PRODUCED WATER DEOILING USING DISC STACK CENTRIFUGES

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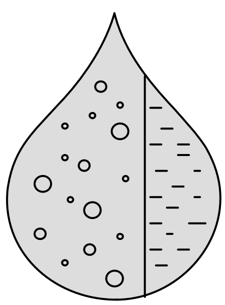
1. INTRODUCTION

The disc stack centrifuge was invented by Gustav de Laval in 1878. The primary objective then was to skim cream from milk. The design of the disc stack centrifuge has undergone many refinements since 1878, including changes is material selection, fluid dynamic design, size, controls, manufacturing process, etc. The basic design concept has however remained the same:

- High g-force generated by the high rpm
- Disc internals to enlarge the settling area, shorten to settling distance and forced coalescence of droplets to a continuous liquid phase.

The combination of the above design features makes the disc stack centrifuge very suitable for removal of small oil droplets from produced water. The disc stack centrifuge can effectively remove oil droplets as small as 1 – 2 micron and the centrifuge has a very large operating window in terms of process changes.

2. PROBLEM DEFINITION



Produced water treatment systems based on mechanical separation can remove oil droplets and continuous oil films from produced water. Dissolved oil can not be removed by mechanical means.

Whereas a continuous oil film is easy to remove from the produced water with most treatment methods, small oil droplets can be very difficult to remove.

Fig. 1. Dispersed and dissolved oil.

2.1 Oil Droplet Size

Stoke's Law describes the relationship between the oil droplet settling speed (rising speed in water) as a function of (d, η, ρ, g-force):

$$v_s = \frac{d^2 (\rho_w - \rho_o)}{18 \eta} g$$

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where: v_s = the oil droplet settling speed (m / sec)
d the oil droplet diameter (m)
ρ_w the water density (kg / m^3)
ρ_o the oil density (kg / m^3)
η the water viscosity (kg / m,sec)
g the g-fore applied (m / sec^2)

Small oil droplets will settle much slower than large oil droplets, since the settling speed is proportional to the square of the oil droplet diameter. Field experience has shown that the oil droplet size distribution often has a peak around 10 – 15 micron and thus the volume of oil droplets below 10 micron can be quite significant. These sub-10-micron oil droplets can be a real challenge for most conventional treatment systems.

Most treatment systems for produced water are based on settling the oil droplets over a certain time period, the equipment *residence time*. According to Stoke's Law, the settling speed is proportional to the g-force applied and to the square of the oil droplet diameter.

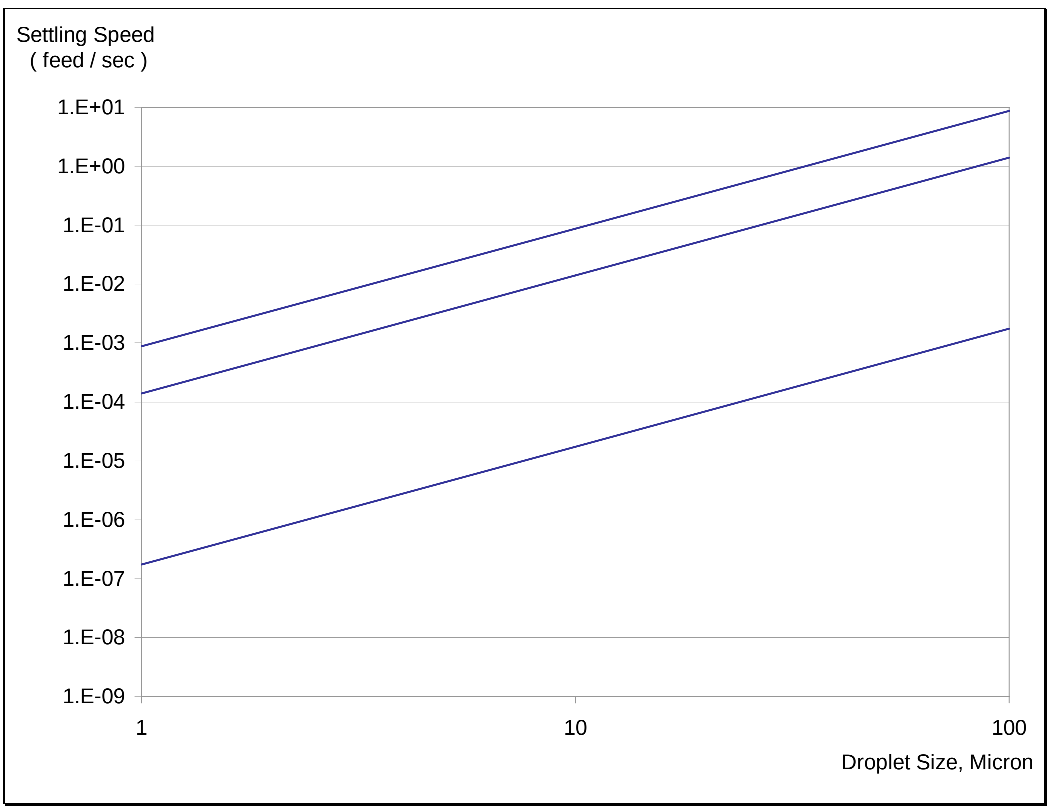

Fig. 2 Settling speed for API° 20 oil droplets in 1 cSt water, for various sizes oil droplets when subjected to different driving forces (g-forces).

