Title

"On-line determination of particle size and concentration (solids and oil) using ViPA Analyser - A way forward to control sub sea separators"

Authors

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Abstract

This paper presents the results of recent development work using Merpro's oily water test loop, an on-line particle size analyser (Jorin's ViPA unit), an industry accepted on-line oil monitor (Rivertrace unit), and solvent extraction / spectrophotometry technique (Wilk's Infracal unit).

The results form these tests showed that the ViPA analyser, not only is capable of measuring oil and solids size distribution in a water continuous stream but also determines their respective concentrations separately by differentiating between each phase dispersed in water.

The ViPA analyser was also found to be a useful tool when characterising the oil removal properties of US Filter Liquid / Liquid hydrocyclone and coalescing behaviour of various media.

Further development work is currently underway to utilise ViPA analyser as a control device for sub sea separators with a view to a better fluid management and enhance oil production.

Objectives

One of the aims of this work was to investigate the possibility of using ViPA analyser to establish oil concentration (ppm of oil in water) along with its primary function of measuring oil droplet size distribution.

The second aim was to determine deoiling characteristics of US Filter liquid / liquid hydrocyclone separator utilising ViPA image analyser and Rivertrace oil monitor (both on line devices). It was originally hoped to generate a "user friendly" computer code to predict the hydrocyclone oil removal performance given certain process and physical parameters.

The third objective was to establish the oil droplet coalescing properties of various units using ViPA unit on line.

Introduction

The ViPA was developed to provide valuable process information such as size distribution and concentration for both oil droplet and solids particles. This together with a knowledge of trend data allows the operators to understand and properly control their unit operations.

One of the areas where ViPA unit can be of great benefits is the produced water re-injection systems. For instance, it could be scenarios where the oil concentration is well within the acceptable injection level, but the oil droplet size is large and could cause injectivity problems.

It seems there is not any compact and robust particle size and concentration monitor in the market for sub sea application. Therefore, it transpired that an instrument such as ViPA could be integrated as part of the topside and sub sea separator control system to manage and enhance oil production.

Test Loop

An oily water test loop was constructed in Merpro's pilot plant facilities. The test loop was purpose built to take on-line representative oily water samples from the process flow lines. The test loop was designed in the recycle mode in order to minimise cleaning up of large volumes of oily water and conduct the test runs indefinitely.

Most of the injected oil was separated and directed to the oily water tank, whilst the trace of oil left in the process stream was removed from the water using two cartridge filters (in series) before recycling back to the clean water feed tank. A simplified schematics of the oily water test loop is shown in Figure 1.

