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Enhanced Deoiling Hydrocyclone Performance without Resorting to Chemicals

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Abstract

There are many produced water deoiling hydrocyclone systems operating today that do not meet the required overboard discharge water quality specification. Common reasons for this include long term changes in field conditions, adverse interfacial chemistry (generally caused by a “cocktail” of chemical additives), small inlet dropsizes or sub optimal deoiling hydrocyclone liner types (e.g. large diameter geometries).

The most common solution to these PWT problems is to implement a chemical injection programme which although can be successful, has a high operating expenditure requirement and can often be more harmful to the environment than the oil it was designed to remove. There is also a general industry initiative to minimise the use of production chemicals in a response to the belief that new legislation governing toxic chemical and dissolved hydrocarbon discharge is imminent.

This paper describes a technology which has been developed by Cyclotech to significantly improve the performance of produced water deoiling hydrocyclone systems without resorting to chemicals. The concept is based on pre-coalescing the inlet oil dispersion to produce a coarser drop size distribution prior to hydrocyclone entry. Field trials have demonstrated that the technology can improve the deoiling performance by as much as 220%. It requires no external control or power source; displays a marked insensitivity to solids fouling and can be easily retrofitted into existing systems without the need for any major vessel or pipework modifications.

The technology is aimed at existing systems which do not meet discharge specification, or require excessive chemical dosing to do so and at new-build systems by extending the applicability of hydrocyclone based solutions to heavy oil, condensate and other historically marginal applications.

Introduction

Deoiling hydrocyclone separation systems revolutionised the offshore oil industry when they replaced conventional gravity separators as the state of the art technology for produced water treatment during the early 1980’s. They were highly efficient, compact, had no moving parts, required little maintenance and were simple to operate. However, fifteen years of operating experience has revealed that deoiling hydrocyclones do have limitations and there are many operating produced water deoiling hydrocyclone systems which do not meet the operator required overboard discharge water quality specifications. The most common reasons for this are:

1. **Long term changes in field conditions**; e.g. decreasing temperature and/or pressure. Hydrocyclone performance is highly sensitive to operating temperature and decreasing operating pressures can reduce hydrocyclone turndown and separation performance;
2. **Adverse interfacial chemistry** – caused by changes in reservoir chemistry but more commonly by an increasing “cocktail” of chemicals commonly added to a modern oil and gas production process e.g. scale inhibitors, corrosion inhibitors, well treatment fluids, demulsifiers, coagulants, flocculents and platform drain fluids containing a host of different detergents, solvents and colloidal particles – these can all lower the interfacial tension which will increase sensitivity to droplet break up;
3. **Adverse physical properties** of phase components such as high viscosities, low phase density difference;
4. **Small inlet dropsize distributions** – caused by dispersion sensitivity to high shear intensity regions of the process such as valves – hydrocyclone separation performance is very sensitive to inlet drop size distribution;
5. **Sub optimal deoiling hydrocyclone geometries** (e.g. large nominal diameters).

The deoiling hydrocyclone was originally conceived to process water effluent discharged from a production separator to ensure that the overboard discharge limit of 40 mg/l required by environmental legislation was achieved. Environmental compliance has historically been legislatively driven, but environmental stewardship is now becoming a key reporting area for the major operating companies. One measurable parameter is total oil discharged to the environment, leading operators to unilaterally impose much lower stretch targets, such as 15 to 20 mg/l. Given that there are many platforms struggling to meet the present limit of 40 mg/l, it is clear that for the majority of production platforms, producing a step change in the efficiency of the existing produced water treatment system is an onerous task.

Improvements in water quality can be obtained by fine tuning the process, for example optimising the producing well profile, the separator liquid levels and the hydrocyclone pressure drop characteristics. However, in most circumstances, these types of process "tweaks" do not usually result in a substantial improvement in produced water quality and thus other conventional solutions are generally investigated. These include:

- Injection of a water clarifier chemical;
- Upgrade the degasser vessel with IGF internals;
- Installation of tertiary treatment equipment e.g. centrifuges, IGF, TPIs etc;
- Implementation of a produced water re-injection scheme.

The most common of these methods is chemical injection as modern water clarifiers can be highly effective, even at very low injected dosages. However, the majority of the highly efficient water clarifiers on the market tend to be Class 1 or 2 chemicals i.e. highly toxic and since most of these chemicals tend to be cationic in nature, the majority preferentially partition to the aqueous phase and are discharged to the environment with the produced water.

