9th Produced Water Workshop
18th & 19th May 2011

New Technology to Improve the Performance of Produced Water Separation Systems

Hugo Liebrand, CoalesSense BV
Eric Wals, Twin Filter BV

---

1 INTRODUCTION

In the production of hydrocarbons, water management has become an increasingly important area. The amount of produced water increases over time. This stresses the limits of current installations, which face a volume flow much higher than the original design capacity. Besides, the fluid composition may alter over time, leading to smaller oil droplets present in the water. Further, legislation concerning discharge is ever more tightened, and operators require efficient and clean technology. Recent developments to enhance the oil recovery, require better, more efficient and more effective separation technology.

To urge this need, *CoalesSense* and *Twin Filter* have developed a rotating coalescer, capable to significantly improve the oil water separation. The use of coalescers is a simple and effective way to improve current installed separation installations, and is hardly inevitable when designing new installations. The Dynamic Centrifugal Coalescer uses proven coalescing technology, combined with novel innovations, to further enhance produced water separation.

2 PRINCIPLE OF THE DYNAMIC CENTRIFUGAL COALESCER

The Dynamic Centrifugal Coalescer (DCC) uses the principles of centrifugation to enhance the separation of micron-sized phases from a carrier liquid. In particular, the DCC is used to increase the droplet size of oil in produced water. The difference in density between the fluids is the driving force in this process.

The core component of the DCC is a rotating element, as seen in figure 1. The element consists of many thousands of small channels, rotating at high velocity. In these channels, high G-forces drive micron-sized oil droplets to the channel wall, where they coalesce and form an oil film. This film builds up and, at the end of the channel, breaks up into large droplets. These large droplets, together with the rest of the fluids, are now available for separation downstream of the DCC. A novelty of the DCC is that the element is integrated in a multistage centrifugal pump housing, therefore combining fully proven pump technology with state of the art coalescing techniques. A more detailed description of the DCC product is given in the next chapter, whereas the working principles are described in detail in chapter 4.

2.1 History of the technology

The patented technology used in the DCC was introduced in the mid-nineties as a new technique for separating solids from gases and fluids [1]. Since this introduction, the principle of the DCC has found its way to market in various applications. The rotating element acted as an air cleaner in an application for domestic air purification. A multinational electronic consumer goods company used the element to remove air-borne particles which can cause respiratory allergic reactions to men in houses and offices. Another application concerns the collection of powders and particles from gases in food and pharmaceutical processes. Here, the stainless steel unit meets the strongest conditions on hygiene and cleaning.

A more recent development is the utilization of the technology in the oil & gas industry. The technology is used in a process called CRS, Condensed Rotational Separation, where CO_2 and H_2S are removed from sour gas fields to a level where the field can be economically exploited [2]. A rapid cooling or expansion of the sour gas initiates a phase-change of the CO_2 and H_2S from a gas to a liquid mist, consisting of sub-micron droplets. This mist is collected inside the channels of the rotating element, where after the clean gas is compressed again.

The latest application of the technology is in the DCC. The DCC integrates the CLSR Coalescer Pump, as developed by CoalesSense, on a skid and is Twin Filters latest addition to their oilfield separation equipment. The DCC technology just recently won the prestigious “Spotlight on new Technology” award at the OTC 2011 in Houston, USA [3].

Figure 1: DCC rotating element

3 DYNAMIC CENTRIFUGAL COALESCER SPECIFICATIONS

To create a large operating window for the DCC, different versions have been developed. Currently, the DCC-15 and DCC-30 are commercially available, and the DCC-45 nears completion.

The DCC-15 is designed for small volume flow rates up to some 500 bwpd (80 m^3/day), which makes it ideal for (gas) production facilities with a limited water flow. Furthermore, its compact size and weight allows for quick installation for testing purposes, either full-scale or on a side stream.

The DCC-15 is incorporated in a vertical multistage pump. It uses the pumps plain bearings, mechanical seal and coupling. The housing material is AISI 316, although other materials are available. The standard model DCC-15 has a 25 bar pressure rating. It has a floor space of about 30 x 30 cm with a height of about 1 meter. Including the motor, the unit weighs around 50 kg. It uses a 1.1 kW Exd three phase motor.