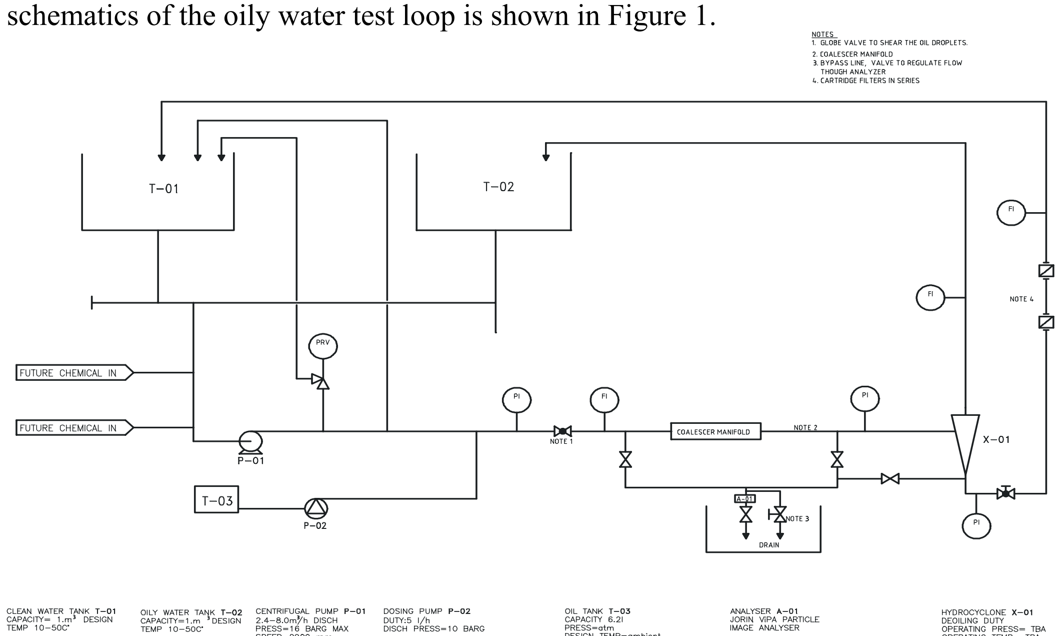


Figure 1 : Schematics of the oily water test loop

It should be noted that fresh water was the main constituent of the oily water used for all the tests and not produced oily water. As a result, the physical properties of the oily water generated in this work was somewhat different to the produced oily water (i.e. water salinity, density, viscosity e t c…). Having said this, all the correct physical parameters were used in our empirical method to predict oil removal characteristics.

The oil was dosed into the process line at the discharge of the feed pump at pre-determined dosing rates using a small diaphragm pump having a variable speed drive.

An immersion heater was installed inside the clean water tank. This enabled us to vary the hydrocyclone feed water temperature from ambient ~10° C to 30° - 40° C.

A shear valve (diaphragm type) was installed downstream of the main feed pump and the oil injection point. By throttling this valve, different oil droplet sizes were generated. This type of valve is known to produce repeatable oil droplet size distribution. This repeatability was also proved during these tests.

Two Ametek deoiling cartridge filters were installed in series on the hydrocyclone underflow to remove most of the oil before returning "filtered de oiled" water to the clean water tank.

Instrumentation

1. ViPA analyser

The **ViPA**, **Vi**sual **P**rocess **A**nalyser, is an on-line instrument for the monitoring of particle and droplet sizes and concentrations. The ViPA can operate continuously on-line at high pressure and elevated temperatures.

The ViPA package consists of the ViPA software set and a compact and robust measuring head (with a built-in cleaning mechanism) that can be located up to 100m from the control computer.

Using image analysis techniques to differentiate between particles and droplets in real time, the ViPA can report from up to seventeen parameters continuously including size and concentration. The ViPA software includes a set of trend algorithms that allow process conditions to be predicted, enabling operators to prevent problems occurring.

