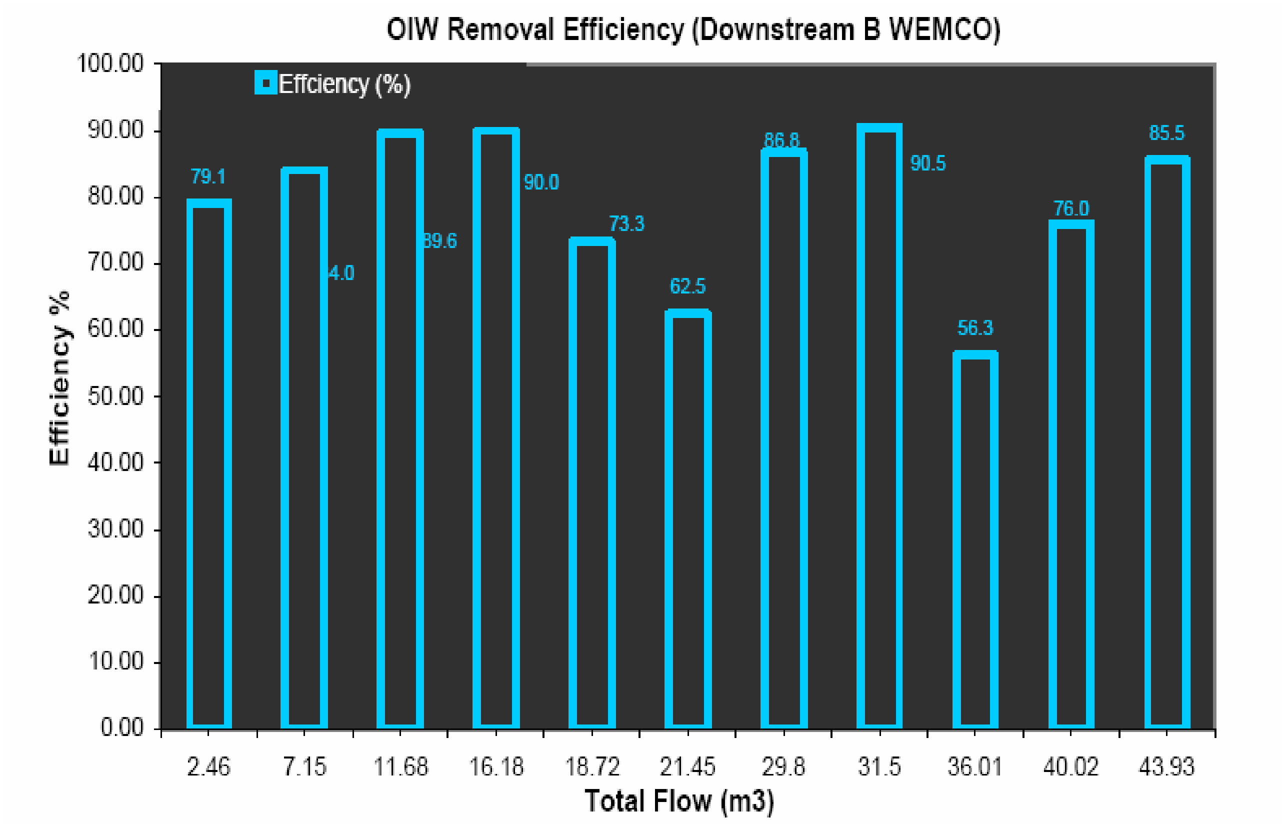

Figure 16. – Trial C, Location #2, OIW Removal Efficiency

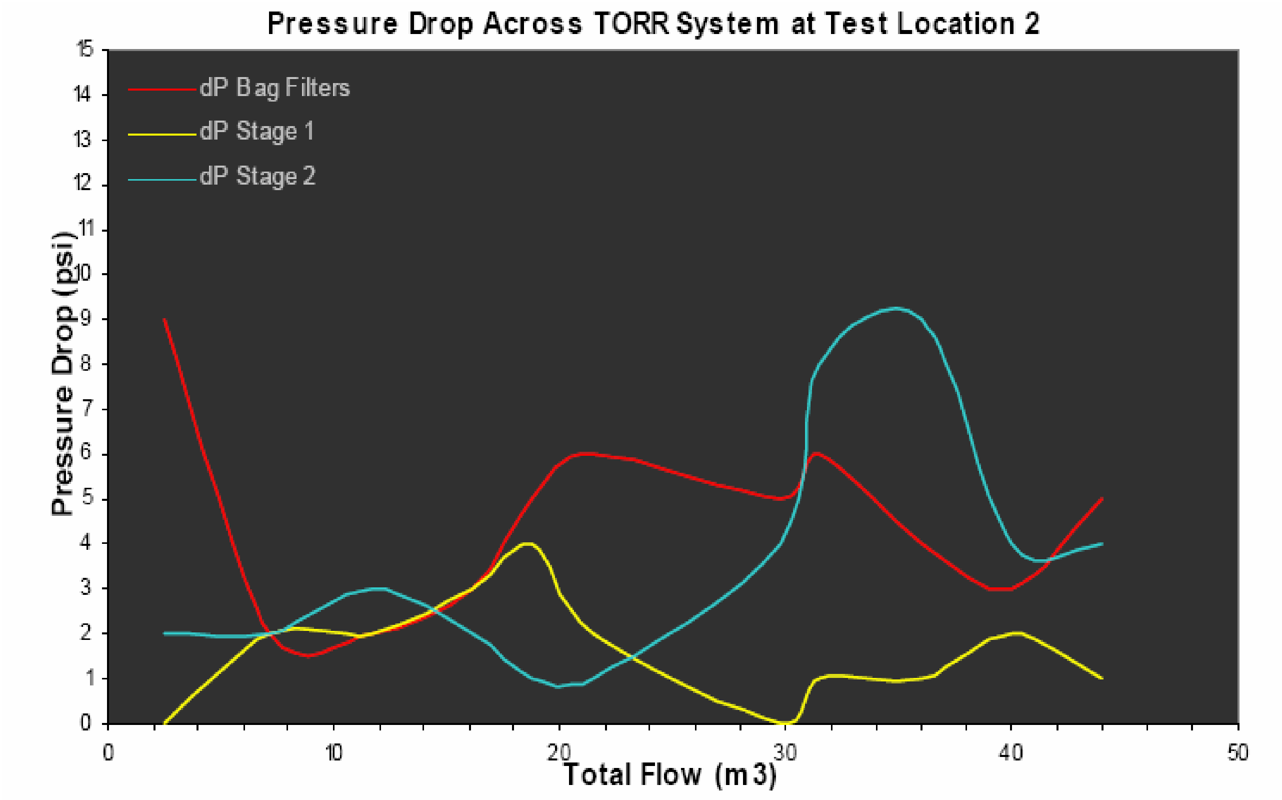