It is quite obvious from the chart that small oil droplets (below 10 micron in diameter) will settle very slowly and also that separation processes utilizing an elevated g-force will increase the settling rate drastically.

2.2 Oil Droplet Generation

Fig. 3 shows a typical size distribution of oil droplets in produced water, where d_{v50} is the average size oil droplet by volume.

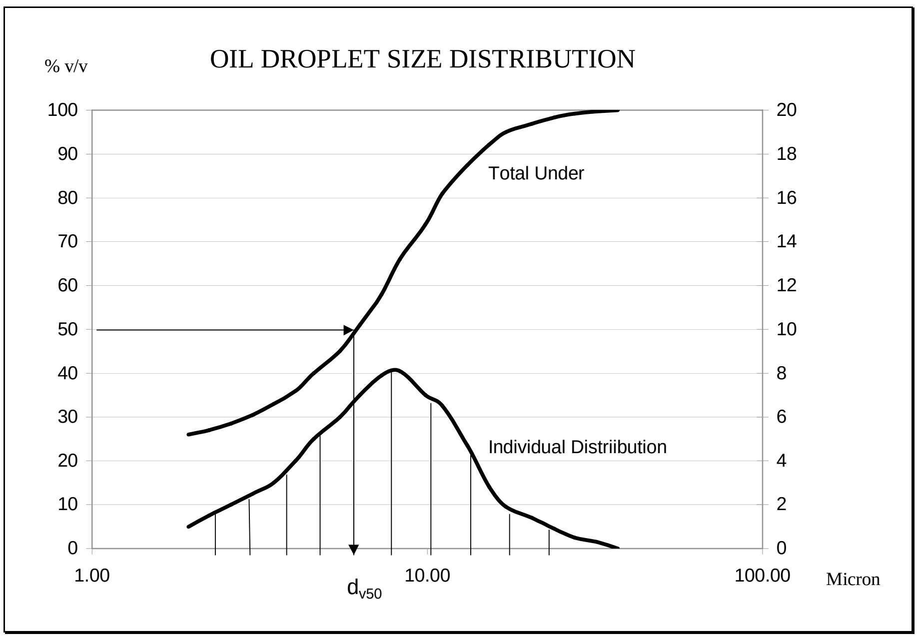

Fig. 3 Typical Oil Droplet Size Distribution

The oil droplet size distribution is a function of the upstream process, the fluid chemistry and the reservoir conditions. Pressure drops in process equipment cause oil droplet break down due to the energy dissipation around the restrictions in the equipment. Process equipment which cause droplet break down are chokes, control valves, inlet devices in vessels, hydrocyclones, etc. Fig. 4 shows the main mechanism of droplet break down in a choke valve.

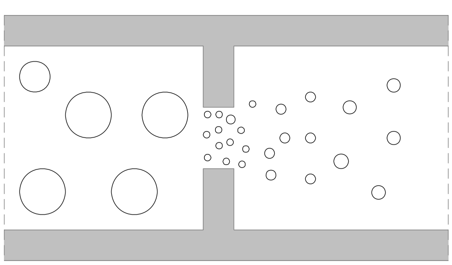

Fig. 4 Droplet break down in choke valves

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The majority of these small oil droplets are generated within the top side process at the platform. It is the choke valve imposing the largest pressure drop in the process which has the largest impact on the size of oil droplets generated. The energy dissipation in choke valves is normally higher than in other process equipment.

Fig. 5 shows average diameter of oil droplets generated as a function of the pressure drop in the equipment. As can be seen from the curve, even moderate pressure drops like 150 psi can generate oil droplets below 10 micron. This curve is also relevant for oil droplets sheared by centrifugal pumps, including feed pumps and downhole electric submersible pumps.