Hydrocarbon discharge limits in the North Sea are governed by the PARCOM (Paris Commission) regulations. These regulations actually prohibit the discharge of any hydrocarbon contaminated water but the regulations allow exemptions to be granted by national governmental bodies within their own national sectors; 40 mg/l is the current limit set in all sectors of the North Sea. This limit only governs the discharge of free oil and excludes the discharge of dissolved fractions. This implies therefore that ironically, a platform can do more harm to the environment by injecting a Class 2 water clarifier and meet the legislative discharge limit rather than do nothing and discharge slightly off spec water.

Water clarifiers also add a considerable operating expense since the chemicals are expensive, the injection systems require operator attention and dosage and chemical type require constant optimisation through field life.

Disadvantages with the other alternative processes listed above are obvious since these options are CAPEX and OPEX intensive, carry considerable space and weight penalties while exhibiting a lower equipment availability due to increased maintenance requirements.

The Strategy

One of Cyclotech's main technology development strategies is to develop high value, low cost, process intensifying technology which can be assimilated to existing conventional separation systems to improve efficiency, expand operating envelope or down-size equipment. This strategy is exemplified by Cyclotech's PECT (Performance Enhancing Coalescence Technologies) range of process technologies; it is believed that pre-coalescence technology, achieved by whatever method, has the potential to significantly impact the performance of not only produced water treatment systems but also production separators and crude dehydrators since the same Stokesian principles apply.

The PECT-F system has been developed to improve the efficiency and extend the operating envelope and flexibility of deoiling hydrocyclone systems while reducing reliance on chemical injection.

The Concept

The physics behind any cyclone, be it liquid/liquid, solid/liquid, solid/gas etc. are the same; a cyclone is a device that utilises pressure energy to effect a separation of two (or more) phases that have a density difference between them (see fig.1). The multiphase feed is fed tangentially at high velocity into the upper swirl chamber which causes the flow to spin in a vortex flow pattern. This vortex creates a high acceleration field (~2000 to 3000g in the case of deoiling hydrocyclones) which forces the lighter phase to migrate to the centre of the cyclone. Due to the differing pressure gradients, the heavier phase in the primary vortex flows out through the underflow (or apex) while the light phase at the radial centre, reverses direction axially and leaves through the overflow.

The resolution of an oil-in-water emulsion becomes less onerous as the dispersed phase drop size distribution of that emulsion increases. Under a given acceleration field within the hydrocyclone, a modified form of Stokes Law (shown below) describes the radial terminal velocity achieved by an oil drop of a given diameter travelling towards the core

$$u_s = \frac{Gg\Delta\rho d^2}{18\mu}$$

where Gg is the acceleration field created by the vortex flow, $\Delta\rho$ is the phase density difference, d is the drop diameter and μ is the continuous phase viscosity. The faster this velocity, the greater the likelihood that drop will reach the oil core (and therefore be separated) before being carried out with the water in the underflow.

Although this is a very over-simplified model to describe the passage of an oil drop within the highly complex and dynamic flow regime of a hydrocyclone, it does indicate the important physical parameters that influence the separation process. Immediately apparent is that the drop diameter is a squared term implying that any droplet growth performed prior to the inlet of a phase separator, will result in a dramatic improvement in the separation performance i.e. a factor of two increase in the drop size would increase the radial settling velocity by a factor of four.

This effect manifests itself in practice as follows. The graph in fig 2 illustrates the typical steep cut size curve for a typical high efficiency deoiling hydrocyclone operating under typical conditions. It can be seen that as the drop size increases from 5 m to 10 m, the separation efficiency will rise dramatically from ~15% to as high as 95% (assuming a mono sized distribution).

With the exception of one or two special cases, the performance of every deoiling hydrocyclone will be governed by the inlet drop size distribution for a given set of physical and operating conditions. This implies that a performance enhancement will be achieved on any system if the inlet drop size distribution is increased. From the above graph, it is clear that only a very moderate increase in the inlet drop size distribution is required to produce a substantial increase in hydrocyclone separation performance. It is this fact which is key to the PECT-F pre-coalescence technology.

