Fundamental Approach to Produced Water Treatment: Validation of an Innovative Technology

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Introduction

The fundamental approach used to develop an innovative technology for produced water treatment has recently been extensively validated. An understanding of the basic physical characteristics of produced water, specifically the oil and emulsion droplet size distribution, poses the basis of performance of most treatment processes. The presented innovative technology has been designed accordingly to address these physical phenomena and has recently been validated through several field trials. The various successes of the field trials provide a new alternative technology for produced water treatment that allows for meeting the strictest of discharge regulations and re-injection criteria. Results have also proven that the need to understand and appropriately quantify the produced water characteristics in order to be able to select and efficient performing technology is inevitable.

Development and Control

Separation of smaller-sized oil-in-water (OIW) emulsions has been developed through extensive experimental testing, in both the laboratory and on many fields, and resulted in an innovative technology. The resulting technology separates and recovers small OIW emulsions with an optimum variable efficiency that is distributed over the OIW droplet size distribution curve of site-specific PW to deliver an effluent that meets the requirements of the treatment process.

The treatment process incorporates two stages of oil adsorbing, coalescing and desorbing porous media in the form of radial-flow cartridges complemented by gravity separation. This is shown in the process flow diagram of Figure 1 as follows:

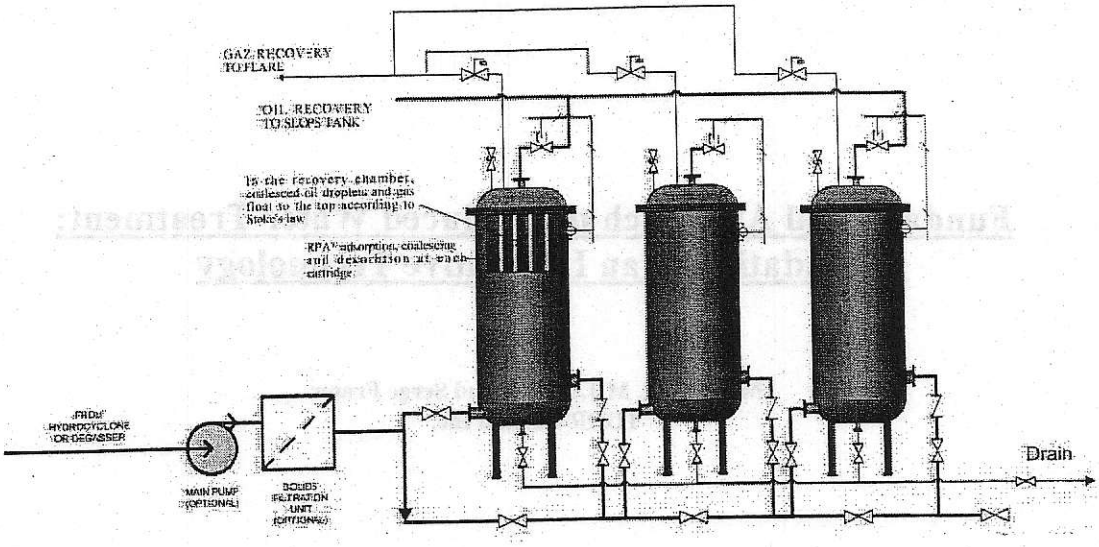

Figure 1: PFD of Technology Process

Development of the process was based on controlling the breaking of OIW emulsions through the media with removal efficiencies as follows:

- 99% of OIW emulsions having characteristic lengths of 15μm and above.
- 97% of OIW emulsions having characteristic lengths between 10μm and 15μm.
- 90% of OIW emulsions having characteristic lengths between 5μm and 10μm.
- 75% of OIW emulsions having characteristic lengths between 2μm and 5μm.

Removal efficiency calculations are weighed by particle count. These oil droplets are coalesced in the media and released to the separation chamber. The gravity separation of the released oil droplets is based on Stoke's Law as follows:

$$V_r = gd^2(\rho_w - \rho_{oil})/18\mu$$

Where V_r is the oil droplet rise velocity
d is the diameter of the oil droplet
ρ_w is the density of water
ρ_{oil} is the density of oil
μ is the dynamic viscosity of water
g is the gravitational acceleration

The process controls the gravity separation of the released oil droplets based on the following criteria:

- Recovery of all released oil droplets having characteristic lengths of 1000μm.
- Variable optimum recovery efficiency based on the characteristics of the crude oil in the PW (see following example).