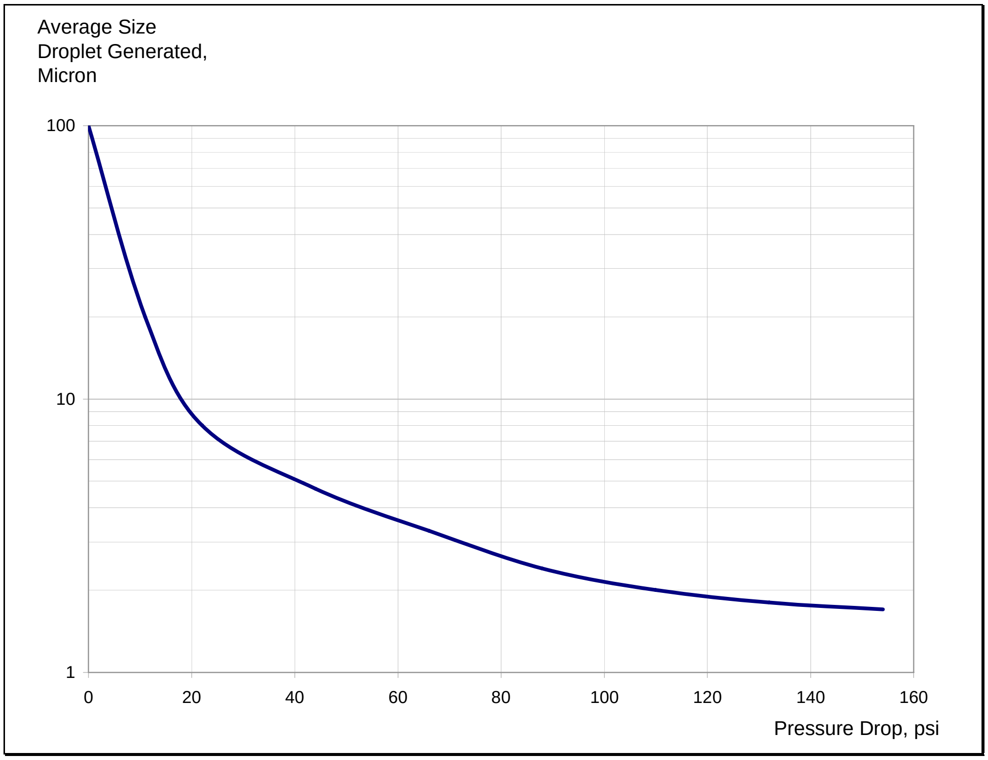

Fig. 5 Average size droplet generated as a function of pressure drop

2.3 Influence of Production Chemicals

Another factor influencing the degeneration of oil droplets is the interfacial tension of the oil droplets. A reduction in interfacial tension leads to easier droplet break down. O.J. Hinze found that the max. diameter of oil droplets can be expressed as:

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$$d_{max} = C \frac{\sigma^{0.6}}{\varepsilon^{0.4} \rho^{0.2}}$$

where:

C	=	correction factor (0.725)
σ		interfacial tension (10^{-2} Dynes/m)
ε		energy dissipation (1 / sec)
ρ		density of continuous phase (kg/m^3)

Production chemicals which reduce the interfacial tension include Methanol and Corrosion Inhibitors. Produced water containing Methanol and / or Corrosion Inhibitor can thus contain large amounts of small oil droplets.

2.4 Oil Droplet Coalescence

Many of the small droplets generated in the choke valve will coalesce to larger oil droplets if conditions are right. Factors working against coalescence include:

- electrostatic charge of droplets causing droplets to repel each other
- stabilization by surface active chemicals
- fine particulate matters adsorbed to the droplet surface causing steric stability

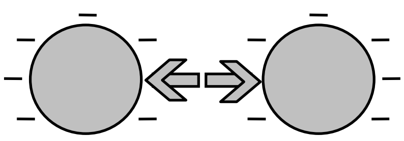

Fig. 6. Electrostatic charge causing oil droplets to repel one another

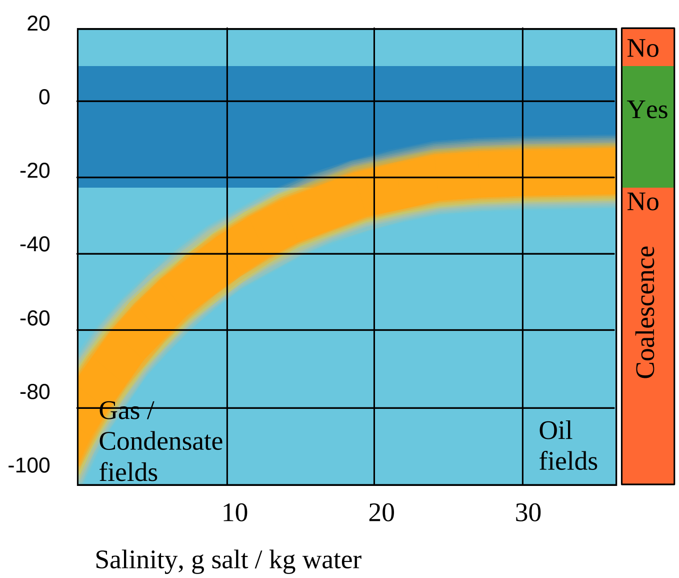

Fig. 7 Effect of water salinity.

As can be seen in Fig. 7, the salinity of the produced water has a direct influence on whether the oil droplets will coalesce or not. The droplet electrostatic charge is higher when the salinity is low, thus preventing coalescence. When the salinity is higher, say 2 % or more, the electrostatic charge is low and thus conditions for coalescence exist. Condensed water from gas / condensate field typically has very low salinity and thus often contain very small oil droplets.

Particulate matters in produced water, like clay or scale often adhere to the oil droplet surface and thus prevent natural coalescence. So does surface active chemicals.

