Rotational Phase Coalescing

How to get more miles out of your IGF or hydrocyclone

Paul Schouten, Michiel Arnoldy, Hugo Liebrand
Cebo Fluid Treatment
Westerduinweg 1, 1976 BV Ijmuiden, The Netherlands
Tel: +31 255 546 262, Email: info@cebo-ft.com

Introduction

In the production of hydrocarbons, water management has become an increasingly important area to the oil industry. As a well matures, the amount of produced water increases; water-cuts can easily reach 90%. Conventional facilities alone are not capable of handling these increased water flows. Furthermore, the challenge for cleaner water for re-injection or disposal puts even more pressure on the conventional approaches. Main concerns for producers therefore are that production facilities should not only be capable of handling larger volumes of water, but also that the water quality for re-injection or disposal meets high standards. A new promising technique in this light is the Rotational Phase Coalescer. Without requiring complete new facilities, the Rotational Phase Coalescer can get more miles out of conventional techniques.

Principle of the Rotational Phase Coalescer

The Rotational Phase Coalescer (RPC) is a new method exploiting the principles of centrifugation to enhance the separation of micron-sized phases from a carrier liquid. In particular the RPC is used to separate residual oil from produced water.

The core component of the patented RPC is a rotating filter element (figure 1). The element consists of thousands of small channels, typically 1,5 mm in diameter and 200 mm in length, rotating at high velocity. In these channels, under influence of high G-forces, micron-sized oil droplets are driven to the inner channel wall, where they coalesce into a liquid film. This oil film builds up and, at the end of the channel, breaks up into large droplets. These large droplets are now available for separation downstream of the RPC filter element.

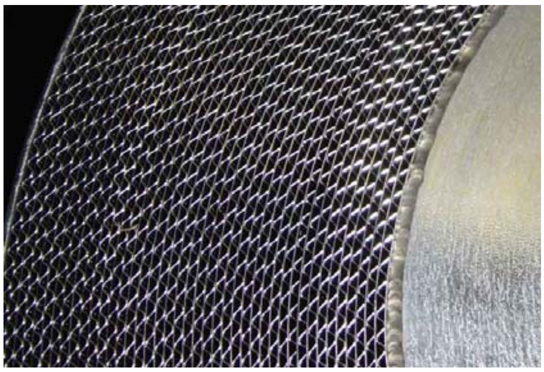


Figure 1: Filter element

The key advantage lies in the size and number of channels. Each of the thousands channels act as a small centrifuge. A very small channel diameter (1,5 mm) allows for a very compact channel length (200 mm), while droplets in the micron range are separated. The number of channels (several thousands) furthermore allows for a high throughput.

The technology of the RPC was introduced to the market in the mid-nineties, as a new technique for separating solids from gases and fluids. Since this introduction, the principle of the RPC has found its way to market in various applications, such as domestic air purification, recovery of powders and particles in food and pharmaceutical processes and the filtering of gases from combustion and gasification processes. A major advantage is that the filter element can be completely made of stainless steel, which allows it to operate at high temperatures, meet the strongest conditions on hygiene and prevent corrosion.

A more recent development is the utilization of the RPC in the oil industry. Projects in separating CO2 and H2S from natural gas and in de-misting of natural gas are underway, while the current project, focussing on coalescing dissolved oil droplets from water, has reached the stage of market introduction.

Through its design, the RPC can coalesce oil droplets as small as 5 micron from water at only 1500 revolutions per minute to droplets of 200 micron. As the filter element is only very small, the RPC is compact in size and weight while capable of handling large volumes of water.

Demo unit RPC

A full-scale demo unit of the RPC was build and lab-tested in 2007. The unit is shown in figure 2. The test unit is designed to operate with a volume flow of 20 m3/hr, while rotating at a design speed of 1500 rpm. The demo unit is built in a pressure vessel, allowing for pressures up to 30 bar.