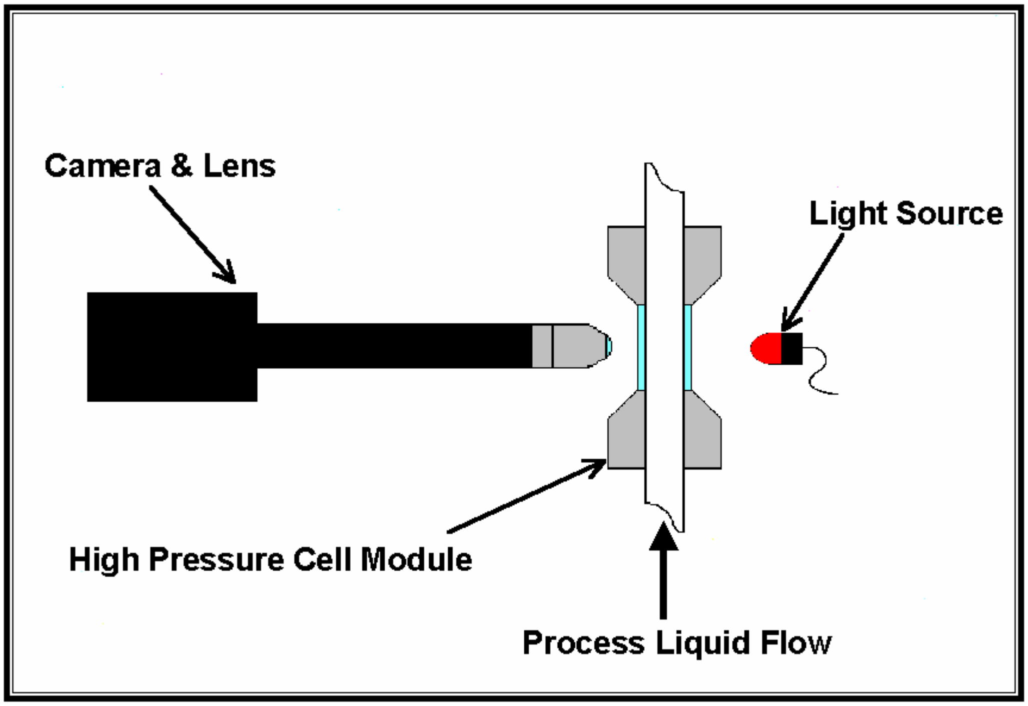


Figure 2: The ViPA general arrangement

The ViPA uses a video microscope assembly consisting of a video camera and lens and a light source to examine the contents of a liquid, see Figure 2. The liquid to be examined passes through the ViPA's cell module, which has a pair of transparent windows, and the camera looks through the liquid at the light source. This allows the video microscope a backlit view of the objects in the liquid flow, whether these are solid particles, liquid droplets or gas bubbles. The ViPA operates by freezing a single frame of the video image and analysing the objects present. A database of information is built by rapidly acquiring and analysing sequences of these frozen images (approx. 20 frames per second regardless of the number of objects per frame).

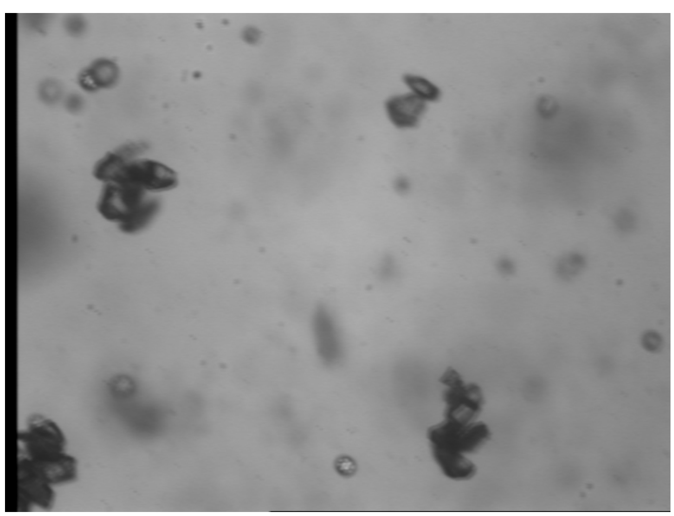


Figure 3 : A Typical Image as 'Seen By' the ViPA

Figure 3 is the image of ground garnet mixed with a light lubricating oil. The individual garnet crystals are approximately 35µm in size.

The Jorin ViPA was used primarily to measure oil droplet size distribution in the process line. The on-line mode of this unit ensured representative samples of oily water were measured at operating pressures without any undue shear on the oil droplets exerted usually by a pressure reducing valve.

2. Rivertrace oil monitor

A Rivertrace oil in water analyser was used to measure oil concentration on-line. The principle of measurement is known as the "scattered light technique". Light beams of specific wavelength, are projected through the wall of the glass measurement cell containing the moving conditioned sample. The intensity of the light received on the other side of the cell, at selected angles, is dependent upon the type of oil, and presence of solids.

3. Infracal analyser

The Infracal analyser makes use of the fact that hydrocarbons such as oil can be extracted from water through the use of a suitable solvent and solvent extraction procedure. The extracted hydrocarbons absorb infrared energy at a specific wavelength and the amount of energy absorbed is proportional to the concentration of the oil in the solvent. This method is the industry certified method to monitor the hydrocarbon content in the produced water.