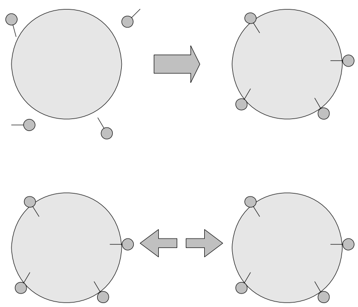

Fig. 8 Droplet repelling due to steric stability

3. TOOLS FOR ANALYSIS

In order to get a better understanding of the separability problem for the current produced water project, Alfa Laval Oilfield provides the following tools for analysis of the process:

	Existing Field	New Field
PROSEP PC Program	Yes	Yes
Characterization Test Rig		Yes
Droplet Size Analysis / IR	Yes	Yes
Test Centrifuge	Yes	

3.1 PROSEP

PROSEP is a PC program which allows comparative evaluation of various produced water treatment options. The present program version includes models for gas flotation cells, hydrocyclones and disc stack centrifuges.
Based on oil droplet size distributions, process conditions and fluid properties, the efficiencies of various treatment alternatives can be estimated.

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Fig. 9 PROSEP PC Program

The PROSEP PC program has been used extensively to simulate the produced water treatment systems for various future projects. The information received about the expected performance of alternative processes has been very valuable for evaluating alternative layouts and processes.

3.2 Characterization Test Rig

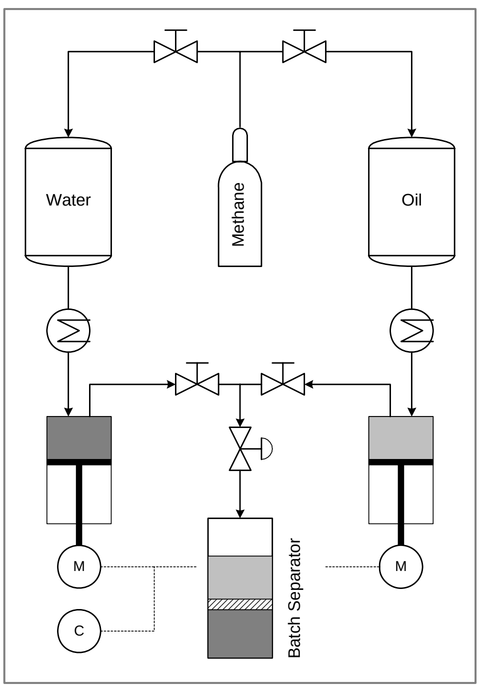

Fig. 10 Characterization Test Rig

The characterization test rig (CTR) was developed to provide information about expected performance of future processes. The rig uses gas saturated oil and water (from representative samples) which are brought to expected process conditions upstream the choke. Water and oil are mixed and subjected to representative pressure drops prior to collection in a gravity batch separator. Based on the following gravity separation, samples of the water phase can be taken at various times and analysed. Produced water process data can thus be verified and possibly used in PROSEP simulations.

3.3 Malvern Droplet Size Analyzer

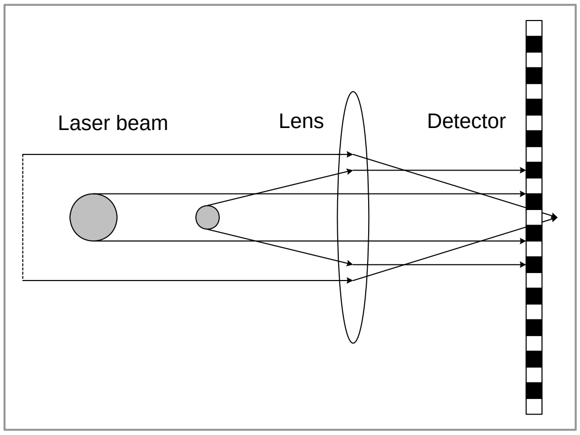

Fig. 11 Malvern laser diffraction

Malvern uses diffraction technology to detect the size of oil droplets dispersed in the produced water, utilizing the fact that smaller dispersed objects diffract the laser beam more than larger objects do. The gathered size distribution data are printed in graphic and tabular format. Malvern provides the following information about the oil droplets in the produced water:

- droplet size
- droplet size distribution
- volumetric concentration

Comparison between Malvern and IR data will provide information about the total oil content, as well as dissolved and dispersed oil.

3.4 Hydroflokk

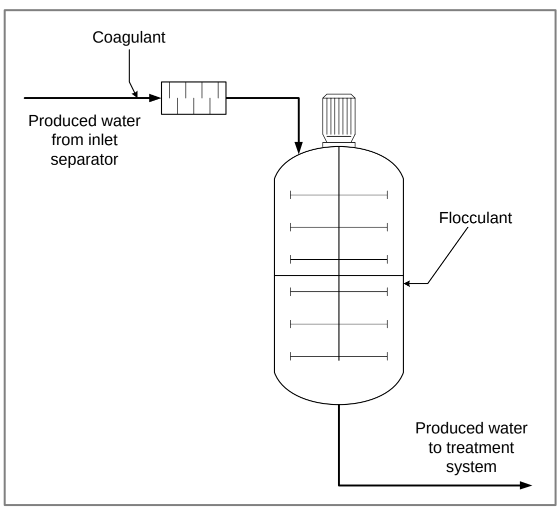

Fig. 12 Hydroflokk Process

Hydroflokk is a new process concept developed for increased separation efficiency for produced water treatment systems. Hydroflokk combines the principles of coagulation and flocculation, resulting in :