The DCC-30 covers a larger volume flow range, up to around 6,000 bwpd (1000 m^3/day). The DCC-30 uses a horizontal multistage pump as a house, and also uses the pumps bearings, seals, couplings and flanges. It has a cast-iron, AISI 316 or (super)duplex casing, standard rated to 40 bar. It has a 2 square meter footprint (including motor) and weighs around 850 kg. It has a 11 kW Exd three phase motor.

Finally, model DCC-45 is designed to deal with some 12,000 bwpd (2,000 m^3/day). In figure 2, two of the models are depicted without the skid and accessories.

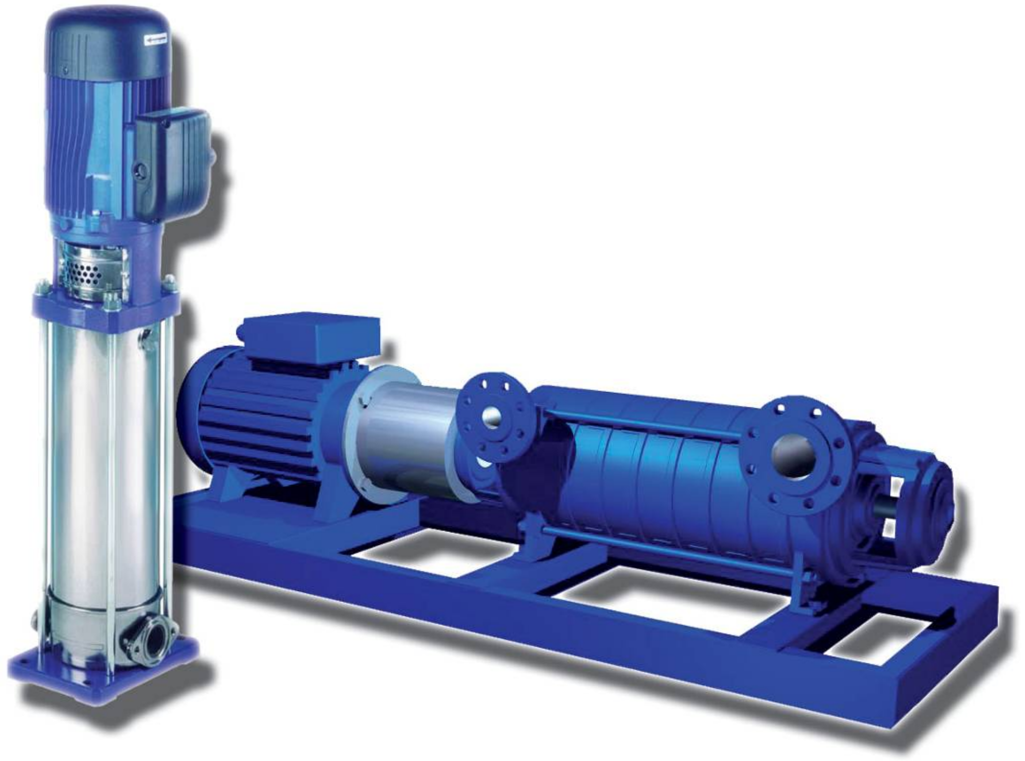

Figure 2: Model DCC-15 (left) and DCC-30 (stripped from skid)

3.1 Internals

The rotating element, the heart of the DCC, consists of an array of axially oriented small tubes, potted in epoxy resin (see also figure 1). The element has a length and outer diameter of respectively 170 mm and 150 mm for the DCC-15, and 700 mm and 300 mm for the DCC-30.

The tubes of the element are standard 1,4 mm in diameter and are made from stainless steel AISI 316. Optional, tubes are made from a special PTFE (Teflon). This proved to be extremely non-stick and is therefore an ideal option when the risk of plugging is present (high solids content). For difficult applications, the tubes can also be chosen smaller in size. For PTFE tubing, the tube diameter can be lowered to 0,7 mm.

4 DYNAMIC CENTRIFUGAL COALESCER TECHNOLOGY

Inside the DCC, two processes influence the result of the coalescing action. First, the size of small oil droplets that are collected, and second, the size of the large oil droplets created. Obviously the goal is to capture droplets as small as possible, and to create droplets as large as possible. Both processes are well understood and follow basic laws of physics. Theoretical calculations of these processes therefore largely correspond with results for experiments.

4.1 Collecting efficiency

When the fluid enters the rotating element, it co-rotates with the element and flows axially through the channels. The oil fraction, present as droplets, is assumed to follow the bulk flow of the water, except for the radial movement induced by centrifugal forces. The equilibrium between the centrifugal, buoyancy and drag forces according to Stokes' law determines the resulting radial droplet velocity of the droplet.