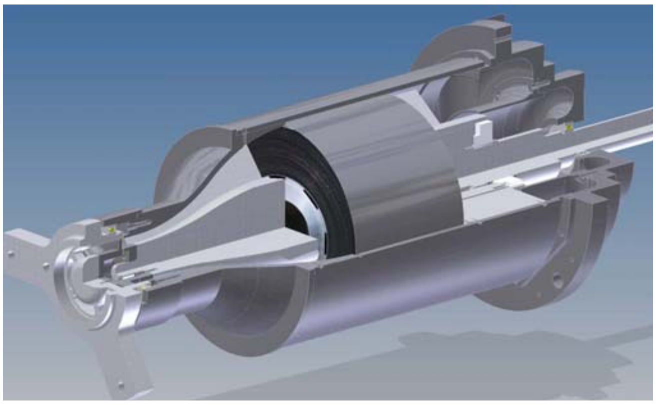


Figure 2: Demo unit Rotational Phase Coalescer

Inlet and pre-separator

At the inlet of the RPC, the water is brought into rotation with a swirl generator. This static element accelerates the fluid to the desired angular velocity. Hereafter, the fluid enters the pre-separator. The function of this separating chamber is twofold. It adjusts the flow to allow a smooth entry of the filter element, and any solid particles are separated to prevent clogging of the filter element.

Filter element

In the filter element, droplets are centrifuged to the wall as described above. Oil droplets hit the stainless steel wall of a channel and coalesce into a film. The water flows through the filter element, while the oil film thickens and moves downstream. Once at the end of the channel, the film breaks-up into droplets under the influence of centrifugal forces.

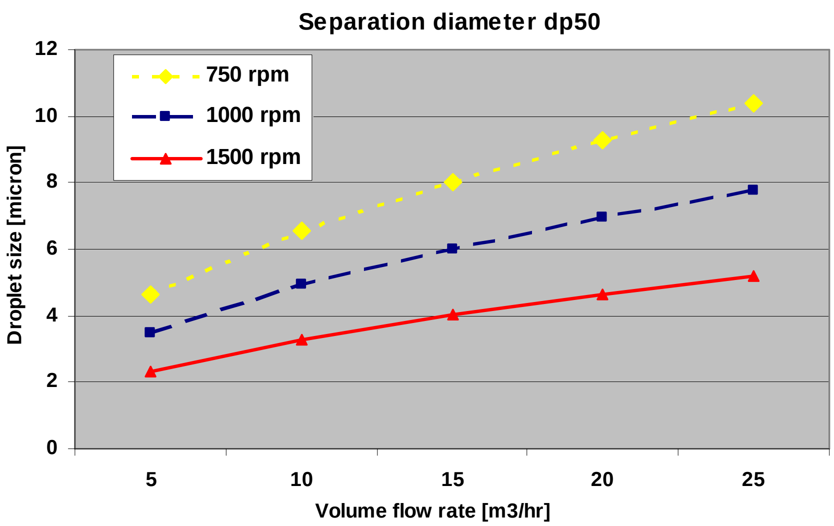
Both the process of separation in the filter element and the break-up of the film at the end of the element are well understood and tested. For separation, the minimum size of the droplets which are separated with a 50% possibility (dp_{50}) is described by:

$$dp_{50} = \sqrt{\frac{9\sqrt{2}\mu_w d_c \phi}{\pi(\rho_w - \rho_o)\Omega^2 L(1-\varepsilon)R_o{}^3 \sqrt{(1+\delta^2)}(1-\delta^2)}} \qquad (1)$$

Where:

	μ_w	: dynamic viscosity of water [Pa s]
	d_c	: channel diameter of filter element [m]
	ϕ	: total volume flow [m3/s]
	$\rho_{w,o}$	: mass density of water, resp. oil [kg/m3]
	Ω	: angular velocity of filter element [rad/s]
	L	: length of filter element [m]
	ε	: area reduction factor (value of 0.1) [-]
	$R_{o,i}$	: outer resp. inner radius of filter element [m]
	δ	: filter dimension ratio R_i/R_o [-]

In the test unit, with fixed dimensions d_c = 1,5 mm; L = 200 mm; R_o = 300 mm and R_i = 150 mm, important parameters as volume flow and rotational velocity can be altered. For typical produced water conditions, several graphs of the filter element are plotted in figure 3 below.