- controlled growth of oil droplets
- formation of stable flocc which can withstand the shear forces in hydrocyclone inlets
- reduced chemical consumption
- improved oil / water separation

Commercial installations utilizing Hydroflokk so far has combined technologies for:

- Hydroflokk - for droplet enhancement
- Hydrocyclones - for bulk water deoiling
- Floatation - for water polishing
- Centrifugation - for hydrocyclone reject treatment and waste minimization

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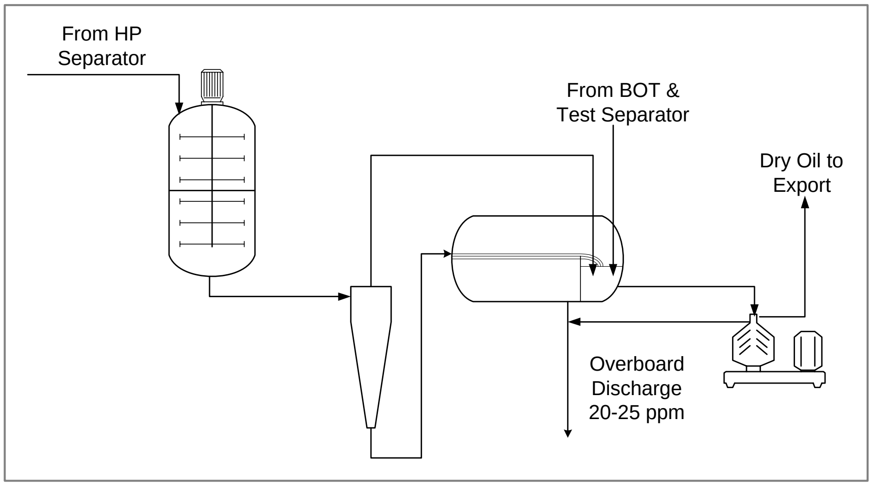

For verification of the Hydroflokk process, a small test unit is available for rent. This unit is housed in a 10' container and is complete with a Hydroflokk vessel, hydrocyclone liners and process valves.

Fig. 13 Hydroflokk schematic

3.5 Process Test Centrifuge

Process test centrifuges are available from Alfa Laval Oil & Gas. Most commonly available units have a nominal process capacity of 2100 – 2250 bwpd. These units are available for onshore and offshore process verification tests. The test units are self contained units, complete with process piping and valves, controls, instruments, starters, etc. for unmanned operation.

Fig. 14. Process Centrifuge incl. feed and treated water sample.

Most test units have dual function and can be used for either duty produced water deoiling, crude oil dehydration or oil recovery from slop oil. The test units are housed in 10" containers and are suitable for installation within outdoor hazardous areas.

Fig. 15 Offshore Installation of Process Centrifuge

4. TREATMENT OPTIONS

The only practical and reliable process equipment for produced water deoiling are based on gravity separation. The efficiency of these equipment depend on the magnitude of the driving force field applied and the effective settling distances inside the equipment. The time required to remove oil droplets is basically the settling distance divided by the settling speed. The shorter the settling distance and the greater the settling speed, the more effective the separation process.

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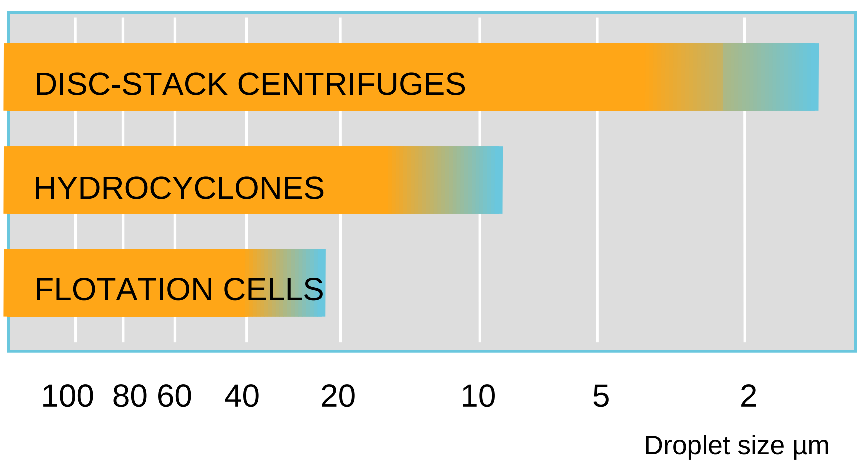
The table below details the driving force and typical settling distance for various types of produced water deoiling equipment.

Equipment	Max. Driving Force	Settling Distance
Flotation Cells	1 g [1]	> 60 inches
Hydrocyclones	~ 800 g	> 0.4 inches
Disc Stack Centrifuges	~ 6000 g	~ 0.02 inches

[1] Enhanced by bubble flotation.

The flotation cells use bubble flotation to enhance the 1 g separation. Both hydrocyclones and disc stack centrifuges utilize elevated g-forces.