Results

a. Oil concentration validation (ppm of oil in water)

An extensive test program was carried out by Merpro and Jorin engineers to substantiate the oil content capability of the ViPA unit. Forties crude oil was injected upstream of the oily water test loop shear valve (see Figure 1). The Rivertrace oil monitor was utilised for all the runs to measure oil content on-line (0 - 200 ppm of oil in water). The solvent extraction / IR spectrophotometry was used for selected runs to validate oil content measurement.

The test program was set out to investigate the effect of oil concentration variation (100 and 200 ppm) and effect of shear across the globe valve (0 to 5 bar pressure drop) at various water temperatures (ambient to 30°C).

The ViPA reports concentration as visible parts per million (ppmv). There is a known volume of liquid for each frame that the ViPA analyses. This volume is calculated as:
(the width of the analysed image) x (the height of the analysed image) x (the depth of focus of the image). In each frame the ViPA calculates the volume of the objects for each particle or droplet population/class. At the end of each analysis the ViPA software

software sums up the volume of all the objects in a population/class and the volume of all the frames, which then allows ViPA to report a volume/volume concentration for each run.

The measured concentration is reported as visible ppm, because only those objects seen are measured and included in the calculation. In other words, materials passing through the cell between frames and objects that are not in focus are not seen and hence not measured.

However, while the concentration figures are not absolute, they are repeatable and indicate how the concentration of a material is changing relative to previous or later measurements.

It rapidly transpired that a strong correlation can be found between the oil content values measured using ViPA and Rivertrace oil monitor. It basically means with the increase in oil concentration the ViPA's oil concentration values were also increased. However, this relationship as can be clearly seen in Figure 4, is a strong function of median oil droplet sizes generated during the test program.

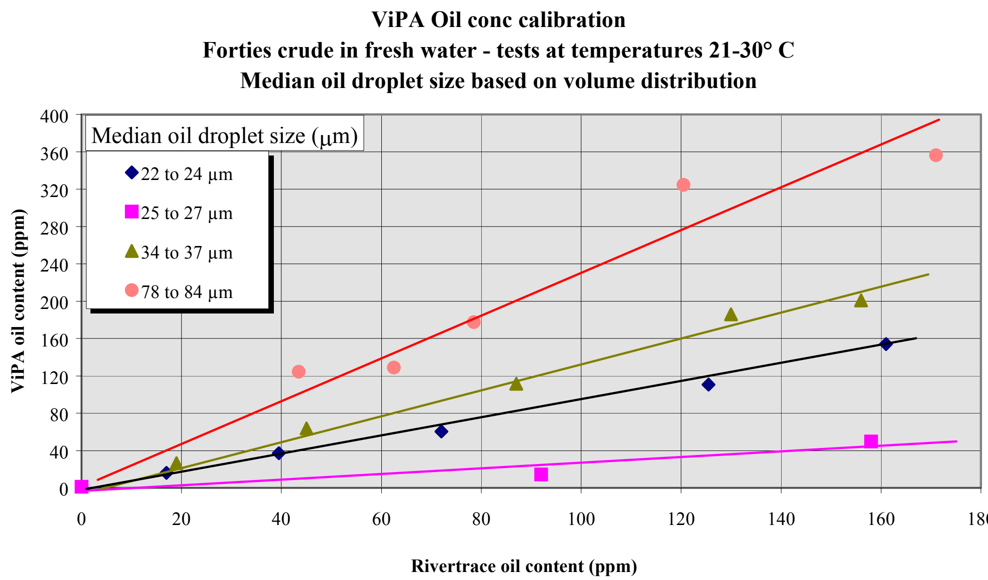


Figure 4 : ViPA vs. Rivertrace oil concentration

The K factor (the ratio of ViPA to Rivertrace oil content) seems to be increasing with increase in median oil droplet size, see Figure 5. It should be highlighted that unlike ViPA unit, the Rivertrace oil monitor requires conditioning and homogenising the oily water samples prior to directing the sample to the measurement cell. The sample conditioning system basically shear the oil droplets to sizes below say 20 microns which facilitates the oil content measurement.