As a typical case, a crude oil having an API° Gravity of 30 would be separated as follows:

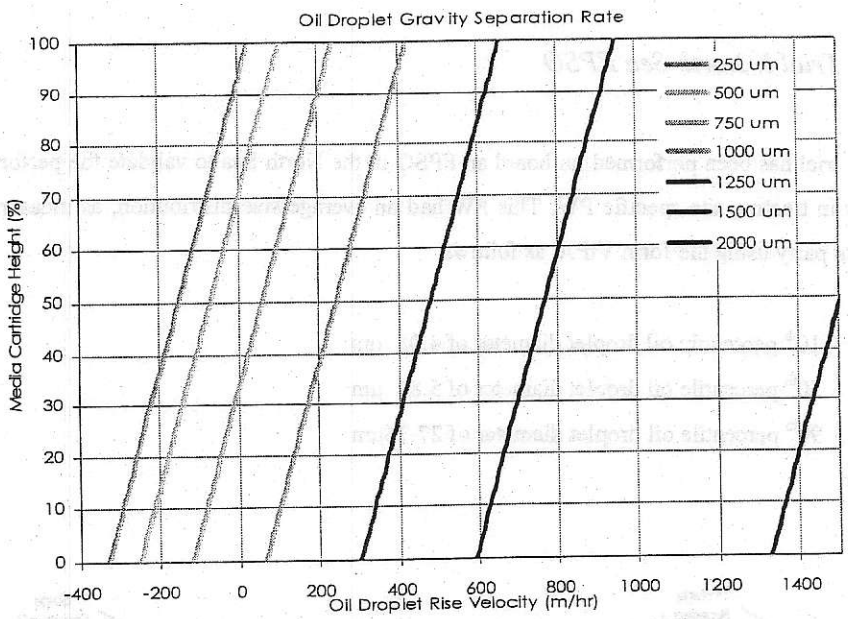

Figure 2: Graph showing example of oil droplet rise velocity in technology process

The graph shows the rise velocity of released oil droplets versus the height of the media cartridges. In other words, all oil droplets of a specific diameter will be recovered if they have a positive velocity. The recovery of the oil droplets will depend on the location they were released with respect to the outlet collection points. The droplets having a negative velocity will be entrained in the effluent. Measurements of the size of the coalesced oil droplet released from the media cartridges have shown that the normal size is in the order of millimeters.

The process controls the separated and released oil droplet rise velocity by controlling the flow distribution in the separation chamber. Heavier oil (API° 20) has been used as the basis for the process design for optimum performance in both parts of the process (emulsion breaking and coalescing and gravity separation). Removal efficiencies of OIW emulsion breaking and recovery efficiency of released coalesced oil droplets will determine the OIW concentration of the effluent. This concentration is controlled through the above process settings and has been measured and validated in several offshore produced water treatment trials.

Validation and Results

Two offshore produced water treatment field trials are presented. The results show that for different site-specific characteristics of produced water, the technology manages to treat and polish the OIW concentration to meet and exceed the regulation values for overboard discharge.

Offshore Trial I: North Sea FPSO

A trial has been performed on board an FPSO in the North Sea to validate the performance of the technology in treating site-specific PW. This PW had an average size distribution, as measured by a third independent party using the Jorin ViPA, as follows:

- 10th percentile oil droplet diameter of 4.08 μm
- 50th percentile oil droplet diameter of 5.86 μm
- 90th percentile oil droplet diameter of 27.76μm

