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De-Oiling of Produced Water – New Technology

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ABSTRACT

The production of hydrocarbons is usually associated with the generation of a produced water (oilfield brine) waste stream. As a production well matures, the volume of produced water increase and constitutes the largest single fluids stream in exploration and production operations. Treatment and disposal of the produced water often becomes the bottleneck in oil production and plays a large role in oil well economics.

For onshore production, produced water is generally reinjected. For offshore production, produced water is commonly treated so that it can be introduced into the ocean environment within strict regulations or reinjected in similar fashion as in onshore disposal.

Assessing the water quality requirements in a produced water injection program by a concentration and particle size distribution of dispersed hydrocarbons and suspended solids are the most crucial characteristics covering both water treatment and water injectivity.

There are several cost drivers associated with produced water in upstream production.

1. **Environmental protection.** This is especially true for offshore platforms disposing of the produced water in the sea.
2. **Lost oil.** High water cuts and the economics associated with treating and handling this water can be a key factor in the decision to abandon the well.
3. **Well intervention costs.** Poor quality produced water increases the frequency of formation plugging, increased injection pressures and reduction of oil production. Stimulation in the form of matrix acidizing, hydraulic or acid fracturing will be required.
4. **Facility bottlenecks.** Oil production is often limited to the producer's ability to handle and treat the produced water.
5. **Operational complexities.** Produced water treatment can involve several stages of treatment equipment that adds to the operational costs of production. The simpler the treatment technology for produced water, the better for operational issues.
6. **Extended economic life.** Efficient treatment of produced water especially from high water cut wells can extend the economic life of the well.
7. **Chemicals.** Chemicals add to overall production costs.
8. **Electricity.** The cleaner the produced water, the less pressure and horsepower needed for reinjection.
9. **Labor and fixed costs.** Elaborate treatment systems add to maintenance and operational expenditures.

This paper presents a novel technology called TORR™ (Total Oil Remediation and Recovery) for the de-oiling of produced water. This technology offers the producer a unique opportunity in produced water treatment since it coalesces and recovers dispersed hydrocarbons with a rise velocity of 0.8mm/hr or greater without the need for additional heat, chemicals or pH adjustment. The technology is a combination of filtration, coalescence and gravity separation principles and has the ability to address a broad spectrum of dispersed oil emulsions in water. Produced water is cleaned for efficient and economical reinjection or to exceed environmental discharge regulations.

The paper shall explain the basic principles of oil/water separation, the limitations of existing technologies and the

theory behind this new development. A detailed explanation of the operation of the technology will be reviewed and reference will be made to actual onsite testing of the technology.

BASIC SEPARATION THEORY

The removal of dispersed oil from produced water 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.

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

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 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. In general, oil in water can be present as free-oil, and/or dispersed (emulsion), and/or dissolved states in different proportions. This oil droplet size distribution is one of the most important factors affecting the design and efficiency of oil-water separators.

There are other factors that can affect the rise velocity of an oil droplet in water such as surface tension, density of oil and the presence of solids within the oil globule. For technology comparison purposes, this paper will address oil droplet size in general terms to highlight the limitations of various oil/water separation methods.

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. Dispersed oil is oil which is dispersed in the water in a stable fashion due to its small diameter and thus to its low rise velocity.

Dispersed oil can be found in two types: mechanical emulsions and chemical emulsions. Mechanical emulsions are created through the process of pumping, large pressure drops through chokes, control valves, and otherwise mixing the oil-water solution. 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 dispersed oils is to destabilize the emulsion so that the oil will separate by gravity or flotation. Essentially what is done is inter-droplet contact is promoted 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 the 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 (IAF) or dissolved (DAF) air flotation (other gases such as methane, carbon dioxide or nitrogen can be used instead of air in some applications). Air is introduced (either at atmospheric pressure or dissolved under pressure) to provide air bubbles, which tend to attach to the oil droplets decreasing its specific gravity and then float quickly to the surface. More rapid oil removal can be achieved than by gravity alone, resulting in smaller footprint. Finally, it is often necessary to use chemical coagulants with flotation units. Chemicals such as 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). Hydrocyclone performances 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 primary advantages and disadvantages of the previous oil separation processes described above are given in Table 1.

The challenge of removing small oil droplets:

Even under favorable 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.