The diagram below indicates the size of the oil droplets which the respective equipment can remove:



Flotation cells are suitable for easy to remove oil droplets only. Hydrocyclones and disc stack centrifuges can remove much smaller oil droplets. Due to the different operating windows, working principle and design, hydrocyclones and centrifuges should be regarded as complementary equipment rather than competing technologies. Disc stack centrifuges are the only effective equipment when the oil droplets are below 10 micron.

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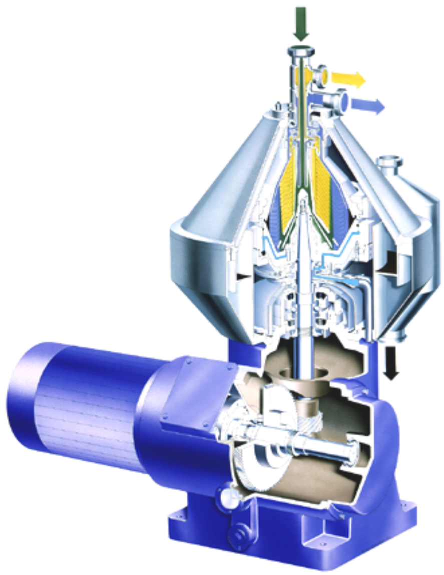
5. DISC STACK CENTRIFUGE DESIGN

The disc stack centrifugal separator consists of the following main parts: the frame, the drive motor, the transmission, the separator bowl and the inlet / outlet arrangements. The separation process takes place inside the rotating bowl at 5000 – 6000 g's force field.



The centrifuge bowl is fitted with special inserts which shorten the settling distance for separated oil droplets and sediment particles. The spaces between the discs form annular channels, with approximate 0.5 mm spacing which can be regarded as a number of parallel separation vessels. The oil / water / sediment separation takes place between the disc inserts. These inserts (the discs) also act as emulsion breakers.

Fig. 16 Disc Stack Centrifuge

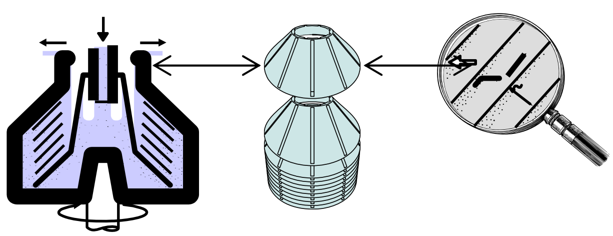


Fig. 17 Separation Bowl and The Disc Stack

The feed is introduced in the center of the bowl through the feed pipe and is accelerated to full rotational speed in straight rectangular sections, to minimize shear and droplet break down. The feed is evenly distributed between the discs and is instantly separated into oil, water and solids due to the high g-force inside the bowl. The oil flows towards the center of the bowl against the upper side of the disc below. Water and sediment flows outwards against the under side of the disc above. From here, the liquid phases are led to the neck of the centrifuge bowl from where they are discharged through the internal paring discs under pressure.

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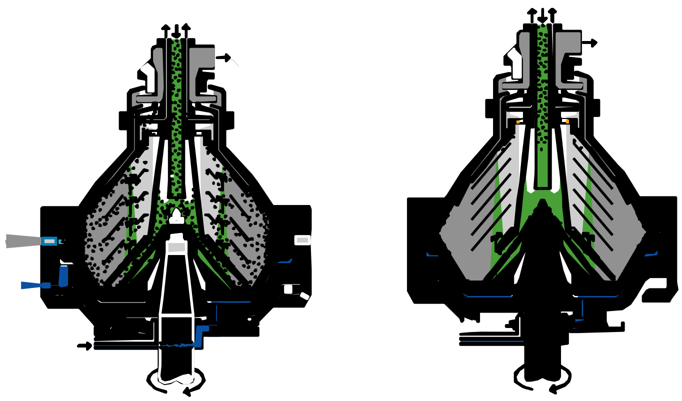
The solids phase is collected in the sludge space in the bowl periphery, from where it is discharged intermittently.



Before discharge After discharge

Fig. 18 Intermittent Solids Discharge

At the widest point, the centrifuge bowl is perforated by a number of rectangular solids discharge ports. The centrifuge bowl has an internal piston, which in its upper position covers these ports. Through a hydraulic mechanism, this piston can be moved up or down. When the piston is in its lower position, sediment is discharged through the discharge ports to the surrounding collecting cover. Sediment discharges are done intermittently, take around 20 ms and are carried out without process interrupt.

The oil / water interface is regulated by a weir plate in the water outlet. The interface can be further adjusted by imposing a back pressure in the water outlet of the centrifuge. Since the interface position is based on a hydrostatic balance, the centrifuge is insensitive to variations in feed rate and feed composition. The separation performance is thus very consistent and major upsets can be handled by the centrifuge with no significant impact on the separation result.