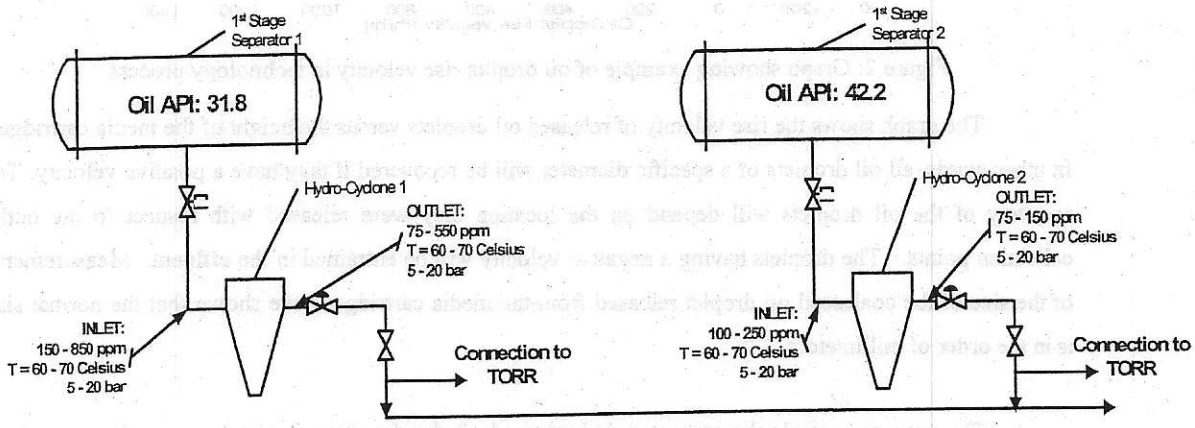

Figure 3: Process Flow Diagram of Produced water treatment line showing TORR™ tie-in locations.

The oil in the PW had an API° density of 31.8, a viscosity of 8 cSt @ 40°C, a paraffin content of 6%, and an asphaltene content of 0.35%. The PW temperature was 65°C. The production chemicals in the fluid stream included: a corrosion inhibitor, a scale inhibitor, a demulsifier, and a defoamer.

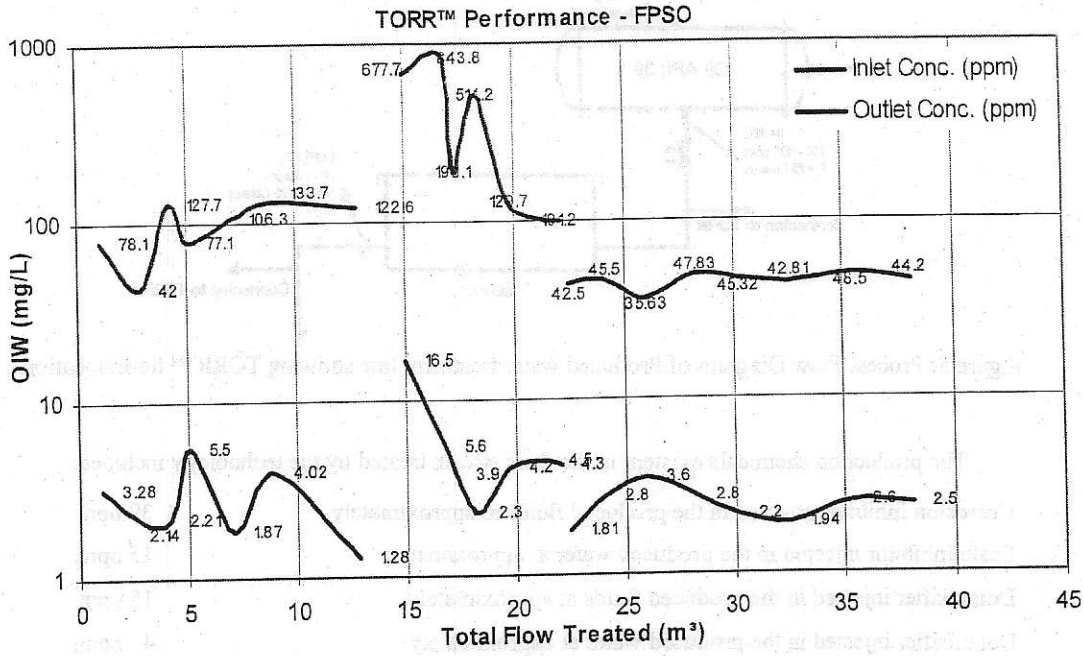

Figure 4: Oil Removal Performance on Board North Sea FPSO

The effluent from the technology's system was measured for OIW concentration using UK Department of Trade and Industry approved methods on board the FPSO. The results for both the influent and effluent are presented above in Figure 4. The trial showed that the technology's process was capable of reducing the total OIW concentration of the FPSO's specific produced water with an average efficiency of over 96%.