Figure 17. – Trial C, Location #2 – Pressure Drop Observations

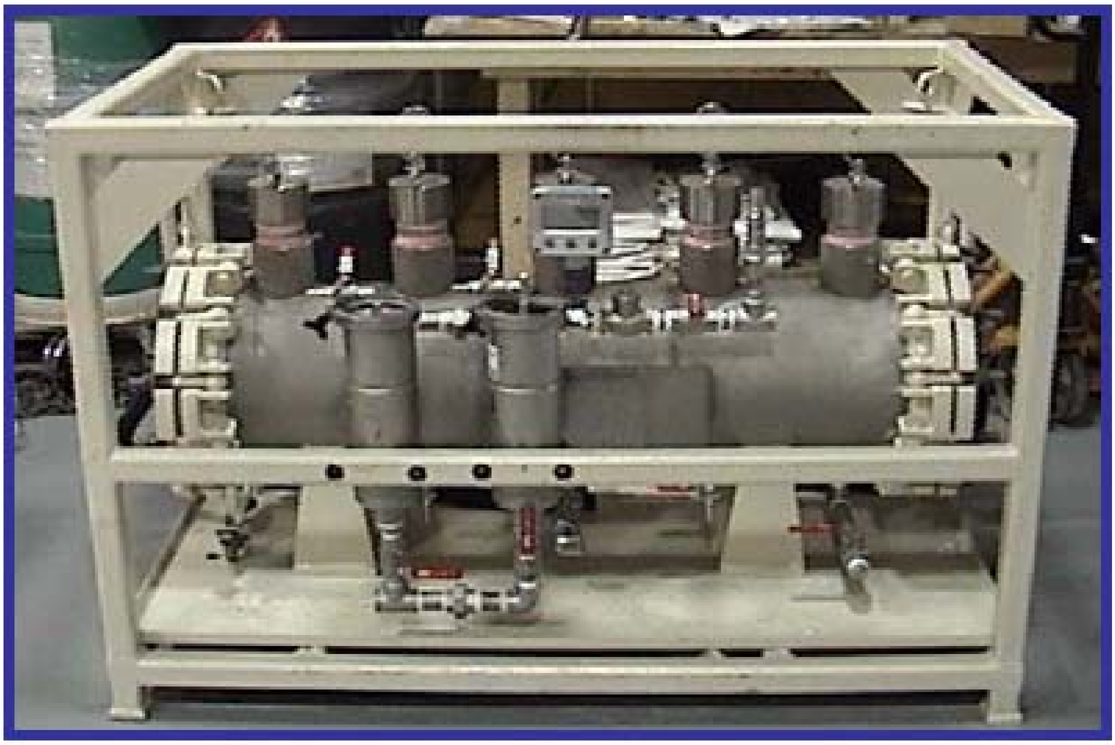

Figure 18. – Technology Demonstration Unit for Offshore Trials