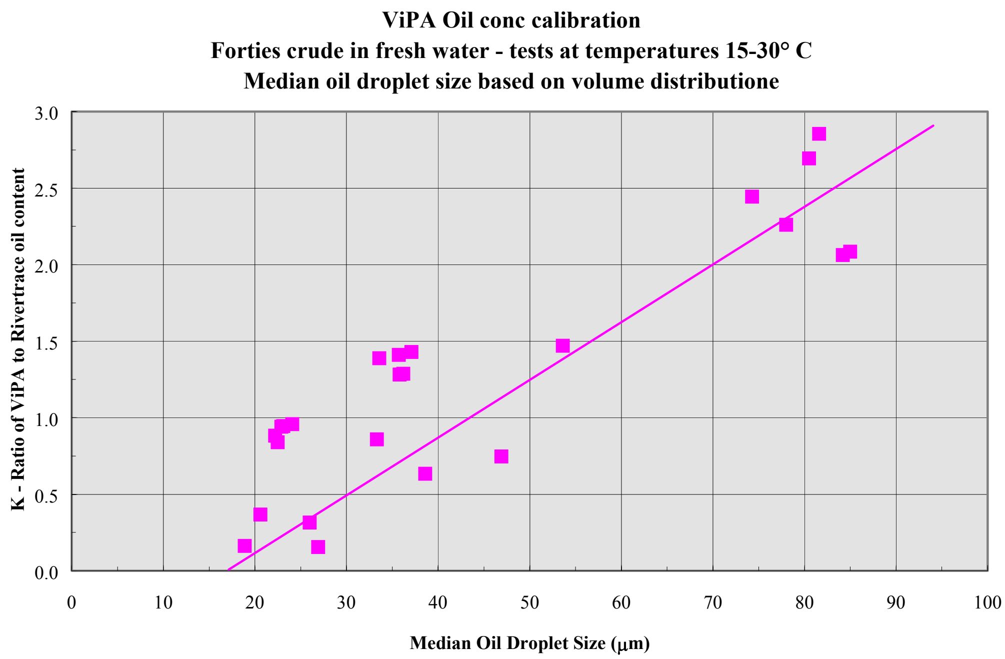


Figure 5 : ViPA vs. Rivertrace K - Factor

A limited number of runs was also conducted using IR / solvent extraction method instead of Rivertrace oil monitor. These runs were only carried out at a fixed pressure drop across the shear valve. Again, similar correlation were found which validated the findings as for Figures 4 and 5. Figure 6 shows the oil concentration readings for IR and ViPA units.