A value for the size of the droplet that is collected with a 50% efficiency is given by $d_{50\%}$:

$$d_{50\%}^2 = \frac{13.5\mu_w d_c \phi}{\Delta\rho\pi L(1-f)(R_o^3 - R_i^3)\Omega^2} \tag{1}$$

Where: μ_w : dynamic viscosity of water [kg/ms]
d_c : diameter of the channels [m]
ϕ : volume flow [m^3/s]
$\Delta\rho$: oil – water density difference [kg/m^3]
L : length of channels [m]
f : area reduction factor [-]
$R_{o,i}$: outer / inner diameter of the element [m]
Ω : angular velocity of the element [rad/s]

For two of the models of the DCC, the DCC-15 and DCC-30, some resulting droplets sizes are given in figure 3. In these calculations, a water viscosity of 1 cP and a density difference of 175 kg/m^3 are used. The dimensions used in the calculations correspond to the dimensions given in chapter 3.

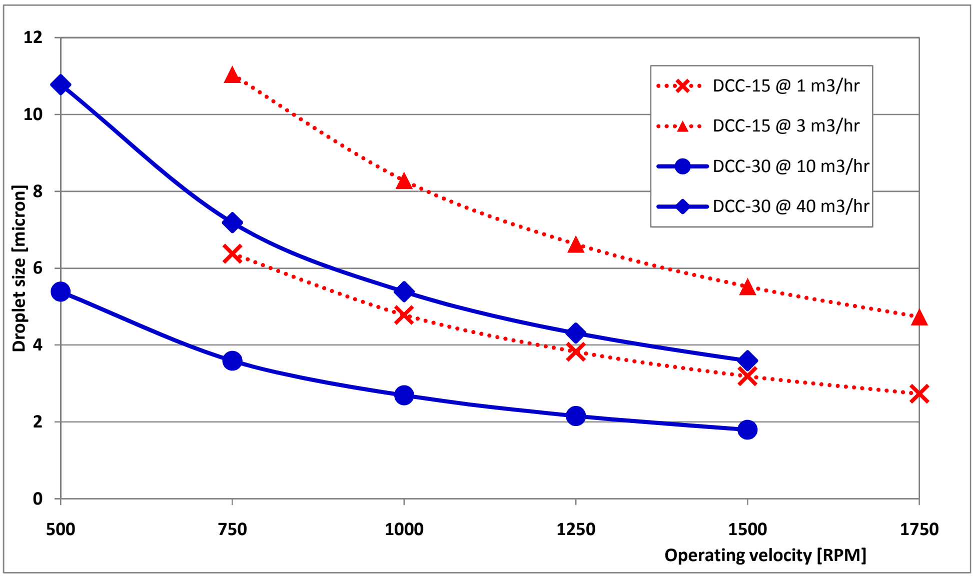

Figure 3: Theoretically collected droplet size for DCC-15 and DCC-30.

As shown in this figure, both models are easily capable to separate 50 percent of the oil droplets down to 5 micron.

4.2 Droplet creation

As the droplets hit the channel wall, the adhesion with the channel and cohesion with other droplets prevents the droplets form re-entering the bulk water flow. Droplets coalesce, and form a thin layer on the channel wall closest to the axis of rotation. The Poiseuille flow pattern inside the channel and the no-slip condition at the channel wall ensure liquid film to flow gradually forward, with a lower velocity as the bulk water. This ensures a certain hold-up, where more droplets can be added to the film, thus growing further in size.

At the end of the channel the film breaks up, and oil chunks are released into the water. These newly created droplets are much larger than the droplets captured. A theoretical description of the droplets that are created is given by $d_{break-up}$:

$$d_{break-up} = \sqrt{\frac{6\sigma}{\Delta\rho\Omega^2 R}} \tag{2}$$

Where: σ : interfacial tension oil-water [N/m]
R : radius where breakup occurs [m]

Important in this process is the interfacial tension between the water and oil. In practical cases, this value is hardly ever known, making a valuable prediction of the size of the droplets a stretch. Furthermore, after the newly created droplets re-enter the water downstream of the element, large droplets will again be disrupted. Shear forces, inevitable in a rotating flow, will reduce the droplet size again. Much effort is given to create a low-shear chamber after the element, where shear is minimized to prevent this effect as much as possible.