6. CASES

Case 1 – Direct Centrifuging of Produced Water

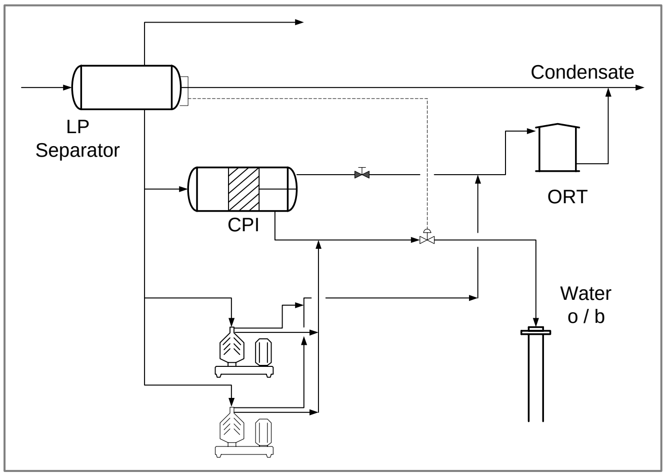


Fig. 19 Process Installation

Retrofit installation where the CPI did not perform as expected. Centrifuges were installed in parallel with the existing CPI and handling around 95% of the produced water.

High pressure drops upstream the LP Separator. The produced water had appr. 1% salinity and suspended chalk particles. The d_{v50} down stream of the LP separator was around 10 micron. High chemical costs prior to centrifuge installation.

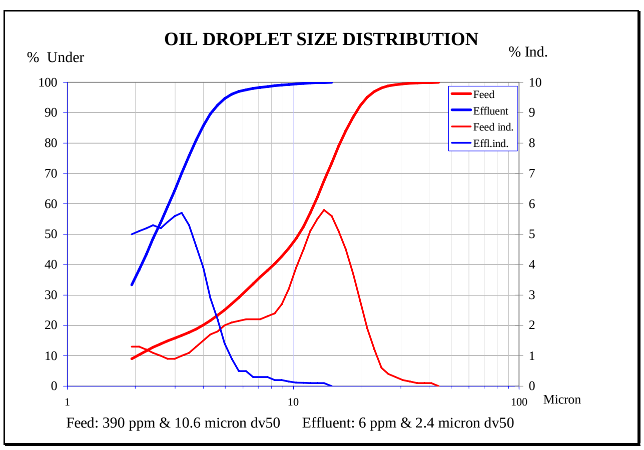
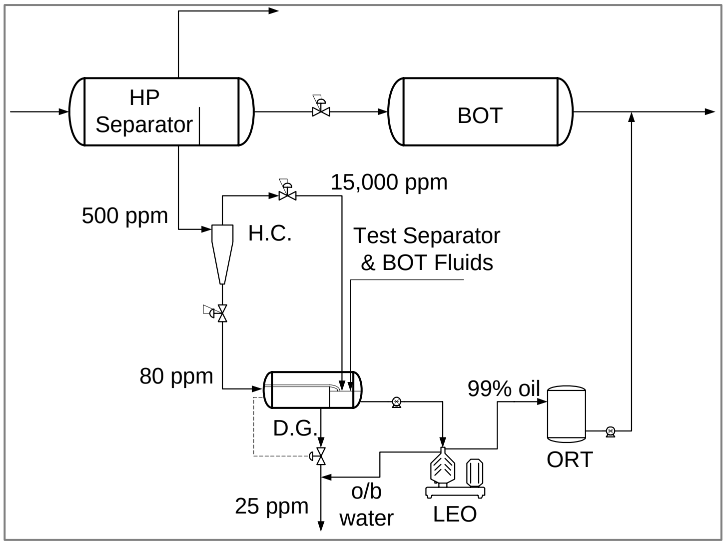


Fig. 20 Oil Droplet Size Distribution

With reference to the droplet size distribution chart, the centrifuge removed the majority of the oil droplets larger than 5 micron with a d_{v50} around 2 micron. The treated water had an oil content around 10 ppm. The recovered condensate was dry and water clarifier injection was eliminated. Total installed capacity: 69,000 bwpd

Case 2 – Combination Hydrocyclones & Disc Stack Centrifuges



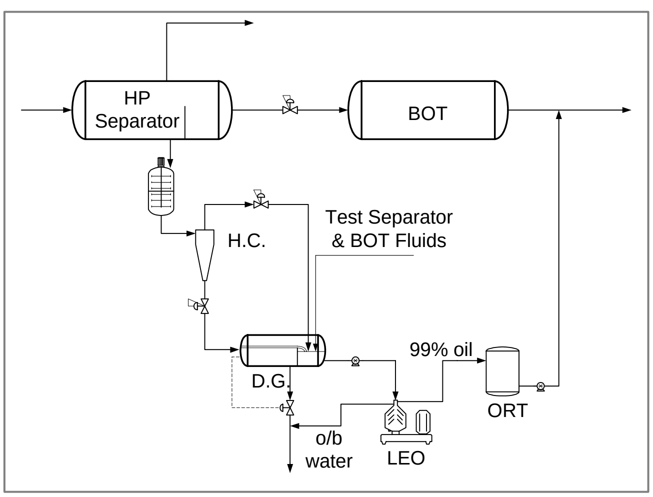
New field development in the North Sea. Due to the high water volumes, hydrocyclones chosen as primary water deoiling equipment. Both accept and reject streams routed to a 2-compartment degasser.