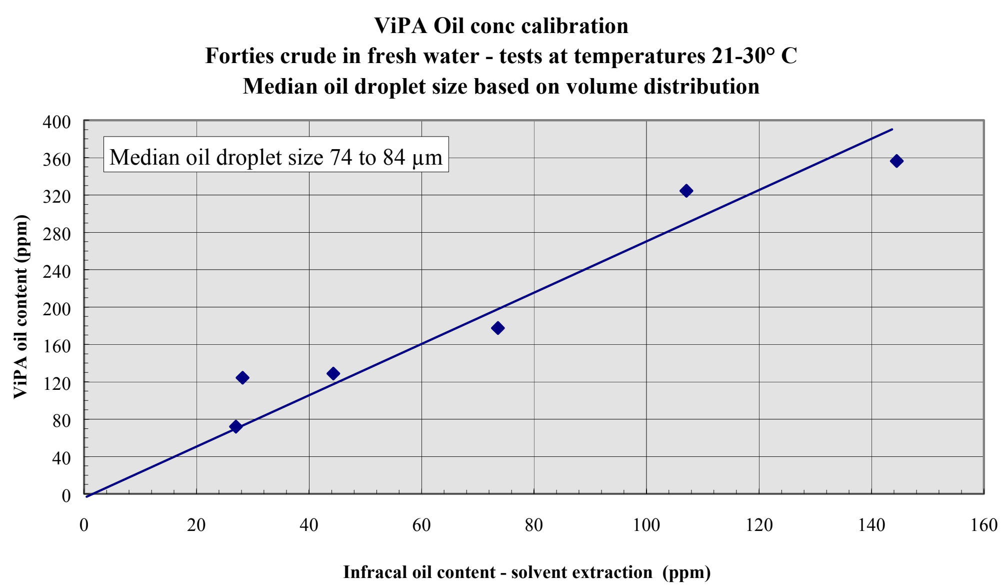


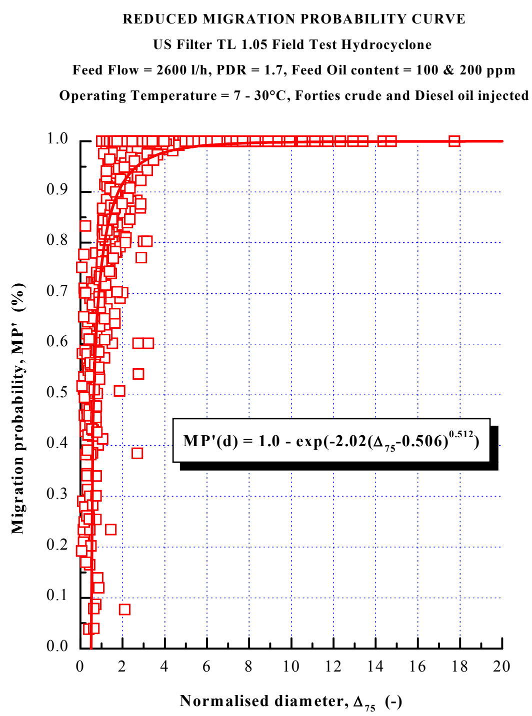
Figure 6 : ViPA vs. IR / solvent extraction concentration

This means that the ViPA software can be easily modified to correct the measured oil content following determination of the median oil droplet size. The ViPA software will be upgraded to incorporate the findings of this work. The K-factor, as indicated in figure 5 or 6, will be used to modify the concentration values (note: visible ppm) from the ViPA to take into account the effect of the median size on reported concentration.

This calculated concentration value will be reported in addition to the existing visible ppm.

b. deoiling characterisation of US Filter Liquid / Liquid hydrocyclone

A migration probability curve, (see Figure 7), was successfully fitted for all the experimental data using an exponential type function similar to Coleman and Thew's[1]. However, the newly derived coefficient and exponent were somewhat different to Coleman and Thew's[1] . The two main differences between this and Coleman and Thew's work are a different type of hydrocyclone and the sampling method, on-line non-intrusive sampling was used for these tests.



Normalised diameter, Δ_{75} (-) is the ratio of oil droplet diameter to the separation diameter d'_{75}

Figure 7 : Migration probability curve for US Filter deoiling hydrocyclone

The Jorin ViPA size analyser proved to be an excellent tool to accurately characterise hydrocyclone separation performance in a very short time.

A new dimensional analysis method was developed to fit the separation diameter parameter with the hydraulic information as Coleman and Thew's work method was unable to derive a useful curve for incorporation in our oil separation prediction software. See Figure 8 showing the new dimensional groups and the curve which successfully fitted all the data points.