Continuous improvements of this chamber are examined. Currently, in cooperation with the Eindhoven University of Technology, the Netherlands, a three-dimensional computational fluid dynamics (CFD) model is examined with Fluent. With pre-processor Gambit, multiple meshes of different version of the exit chamber are created. Results of this study, available this summer, will be used to further optimize this chamber.

Another noteworthy point in the effect of capturing and creating droplets is the fact that the angular velocity counteracts both desired results. A higher angular velocity –rpm of the element- leads to the collection of smaller droplets. A lower velocity on the other hand leads to the creation of larger droplets. A tradeoff between these two effects is required. In practical applications, the latter effect is of less importance, as downstream separators do not require droplets of over hundred microns to function duly.

5 PERFORMANCE IMPROVEMENT

During the design period of the first demo DCC, extensive lab testing has been done on the sizes of the droplets captured and created. These data have been used for further improvement of the design. With the final units, a DCC-15 and DCC-30, trials have been performed with multiple companies / OEMs, on different separators, such as a CPI, Filter cartridges, hydrocyclones and gravity separation vessels. The specific case of the performance improvement realized with the combination of the DCC and a hydrocyclone is discussed in section 5.2.

5.1 Validation with droplet sizing techniques

A large scale test setup was built in Tilburg, the Netherlands, to test the DCC-15 and DCC-30. Schematic overviews of both setups –which correspond to great extend- are given in figure 4 and 5.

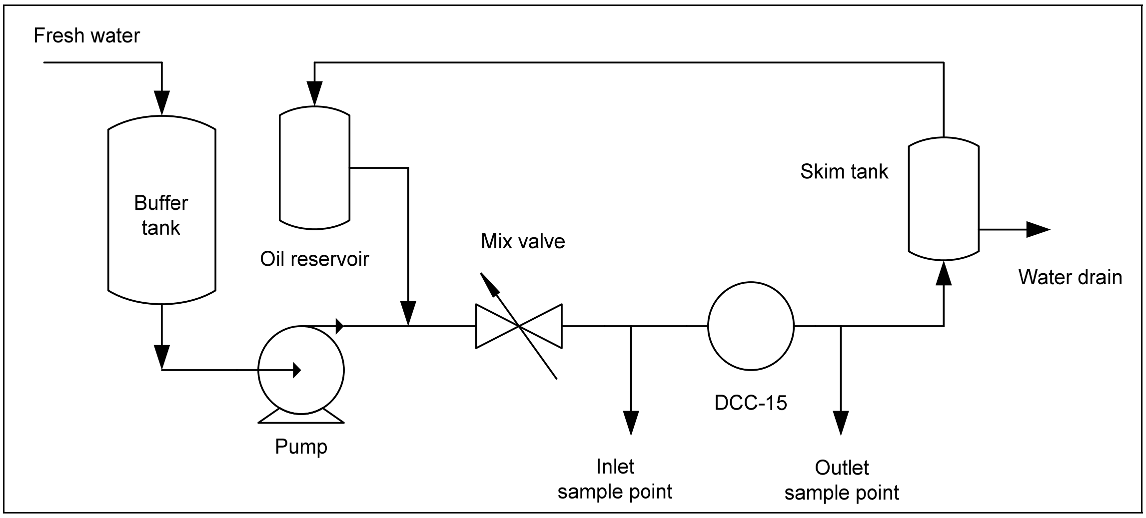

Figure 4: Schematic test setup DCC-15

The DCC-15 test facility allowed for single pass testing, thus constantly using fresh water with new oil added to the water. A pump and a mix shear valve were installed to create a suitable pressure drop to disrupt droplets to a defined size. Oil was freshly injected and emulsified with this pressure drop. Different mineral oils were used to test the DCC. Two isokinetic sample points were present, before and after the DCC.

The DCC-30 test facility was equipped with two 3 m3 buffer tanks, allowing for loop testing of the DCC. Again, isokinetic sample points were present before and after the DCC. Oil was either freshly injected, or re-emulsified with the pump and mix valve.