Media properties:

μ_w = 1e-3 Pa s

ρ_w = 1050 kg/m3

ρ_o = 900 kg/m3

Figure 3: Separation diameter dp_{50} at different flow rates and velocities.

It is seen that with a flow of 20 m3/hr and a filter velocity of 1500 rpm, oil droplets with a dp_{50} of 4,6 micron are separated in the filter element. A cumulative probability plot of the separated droplets is made at these conditions; the efficiency curve is shown in figure 4. Here it is seen that droplets of 9,3 micron and larger are completely separated in the filter element.

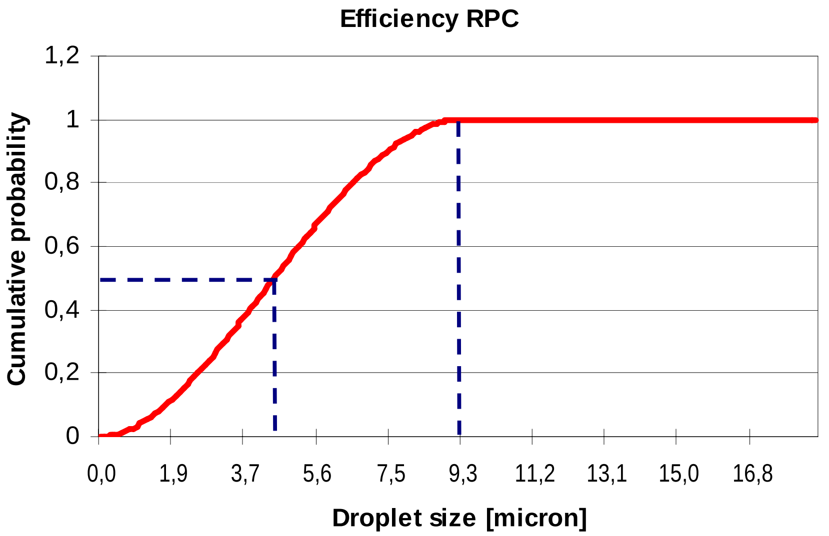


Figure 4: Efficiency of the filter element at 20 m3/hr and 1500 rpm.

The process of the break-up of the film at the end of the channel is also well understood. Here, the equilibrium between surface forces and centrifugal forces determines the minimum size of the droplets created after break-up. This droplet diameter $d_{break\text{-}up}$ is given by:

$$d_{break-up} = \sqrt{\frac{6\sigma}{(\rho_w - \rho_o)\Omega^2 R}} \qquad (2)$$

Where: σ : interfacial tension between oil and water [N/m]

R : radius where droplet break-up occurs [m]

As rotational velocity is the only adjustable condition that influences break-up, droplet sizes are easily calculated. In the calculations, σ = 0,020 N/m and R = R_o = 150 mm. For velocities of 750, 1000 and 1500 rpm, the break-up droplet diameter is 465, 349 and 232 micron respectively. For the standard operating conditions (1500 rpm, 20 m3/hr) as shown in figure 4, the droplets are enlarged 25 times, from 9,3 to 232 micron. Theoretically, the velocity can be raised up to 7000 rpm while the resulting break-up droplet diameter is still 50 micron. However, further break-up of the droplets downstream of the droplets does occur, so caution must be taken to minimize this.

Post-separator

In the demo unit, a coarse centrifuge-like separator is used as the separation chamber. After the filter element, the newly formed droplets enter this post-separator. This separation chamber works as an axial centrifuge and is entirely filled with fluid. The large oil droplets are collected around the axis of the RPC while the pre-cleaned water is forced to leave the RPC at the outer radius. This water is then available for further separation in conventional installations such as plate pack separators, IGF installations or hydrocyclones.

In the post-separator, special measures are taken to minimize secondary flows and turbulence, as they disrupt droplets and disturb the separation process. At the outlet, the heavy phase consists of purified water with a minor component of residual oil; the lighter phase consists of an dispersion of oil and water. In this dispersion, the oil is generally present as very large droplets, allowing for easy recovery of this "waste" oil.