Hydrocyclone reject stream and test separator water treated with disc stack centrifuge, to avoid recirculation of fluids.

Fig. 21 Combination Hydrocyclones and Disc Stack Centrifuges

Total water flow expected: 300,000 bwpd. During initial low water production, all water was handled by the centrifuges. Overboard water has around 25 ppm hydrocarbon content. Recovered oil is dry.

Case 3 – Combination Hydroflokk, Hydrocyclones and Centrifuges



Retrofit at existing hydrocyclone installation. Due to the presence of large volumes of small oil droplets in the produced water, the final process installation contains:

- Hydroklokk for oil droplet enhancement
- Hydrocyclones for bulk water deoiling
- Disc stack centrifuges for treatment of hydrocyclone reject and water from test separator & BOT

Fig. 22 Treatment Process

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Case 4. Improved Drain Water Treatment System

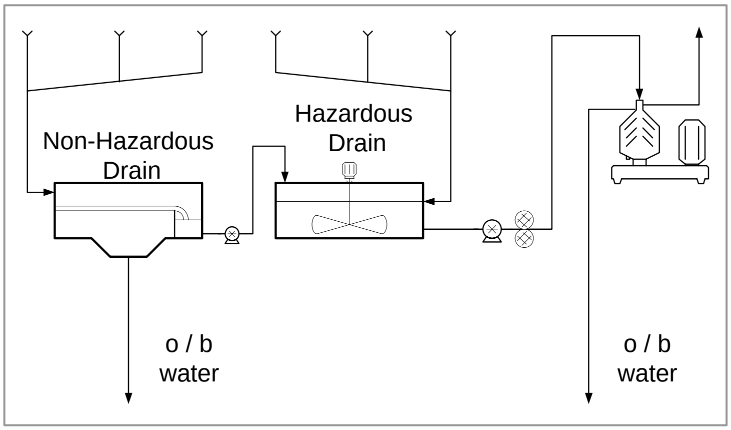

Fig. 23 Drain Water Process

Drain water contains a variety of different components and its oil / water / sediment composition and flow rate changes widely and frequently.

Hazardous drain further contains large amounts of small oil droplets, chemicals, emulsions, small and large particles.

Disc stack centrifuges have been used widely for treatment of drain water on the large CONDEEP platforms, TLP's and jacket structures in the North Sea. The 3-phase disc stack centrifuge effectively breaks the emulsions present and recover a pure oil phase from the oily drains, while the deoiled water can be discharged overboard. Particulate matters travel through 5000 g's prior to being discharged from the centrifuge bowl and are thus free from oil. Fig. 24 shows performance of one such oily drains water treatment system.

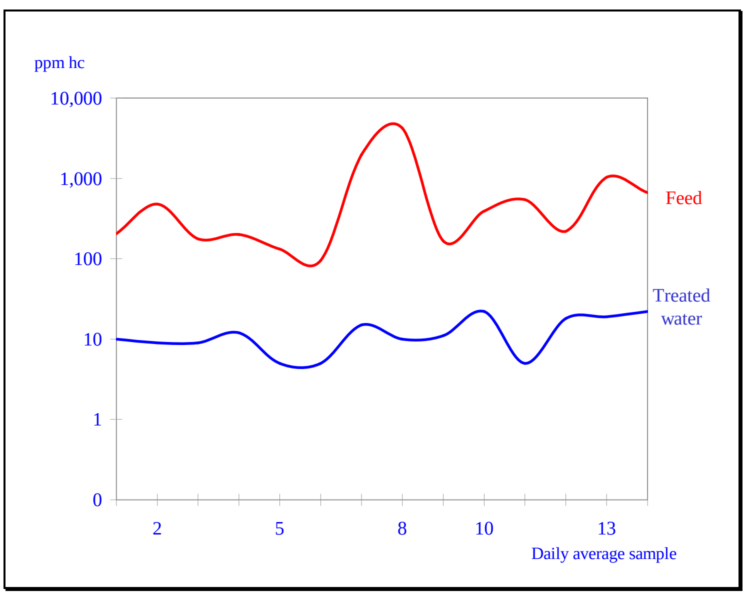

Fig. 24 Performance of an oily drains water treatment system.

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7. SUMMARY

Disc stack centrifuges have been used for deoiling of produced and / or process drain water at offshore platforms for about a decade. Considering that the disc stack centrifuge was invented in 1878, the disc stack centrifuge technology must be considered one of the oldest 'novel technologies' ever to be introduced to the oil field industry. A previous limitation for this technology was the limited size of the disc stack centrifuge bowl – however with the introduction of process centrifuges with 15,000 blpd capacity, this technology has become a realistic alternative to conventional treatment systems.

The installed systems have demonstrated that disc stack centrifuges are extremely effective in removal of small (as well as large) oil droplets from the oily water. Due to the internal design of the disc stack centrifuge, the separated oil droplets are coalesced into a continuous and concentrated oil stream, which can be returned to the main process without further treatment.

Considering the fact that the disc stack centrifuge does not require performance enhancement chemicals and that there is no reject stream from the centrifuge which require further treatment, the life cycle costs for a disc stack centrifuge system are very attractive.

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