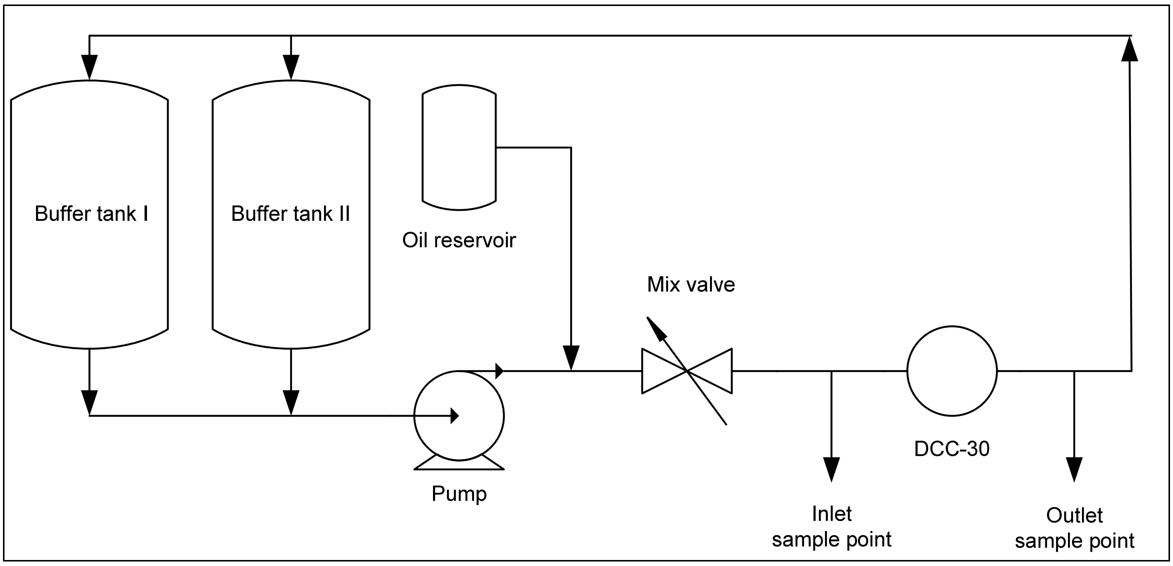

Figure 5: Schematic test setup DCC-30

To determine the droplet size distribution of the oil, a Malvern Mastersizer S was used in both test facilities. The Mastersizer uses laser diffraction techniques to measure particle sizes. The Mastersizer was connected to the sample point from which the emulsion was led to the Mastersizer flow cell.

With different flow rates, oil type, oil concentration, shear pressure drop and operating velocity of the DCC, an operating performance matrix was created. The rapid response time of the Mastersizer allowed for the precise and reproducible creation of a desired emulsion on the inlet of the DCC, where the emulsion created after the DCC could be easily referenced to other operating conditions. This gave valuable feedback on the operating conditions and helped us in further improving the design and thus the performance of the DCC.

In figure 6, a typical droplet size distribution is presented of the DCC-15. In this case, the DCC-15 operated with a flow rate of 1,5 m^3/hr at 1500 rpm. Fresh water was used (no added salt) and a natural oil with a specific gravity of 0,891. The DCC-15 was equipped with 1,4 mm stainless steel tubes.