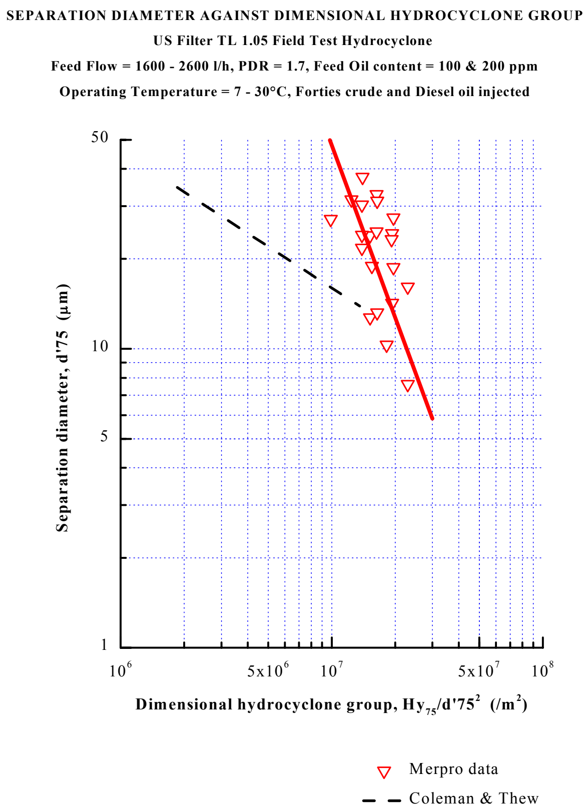


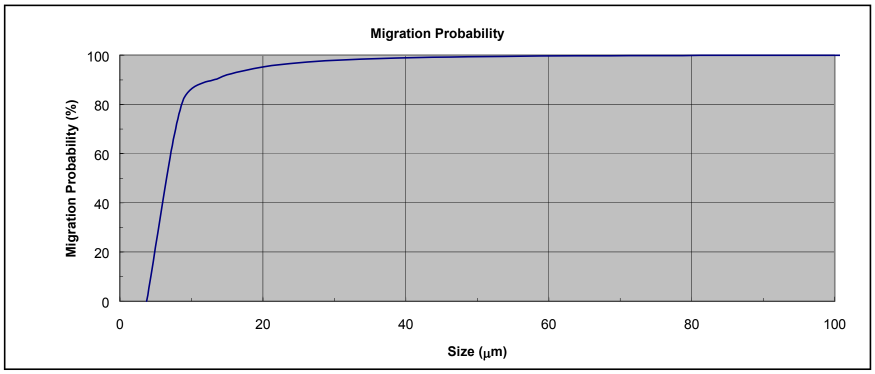
Figure 8 : Hydrocyclone dimensional group for the US Filter deoiling hydrocyclone

INPUT PARAMETERS

Operating Water Temperature	**55**	°C
Hydrocyclone Feed Pressure (gauge)	**7**	bar
Oil Density at 25 °C	**930**	kg/m³
Available pressure drop across Hydrocyclone	**60**	psi
Hydrocyclone Feed Oil Concentration (Design)	**600**	ppm
Hydrocyclone Outlet Oil Concentration (Design)	**40**	ppm

FEED OIL DROPLET SIZE DISTRIBUTION DATA

Oil Droplet diameter µm	Feed cum. undersize (%)	Oil Droplet diameter µm	Feed cum. undersize (%)	Oil Droplet diameter µm	Feed cum. undersize (%)	Oil Droplet diameter µm	Feed cum. undersize (%)
3.7	0.0	33.7	40.0	63.7	95.0	93.7	100.0
8.7	10.0	38.7	50.0	68.7	98.0	98.7	100.0
13.7	15.0	43.7	60.0	73.7	99.0	103.7	100.0
18.7	20.0	48.7	70.0	78.7	100.0	108.7	100.0
23.7	25.0	53.7	80.0	83.7	100.0	113.7	100.0
28.7	30.0	58.7	90.0	88.7	100.0	118.7	100.0



SUMMARY OF RESULTS

Oil Separation Efficiency- (design)	**93.3**	%
Oil Separation Efficiency - (prediction)	**92.0**	%
Hydrocyclone Outlet Oil Concentration - (prediction)	**48.2**	ppm