Hydrocyclones have a critical internal geometry to effect their high performance and thus cannot be scaled to suit differing flow capacities. In commercial systems, hydrocyclone liners are manifolded in a vessel fitted with two internal support plates which divide the vessel into three separate chambers – in the case of deoiling hydrocyclones these are oily water inlet, water out and reject oil out. As can be seen from fig 3, the central inlet chamber of a modern high efficiency system is the largest and has typical residence times of ~10 seconds with flow velocities in the range of 0.05 to 0.2 ms-1. A Reynolds number of ~8,000 implies that the flow field within this chamber is relatively quiescent.

The PECT-F concept is to fill the inlet chamber with a fibre based coalescing structure. These fibres will entrap the oil droplets as they pass through the media and significantly increase the level of coalescence to produce a coarser oil dispersion (and thus one that is easier to separate) prior to the inlet to the individual hydrocyclone liners.

Conventional gravity based coalescing separators operate on the principle of a coalescing stage followed by a gravity separation stage. Since the separation stage is gravity based, the coalescing stage has to substantially increase the drop size (say by an order of magnitude) to effect any significant improvement in separation performance. This implies that the coalescing stage generally consists of fine, high density media (usually in the form of a cartridge) where contact time is maximised by limiting the flow velocity through the media. These coalescing cartridges are highly sensitive to solids fouling and would in many cases require upstream filter protection. Since both the filter and coalescing cartridges would require periodic replacement, this option becomes unattractive for high volume produced water treatment applications.

However, given the very moderate level of droplet growth required to achieve a substantial improvement in hydrocyclone separation performance, an optimally designed low residence time, high flow velocity and highly open media device is sufficient to produced the required partial pre-coalescence while maintaining a marked insensitivity to solids fouling.

Coalescence Theory

The principle behind a fibre based pre-coalescer is to inhibit the flow of the dispersed phase to increase its residence time within the coalescer section. This will serve to increase the apparent dispersed phase concentration which lowers the average inter-droplet spacing. This increases both the number of droplet collision events within a given time period and the proportion of these collisions that result in a successful coalescence event. The mechanism of droplet coalescence promoted by a fibre based media can be divided into three main steps:

Droplet Capture. – The dispersed phase droplets must impinge and adhere to the fibres by either direct interception, inertia impaction or inter-molecular forces.

Droplet Growth. – The drops that are still flowing in the continuous phase impact the captured drops on the fibre resulting in a captured drop with a larger diameter. The larger the captured drop diameter, the larger the viscous drag force experienced by that drop which will cause it to travel down the fibre with a greater velocity than a drop with a smaller diameter. This velocity mismatch will cause captured drops to collide on the fibre.

Droplet Disengagement. – Coalesced droplets will disengage from the media once the viscous drag forces exceed the forces of adhesion. It is important that the droplets disengage intact and do not break up as a result of effects such as “jetting”.

In order to optimise the above process, there are a number of factors which must be understood. For a given inlet drop size distribution, coalescence efficiency increases with:

- decreasing superficial velocity
- increasing fibre density
- increasing contact time

Importantly, these effects can be traded off with each other. For example, the same coalescing performance can be obtained with a high fibre density/short contact time configuration as a lower fibre density/longer contact time configuration. This allows considerable scope for configuration optimisation to achieve the required coalescence performance while minimising solids fouling potential. Correct specification of other parameters such as fibre material(s) and surface treatment offer potential to maximise the overall coalescence performance.

The PECT-F media comprises of the following basic modular stages to allow variation (within each stage) in fibre density, fibre material and fibre surface treatment:

- Inlet Stage – Drop Capture
- Inter Stage – Drop Growth
- Outlet Stage – Drop Disengagement

Each media system would be optimised to the specific application by using the results of a single liner field trial.

PECT-F Installation

The PECT-F technology is primarily intended to be retro-fitted into the inlet chamber of the current design of deoiling hydrocyclones, i.e. those where the inlet compartment is the central compartment of a three compartment vessel, although non-standard designs are available for other vessel configurations. Furthermore, to maximise applicability to any manufacturers hydrocyclone, its design is flexible enough to accommodate different liner shapes and sizes, and different vessel diameters and configurations.

The PECT-F system is currently supplied in four main components:

- Inlet device
- Inlet Media Cage
- Inter Media Cage
- Outlet Media Cage

The inlet device performs the functions of (1) diverting incoming water to the end of the inlet compartment furthest from the liner inlets to maximise contact time in the PECT-F media, minimise short circuiting and direct the flow the correct direction through the media and (2) providing a robust frame in which to locate the Coalescing Media Cages.