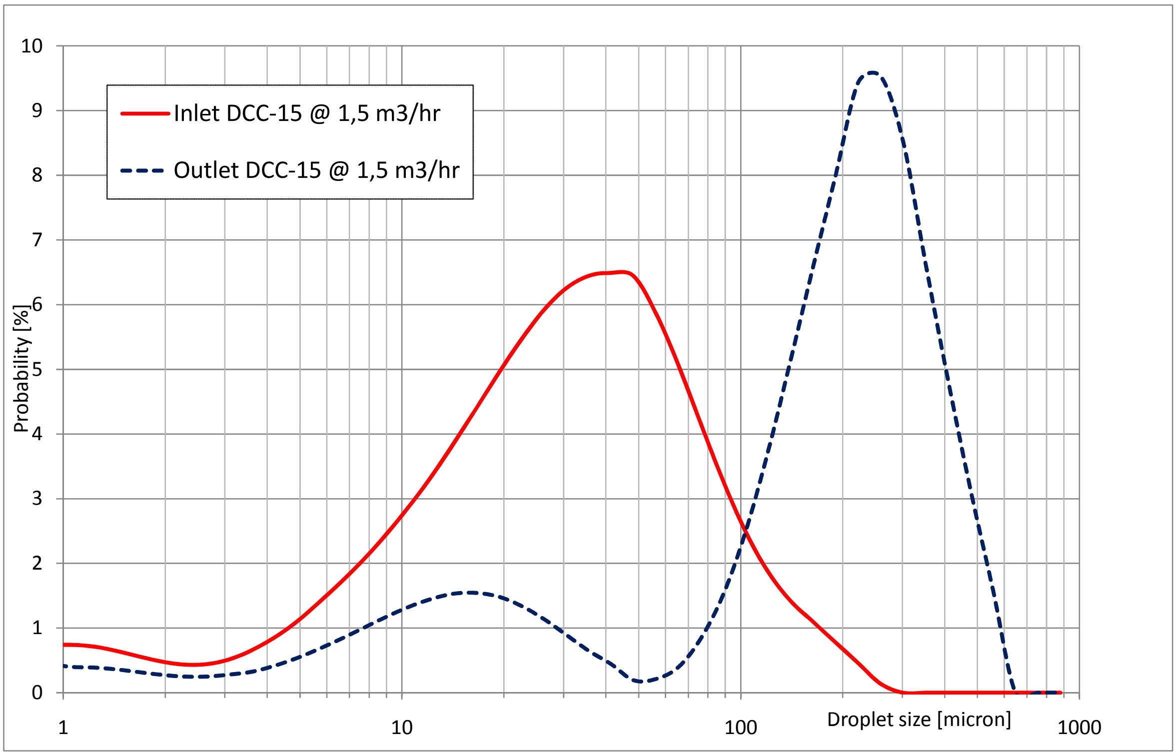

Figure 6: Measured droplet sizes before and after the DCC-15

5.2 Improvement of Hydrocyclone performance

In February 2011, a two week test was done with a major oilfield service company in the USA. Goal of the test was to evaluate the performance improvement of hydrocyclones with a DCC-15 installed upstream.

The test facility was equipped with a large 4 m^3 Oil-Water Separator (OWS), used as a buffer tank. Downstream of the water pump, located at the water outlet of the OWS, the oil was pumped from the OWS into the water. Two precise needle valves were used to create a pressure drop and ensured a suitable oil-in-water emulsion. Aim was to create an inlet oil in water emulsion with an average oil droplet diameter of around 20 micron.

The water was then either directly led through a hydrocyclone, or through the DCC-15 and then through the hydrocyclone. The over- and underflow of the hydrocyclone were put back in the OWS.

Samples of the inlet of the hydrocyclone and the underflow were analysed for oil content, and constant droplet size measurements were done with the Malvern Mastersizer, and with a Canty Oil in Water Analyser. A schematic of the test setup, along with some parameters, is depicted in figure 7 and table 1.

Table 1 – DCC – Hydrocyclone test loop parameters

Test loop parameter	Value
Volume flow rate	~ 1,5 m^3/hr
Average inlet concentration	800 – 1100 ppm
Average HC inlet pressure	2,3 bar(g)
DCC-15 internal	0,7 PTFE and 1,4 PTFE
DCC-15 rpm	1200 - 1800; 1500 average
Mean droplet size at inlet	15 – 25 micron
Sample point I	Connected to Mastersizer
Sample point II	Connected to Mastersizer / concentration measurements
Sample point III	Concentration measurements
Crude type	22 °API