Offshore Trial II: North Sea Fixed Drilling and Production Platform

Another trial was conducted on board a fixed drilling and production platform in the North Sea to validate the performance of the technology in treating this different site-specific PW. This PW was produced from several wellheads and mixed together in a single stream. The platform produces approximately 4000 BBL of oil (API° Gravity 39, viscosity of 3.8cP, a paraffin content of 17%, and an asphaltene content of 0.4%) and 100,000 BBL of produced water per day (PW Temperature: 70°C, PW pH 6.5, and maximum H_2S concentration of 2000ppm). Production fluids also come from another platform. Through the first part of the trial, the technology was to treat the PW downstream of the first stage separator and upstream of the WEMCO separators. The OIW concentration downstream of the separator was around 250mg/L. The second part of the trial was 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.

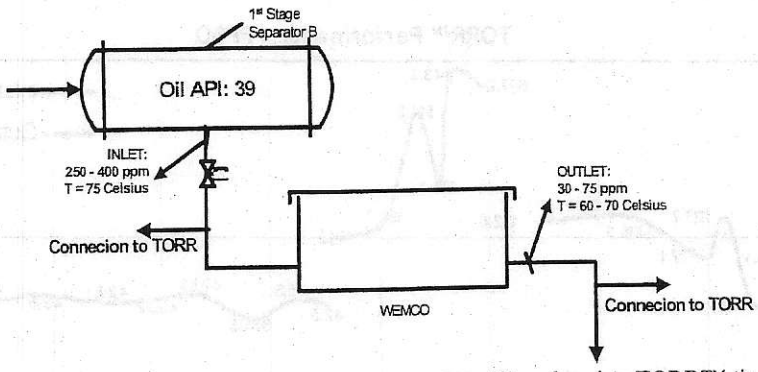

Figure 5: Process Flow Diagram of Produced water treatment line showing TORR™ tie-in locations.

The production chemicals existent in the fluid stream treated by the technology included:

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

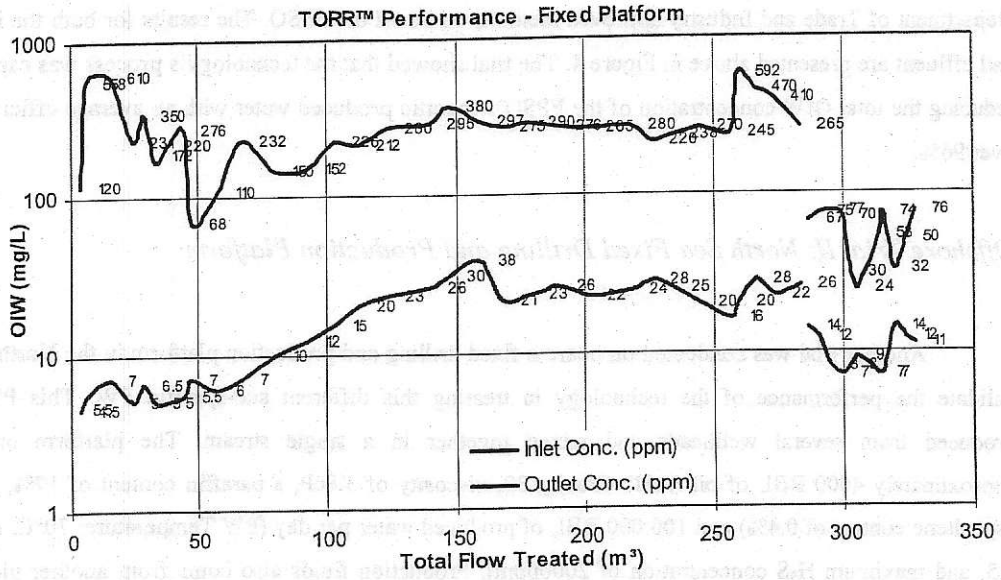

Figure 6: Oil removal performance on board North Sea fixed drilling and production platform

The results demonstrated the technology's performance in terms of oil recovery and lowering the PW oil concentrations to levels meeting the trial target of 15mg/Liter OIW or below. Department of Trade and Industry (DTI) approved methods for 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's process was maintained at levels around 95%.

Concluding Remarks

The technology merits serious consideration for applications of polishing produced water to meet and exceed discharge regulations.

The technology is capable of coalescing and recovering oil from produced waters.

The technology demonstrates characteristics of handling upset hydrocarbon concentrations on the inlet feed.

A clear understanding of oil-in-water measurement protocols utilized is necessary to derive a fair conclusion on the performance results.