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Separator Type	Technology	Oil Droplet Removal Range
API	Gravity	Down to 150 µm
CPI	Gravity Coalescer	Down to 50 µm
DAF, IGF	Air/Gas Bubbles	Down to 25-30µm
Hydrocyclones	Centrifugal Force	Down to 20 µm
Centrifuge	Centrifugal Force	Between 5-30 µm
TORR™ System	**Filtration/Coalescing/ Gravity**	**Down to 2 µm**
UF, RO, Micro, Nano	Membrane	Less than 1 µm

Fig.# 1 – Limitations of Separation Technology

PRINCIPLE OF EARTH'S TORR™ TECHNOLOGY

The TORR™ System (Total Oil Remediation and Recovery System) was developed and implemented by EARTH (Canada) Corporation. This technology offers an effective, reliable and economical process.

The new technology is based on the filtration, coalescence and gravity separation processes and is designed for oily water treatment (both free and emulsified oils). To achieve separation, RPA® (Reusable Petroleum Absorbent), a hydrophobic absorbent developed and patented by EARTH (Canada) Corp. is used as a filtration medium in the technology. The sorbent being highly oleophillic, allows the absorption of very fine dispersed oil emulsions. Another characteristic of the sorbent lies in its capacity to continue to absorb fine emulsions even when it's fully saturated with oil, while continuing to desorb the coalesced oil as free-floating oil. The two principal characteristics of the sorbent (absorption of fine emulsions and desorbtion of larger free-floating oil) allow the removal of fine dispersed oil emulsions with a minimum rise velocity of 0.8mm/hr and is a self-cleaning system (continuous oil separation and recovery).

The technology consists of an engineered envelope divided in several compartments. The highly oleophillic and hydrophobic sorbent is filled in every second consecutive compartment. The other compartments are empty and are designed for recovery of coalesced hydrocarbons.

The sorbent has the ability to adsorb the free-floating and the dispersed oil on its surface. It then coalesces the fine emulsions into larger globules. When it's fully saturated with oil, the drag forces resulting from the flow of water through the sorbent bed promotes the release of the large oil globules while continuing to adsorb the smaller incoming oil emulsions. At equilibrium state (when the sorbent is totally saturated), the quantity of oil released is equal to the quantity of oil adsorbed. The coalesced oil released is then recovered in the adjacent empty compartments. Here the large oil globules that have been formed are skimmed into a collection header and sent to an oil recovery chamber for quick and easy separation.

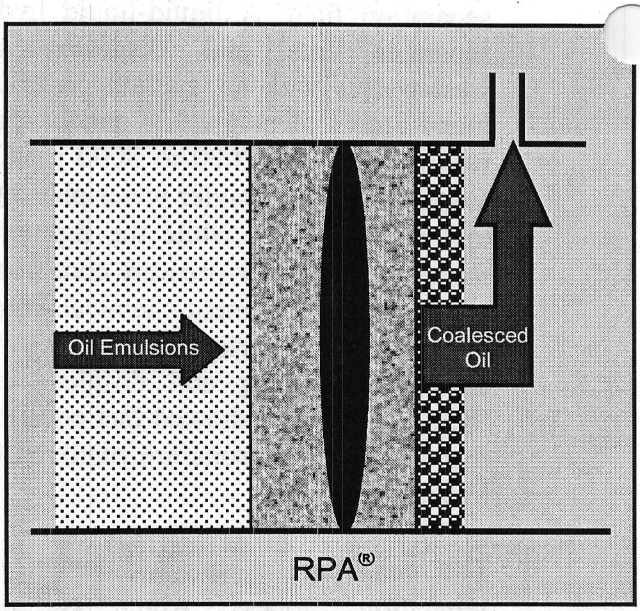

Fig.# 2 – Absorbtion/Desorption Cycle in TORR™

The transformation of the oil droplets and the recovery of oil considerably increase the volumes of oily water to be treated. The self-cleaning action of the sorbent (absorbtion/desorption process) allows for continued operation over extensive periods.

Field Trial

The technology was installed at a client's upstream processing center in Europe for a period of 30 days of continuous operation. This particular demonstration unit was capable of treating 3 m^3/hr of produced water and contained 14 coalescing beds. The inlet and outlet oil concentrations were sampled every second day and sent to a lab for measurement according to EPA 413-2 reference method. The technology was placed after the skim tank that supplied oily produced water feed to the technology at an average rate of 2.3 m^3/hr. Pressure was also monitored at the inlet and outlet along with the instantaneous flow rate and cumulative flow.