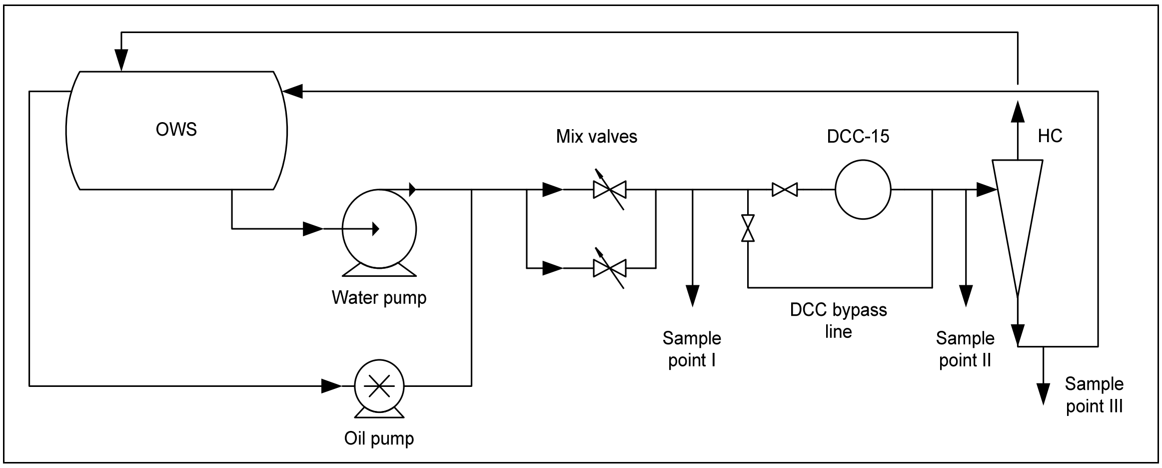

Figure 7: DCC - Hydrocyclone test setup at test facility in USA.

5.3.1 Results of hydrocyclone tests

The tests showed a reproducible performance improvement of the hydrocyclone of over 50 percent. In table 2, the inlet and underflow concentrations of the hydrocyclone are given with and without the DCC present. Typically, the resulting oil concentration in the underflow was over 50 percent lower when the DCC was installed upstream. In figure 8, a droplet size distribution from the Mastersizer (corresponding with run 3) is given. The mean oil droplet size in the inlet over the hydrocyclone was increased from 25 micron without the DCC, to 70 micron with the DCC. Thus, when the inlet oil distribution (solid line) is presented to the hydrocyclone, it removes 39% of the oil. When the DCC is used, the distribution is changed to the dashed curve, and the hydrocyclone as a result collects 72% of the oil.

In figure 9, the difference in water quality is clearly visible. From the left, the samples are: the underflow of the hydrocyclone with the DCC; the underflow of the hydrocyclone without the DCC; the inlet of the hydrocyclone.

In an added test to simulate a longer DCC element, two DCC-15 units were placed in series upstream of the hydrocyclone. In this case (run 4), the removal efficiency improved from 29% to 84%.

The results from these tests showed an opportunity to increase the performance of a hydrocyclone bank to a level where a (final) downstream separation step, such as a gas flotation unit, can be omitted. Currently, investigations are done to find the optimal combined use of the DCC and hydrocyclone to make the hydrocyclone the last polishing step in the water separation train.

Table 2 – DCC – Hydrocyclone test loop results

Run	DCC mode	Inlet con. [ppm]	Underflow conc. [ppm]	HC removal
1	Bypassed	962	573	40 %
	DCC at 1500 rpm	1046	328	69 %
2	Bypassed	756	421	44 %
	DCC at 1500 rpm	847	195	77 %
3	Bypassed	855	523	39 %
	DCC at 1500 rpm	889	251	72 %
4	Bypassed	1096	780	29 %
	2x DCC at 1500 rpm	996	174	83 %