Performance and efficiency

Cebo Fluid Treatment has made a software program available to predict the performance of the RPC. Depending on the actual conditions of the produced water, such as the amount of oil and the oil droplet size distribution, the performance of the demo unit can be predicted based on real cases. Otherwise, this program is used as a design tool to determine size and operating conditions when certain performance is requested.

With this program, the performance of the demo unit as shown in figure 4 (20 m3/hr and 1500 rpm) is presented with a typical produced water inlet concentration of 200 ppm and a representative oil droplet size distribution (lognormal; mean $\mu = 34$ micron; standard deviation $\sigma = 2$.) As was shown in figure 4, the demo unit is capable of coalescing droplets larger than 9,3 micron to droplets of 232 micron and above, and reducing oil content from 200 ppm to 6,3 ppm. This is shown as the coloured area under the distribution curve in the figure.

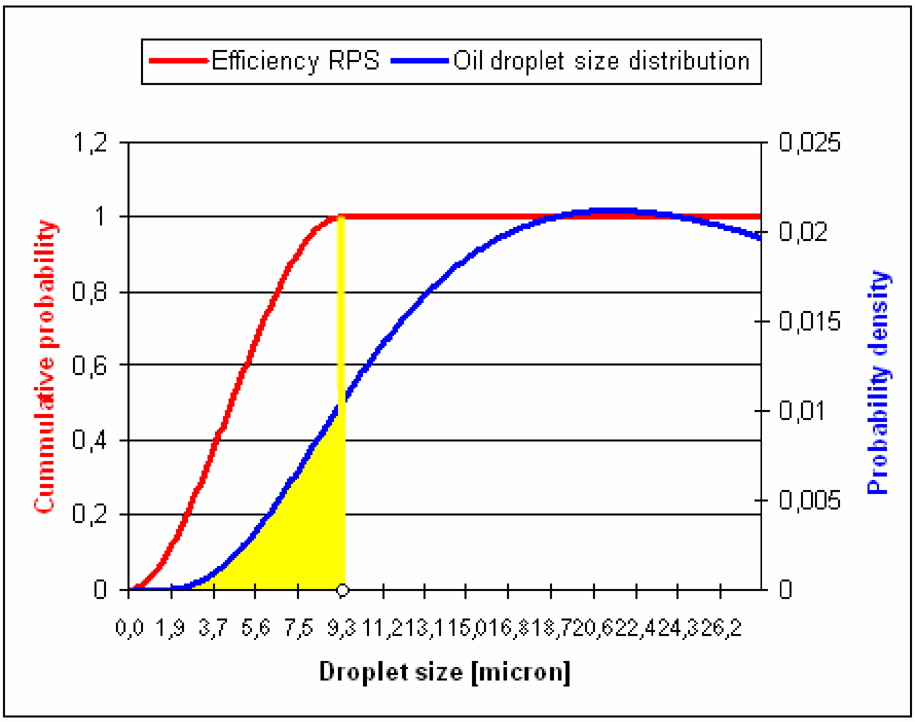


Figure 5: Efficiency with oil droplet size distribution.

Full-scale lab test

Prior to full-scale testing at production locations, the demo unit was extensively tested at Cebo Holland B.V. in Ijmuiden, the Netherlands in October 2007. The test facility was equipped with two 30 m3 buffer tanks allowing for continuous operating of the RPC and a precise oil-injection system combined with a disrupting mechanism to create the desired oil cut and oil droplet size. In addition to test with the RPC as a single separation unit, a Facet Industries high efficient patented M-Pak® coalescing plate separator has been connected to the water outlet.

Tests were performed with a clean water volume flow between 10 and 20 m3/hr, oil inlet concentrations adjustable from 50 to 300 ppm, and motor velocity ranging from 750 to 1000 rpm. Limitations of the motor at that time did not allow for testing at the design velocity of 1500 rpm. Iso-kinetic sample points were available to take samples from the flow to determine the oil content. The samples ware taken at the inlet, prior to entry of the RPC, and at the heavy phase (clean water) outlet. The samples were analysed for oil content (hexane-extraction) at OMEGAM Laboratoria in Amsterdam, The Netherlands.