Hydrocyclone Diameter - Fixed for TL 1.05 hydrocyclone	**0.019**	m

CALCULATION

Pressure Factor	**1.01**	-
Viscosity of Water at Operating Temperature and Atm. Pressure	**0.56**	cP
Viscosity of Water at Operating Temperature and Pressure	**0.00056**	kg/m.s
Oil Density at Operating Temperature and Pressure	**912.1**	kg/m^3
Water Density at Operating Temperature	**985.8**	kg/m^3
Oil and Water Density Difference at Operating Temperature and Pressure	**73.7**	kg/m^3
Hydrocyclone Feed Flowrate	**4.9**	m³/h
Dimensional Hydrocyclone Group	**25842077**	-
d'_{75}, Oil Droplet Diameter at MP' = 75%	**7.4**	µm

Figure 9 : A print - out of the oil removal prediction program (US Filter hydrocyclone)

Figure 9 shows a print out of the computer software (relevant page) written to predict the outlet oil concentration given certain feed process parameters. This software utilises the findings mentioned above (e.g. Figures 7 and 8) and other process calculations to derive the required oil separation efficiency, feed flowrate and separation diameter (d'_{75}).

Future - utilisation of ViPA to improve produced water treatment

One of the important areas in which ViPA unit can be installed to improve the produced water quality is on the feed and "clean" streams of the deoiling hydrocyclone packages. The oil droplet size and oil content data from these streams can be monitored on-line. These information should enable the operator to make rapid judgement and appropriate adjustment to the deoiling hydrocyclone control to maintain the optimum hydrocyclone separation efficiency. As highlighted earlier in this paper and mentioned elsewhere, the oil droplet size has a significant impact on the deoiling performance of the hydrocyclone and consequently its discharge quality (ppm of oil).

Other advantage of the ViPA unit is that gas bubbles and oil droplets can be distinguished (in some cases) due to their characteristics (Jorin future development). Obviously, solids and gas can be detrimental to the hydrocyclone performance. Again, these data can be utilised by the operator to make corrective and rapid actions upstream of the hydrocyclones to minimise solids and gas content.

The other area of great interest, is to use the ViPA unit as a produced water quality controller on the TORE®SEP / hydrocyclone package (for more information see paper entitled "Efficient Compact Centrifugal Separation Utilising Merpro's TORE®SEP Technology") or any other FWKO units which has a low residence. This simply means the ViPA unit will measure the oil content of the oily water discharge from this package and send appropriate signals to control an automated valve situated downstream of the hydrocyclone to ensure the discharge of oily water remains within the required level. This method has the potential of replacing the problematic liquid level control system on the 3 phase separators. Once this technology is proven on top-side oil and gas platforms, it can be easily transferred to control sub sea separators.

ViPA can also be used as a tool to monitor and control the injection of chemicals responsible for oil droplet growth. These chemicals are commonly injected to enhance oil removal efficiency of the deoiling hydrocyclones. The chemical dosing rate could be optimised by continuously measuring oil droplet size distribution to ensure a suitable oil droplet growth and hence achieving the required discharge water quality. The ViPA utilisation will undoubtedly optimise (in some cases minimise) the usage of these chemicals which is not only beneficial as

The other potential area could be minimising the usage of solvent during IR / solvent extraction technique to measure the oil content of the discharge water. The ViPA unit can monitor the overboard discharge water wastes, not only to measure the oil droplet size distribution but monitoring and measuring the oil content of the discharged stream. The ViPA unit can determine the ppm of oil after very short intervals (say 5 - 10 minutes) instead of the routine 12 hourly measurement using IR / solvent extraction. This should lessen the amount of solvent used offshore and also extends the knowledge the knowledge of the oil concentration and droplet size data which should pave the way for a rapid reparation response to the plant operation in general.

References

1. Coleman and Thew, "Correlation of separation results from light dispersion hydrocyclones", Chem. Eng. Res. Des., Vol. 6, July 1983.