Fig. 3 TORR™ Installed at Processing Center

The treated produced water from the demonstration unit was sent to an existing holding tank prior to discharge to the sewers. The coalesced oil and water recovered from the unit was sent to an existing API type separator where the oil was easily separated from the water by gravity separation. All samples and readings were taken at the same time of day

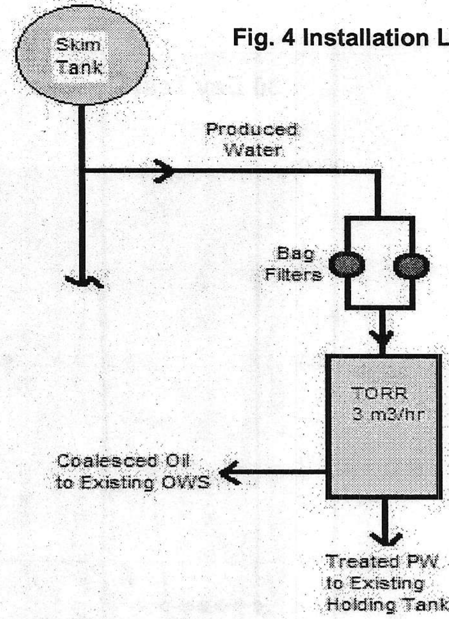

Fig. 4 Installation Layout

Fig. 5 Sample Readings

Day	Cumul. Flow (m^3)	P In (psig)	P Out (psig)	Oil In (PPM)	Oil Out (PPM)
1	0	5	3.0	1400	1
2	69.39	9	5.8	1950	2
3	130.65	7.5	3.5	95	<2
4	193.45	7.6	4.0	-	
5	255.35	7.5	4.0	160	<2
6	317.74	9.5	4.0	-	
7	379.8	9.0	4.5	100	<2
8	439.61	8.5	4.0	-	
9	500.56	9.4	4.0	180	<2
10	561.08	8.9	4.0	-	
11	621.00	9.5	4.0	180	2
12	679.26	11.5	3.0	-	
13	737.66	12.0	5.0	150	7
14	794.70	10.5	4.5	-	
15	851.65	13.0	4.5	180	3
16	908.6	13.5	5.0	-	
17	964.85	12.5	3.5	190	4
18	1018.4	13.5	4.0	-	
19	1073.0	14.5	4.3	180	16
20	1129.0	14.4	4.0	-	
21	1185.0	13.8	3.0	200	11
22	1244.0	13.6	3.4	-	
23	1295.96	14.0	2.0	160	11
24	1350.54	13.5	2.5	-	
25	1405.05	10.0	2.0	210	9
26	1459.04	14.5	3.0	-	
27	1512.25	14.3	2.0	170	6
28	1566.5	14.5	2.5	-	
29	1620.1	14.5	2.0	180	11
30	1672.4	15.0	3.5	-	

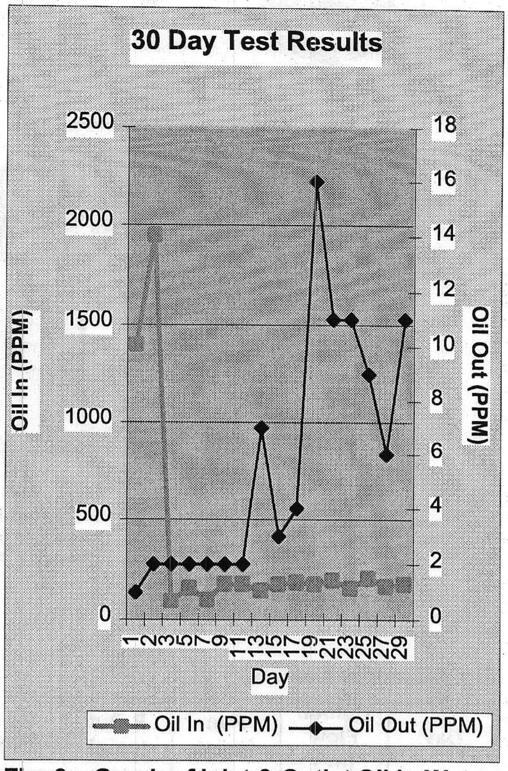

Fig. 6 – Graph of Inlet & Outlet Oil in Water Concentrations

CONCLUSIONS

The one month trial tests confirmed expected performance for the TORR™ process.

1. The technology shows ability to handle upset oil concentration conditions in the produced water feed while maintaining low oil ppm levels in the treated outlet.
2. Over the 30-day period, the treated produced water did not exceed the 20-ppm oil in water discharge level under all operating conditions.
3. The maximum overall pressure drop across the unit for the trial period was 12 to 13 psig. This is as expected. Manufacture claims a maximum pressure drop of 2 psig across each coalescing bed.
4. The recovered oil was added to the sales tank.

The low-pressure drop across the technology adds benefit in low pumping costs. No additional chemicals or heat were added during the trial period and no waste was generated.

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