Results

The test results are shown in the table below. The tests can be divided in several parts. In the first series (test 1 to 5), the RPC was utilized as a single, standalone separating unit, with a focus on achieving a low oil concentration in the water outlet. These tests showed promising results, with an average inlet oil concentration of 70 ppm and outlet concentration of 4 ppm. It also showed that the influence of filter element velocity is small.

In the second series (6 and 7), the influence of different settings such as droplet size and flow split was tested. It confirmed that with smaller droplets at the inlet, the outlet oil concentration rises. Further, higher inlet concentrations resulted in lower performance. Again, influence of velocity is only small.

The third series (8 and 9) were performed with the Facet plate separator connected to the water outlet of the RPC. Only part of the water outlet flow was connected to the plate separator, as it was designed to have a volume flow of 1 m3/hr maximum. The tests were performed with a volume flow rate of 750 l/hr through the plate separator. It showed good results, as oil concentrations after the plate separator are very low.

Several other tests have been conducted with the RPC as well. The reproducibility of the RPC was tested and proven, as shown in test 1 to 5. Reliability and durability of the system were tested throughout the test period of three weeks and gave good results, and visual inspection of the filter element showed no sign of clogging.

From the results, it can be concluded that the actual performance of the filter element follows the theoretical performance. The RPC reduces the oil content in the water by more than 90%, while at the same time creating water with large oil droplets available for downstream separators.

Test	Configuration	Volume flow rate [m3/hr]	Filter velocity [rpm]	Oil conc. inlet [ppm]	Oil conc. outlet [ppm]	Oil conc. outlet Facet separator [ppm]
1	Single RPC	16,8	1000	**61**	**3,6**	-
2	Single RPC	16,8	750	**62**	**2,8**	-
3	Single RPC	18,5	1000	**68**	**5,7**	-
4	Single RPC	18,5	1000	**68**	**3,1**	-
5	Single RPC	20,3	1000	**93**	**4,7**	-
6	Single RPC, smaller oil droplets at inlet	21	750	**48**	**7,1**	-
7	Single RPC, high flow through oil outlet	19,5	750	**63**	**5,0**	-
8	RPC, Facet separator at water outlet	16,8	750	**120**	**-**	**2,4**
9	RPC, Facet separator at water outlet	18,5	750	**85**	**-**	**3,2**

Table 1: Test results demo RPC Ijmuiden 2007

Field test at LUKOIL, Ploieşti, Romania

As part of a large oil recovery and cleaning operation, the RPC was field tested in November 2007 in Ploieşti, Romania. The RPC was connected to the outlet of a settling tank, with water contaminated with, among other things, iron-oxide and dissolved and dispersed oil. The RPC was utilized as a stand alone separator, as well as a coalescing unit upstream of the Facet plate separator. Unfortunately, no exact date of these tests have become available, although similar results as in the lab test were seen.

Future outlook

The Cebo Fluid Treatment RPC is ready for market introduction. Combined with downstream separators, tests will be conducted to improve processes involving extraction and separation with IGFs, plate pack separators, hydrocyclones and more.

The RPC demo unit is available for testing at on- and offshore production locations in the USA as of February 2008.

Conclusions

Tests with the Rotational Phase Coalescer have shown that it can be a valuable addition to current produced water treatment installations. Firstly, in all cases the RPC achieved a minimum of 90% reduction in dispersed oil content, while at the same time offering water with large droplets to downstream separators.

With the RPC demo unit operating at design conditions, droplets larger than 4,6 micron are separated with a 50% probability and coalesced into droplets of 230 micron and larger. Droplets are enlarger up to 25 times in the filter element.

- With only very small radial distances to cover, even micron sized oil droplets are separated
- Thousands of channels each function as a small centrifuge, resulting in high throughputs while maintaining a high efficiency
- Dispersed oil droplets are enlarged up to 25 times
- Oil content reduction of over 90% achievable
- Advanced design of the inlet and outlet of the RPC minimizes shearing of oil droplets
- Large operating window up while maintaining a constant high efficiency
- Possibility to separate solids and heavy particles prior to the filter element