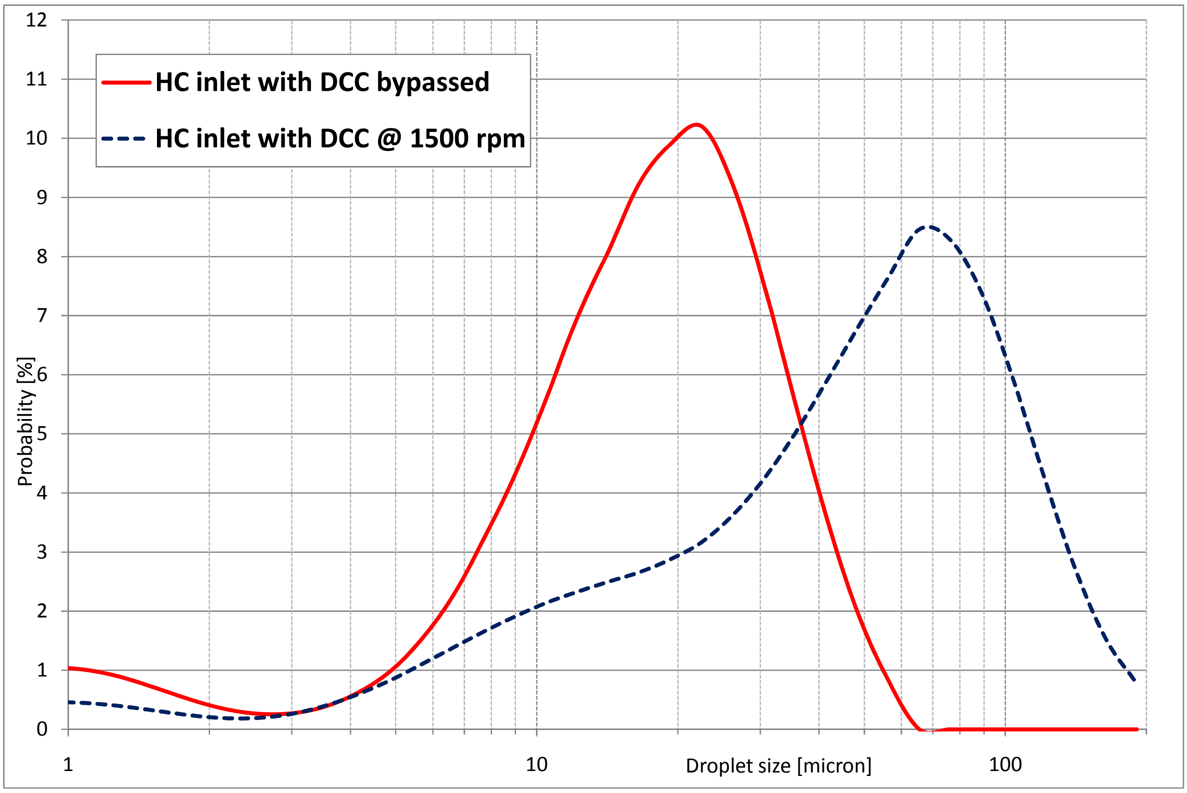

Figure 8: Droplet sizes with and without DCC

Figure 9: Samples: Underflow with DCC / underflow without DCC / Inlet of HC.

6 ADVANCED SEPARATION

With the DCC being capable to separate droplets down to a size where traditional equipment does not work, lots of interest focuses on (future) separation problems, where current separators struggle to meet specifications.

6.1 Case study I: chemically stabilized produced water

The use of corrosion inhibitors injected in the production stream leads to a different chemical composition of the produced water, and interferes with the interaction between oil and water. In the North Sea, where condensate is co-produced in the production of natural gas, platforms suffer from an altered interfacial tension between the condensate and water. This results in a chemically stabilized emulsion, consisting of very small (1-10 micron) condensate droplets.

Not only does it require a very long time to separate these small droplets, the low interfacial tension prevents droplets to remain stable once coalesced. Only a slight disturbance of the condensate recreates the original emulsion.

Tests have shown that with the use of a demulsifying agent (CEFAS registered) the chemical components which change the interfacial tension can be effectively counteracted. This leaves the condensate still as very small droplets, but with the possibility to remain stable once coalesced. The DCC is than capable to enlarge these droplets to a level where current installed separators can easily remove the condensate to a required level.

A large test with a DCC-30 on a North Sea gas production platform is planned early this summer.

6.2 Case study II: Enhanced Oil Recovery

A hot issue within the field of produced water is the removal of oil from produced water with a higher viscosity. Polymer flooding techniques are used to increase the production of crude oil. This results in (much) larger oil production, but has a negative effect on the separation possibilities of the produced water. Current conventional techniques are not or insufficiently capable to remove the oil.

Although the DCC follows the same separation principles (Stokes' law) as many current separators, it initially is capable to separate smaller droplets, up to an order of magnitude. This raises questions whether an upstream DCC would restore the separation capabilities of the current installations.

With a supermajor, a large scale polymer water test with a DCC-15 and several downstream separation techniques is currently being planned.

7 FUTURE WORK

In the coming months, Twin and CoalesSense will perform abovementioned tests on both chemically stabilized production water and polymer water. Furthermore, both field and lab test on (conventional) produced water are aligned for the near future. Test will take place in the North Sea, continental Europe, Africa, and the United States.

The production of the DCC-45 nears completion, and is expected to be ready for an in-house test this summer. The unit will be commercially available as of Q3 this year.

Developments to utilize the DCC more upstream in the production process are underway. Together with a partner, a high-pressure version of the DCC is currently being designed.

8 REFERENCES

[1] J.J.H. BROUWERS. Phase separation in centrifugal fields with emphasis on the rotational particle separator. Experimental Thermal and Fluids Science 26 (2002) 325-334.

[2] G.P. WILLEMS, M. GOLOMBOK et al. Condensed rotational separation of CO2 from natural gas. AIChE Journal (2010): Chemical Engineering Research and Development, 56(1), 150-159.

[3] http://www.otcnet.org/2011/pages/general/awards.php