The Coalescer Cages, of which there are three look similar to thick "discs" of structured packing and contain the various types of coalescer media. Each is a stand alone item containing media of selected configuration, and each is capable of being inserted and removed from the vessel individually by no more than two individuals. A key spline system ensures alignment of all cages relative to each other and the liner ports in the vessel support plates. The installation of a complete PECT-F system requires no pipework or vessel modification, no hot work and can be completed in a single shift. Once the PECT-F system is installed, the liners may be installed /removed at will. This of course also implies that if for whatever reason the system was to fail, the PECT-F internals could be removed in a single shift to leave the hydrocyclone system in its original state, i.e. with no permanent modifications.

Technology Development

Following an extensive internal study and liaison with some operators, a configurable fibre pre-coalescer and single high efficiency deoiling hydrocyclone prototype system was designed, constructed and tested at ERT's test centre on Flotta, Orkney Islands. The test conditions selected were onerous:

Temperature	30ºC
Drop Size	$8\mu m\ d_{(50)}$,$18\mu m\ d_{(90)}$
Inlet Oil Concentration.	200 ppm to 550 ppm
Density	36º API
Viscosity	6 cP (high wax content)

The results showed:

1. A significant increase in hydrocyclone separation performance from over 300 mg/l oil in water concentration to 40 mg/l from inlet of 550 mg/l, a drop of 87% (see fig 4).
2. Consistently good water discharge qualities maintained over entire flowrate range – implying a significantly increased turndown (see fig 4).
3. Inlet drop size to the hydrocyclone was increased from 20 m d(90) to over 100 m d(90) (see fig 5).
4. Pressure drop across the coalescer was maintained at less than 0.5 bar over the flowrate range.

The outer housing of the coalescer used during these trials was constructed from perspex to allow flow visualisation. Fig 6 provides a visual indication of the level of coalescence that the optimised PECT-F system initiated during the trial by comparing the inlet with the outlet. It can be seen that the inlet is very milky and uniform in colour (indicating a very tight emulsion) whereas the outlet is streaky, evidence of a high level of coalescence.

Case Study – BP Amoco Andrew [1]

BP Amoco Andrew Environmental Policy

The Andrew Installation is located in the central North Sea area, approximately 230 kilometres North East of Aberdeen. Fluids from both the Andrew and Cyrus fields are processed via a single fixed platform. A total of 130 million barrels are recoverable.

Andrew came on-stream in 1996 and quickly established a reputation for environmental excellence. A number of initiatives helped to achieve this. Facilities were installed to re-inject all drill cuttings. A stringent flaring policy was implemented to cut, or even cease, production whenever gas export facilities were unavailable. Production chemicals with high environmental impact were not used. The platform was one of the first North Sea installations to achieve EMAS (Eco-Management assurance System) and ISO 14001 accreditation.

The policy objective was to cause no harm to the environment while aspiring to become an industry leader in environmental performance.

Andrew Water Treatment Facilities[1]

Fluids from two fields are received on the installation. Production from the main Andrew reservoir are processed using two stages of separation. Water is removed at both the HP and LP stages and routed to hydrocyclone packages for de-oiling. Fluids from the Cyrus field, a subsea tie-back, reach the platform via a 7 km subsea flowline. A dedicated Cyrus Separator removes water to enable allocation metering of the Cyrus crude which is further processed by commingling with the Andrew fluids that feed the LP separator. Water from the Cyrus Separator is de-oiled in a dedicated hydrocyclone package.

All three hydrocyclone packages were from a well regarded supplier of water treatment process equipment. The design specification was to produce an outlet oil in water concentration of 30 ppm(w) for feed concentrations of up to 1000 ppm(w).

The clean water outlet streams from all hydrocyclone units are commingled and fed to a degassing vessel before passing through a flow meter and then overboard. The design did not include the facility to continuously skim oil from the degasser, therefore effluent quality is solely dependent on the performance of the hydrocyclone packages. The design capacity of the water treatment facilities is for 100 mbd of Andrew water and 20 mbd of water from Cyrus.

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[1] [1] Partners in the Andrew field are:
BP Amoco Expl. (operator), Kerr-McGee Andrew Ltd, Lasmo North Sea Ltd, Talisman Energy (UK) Ltd

Fig 7 shows a schematic of the Andrew water treatment facilities as well as typical performance data and oil drop size measurements.

Andrew Produced Water Performance

Fig 8 shows the monthly average overboard water quality reported on the installation. The chart spans a period of gradually increasing water cut, by December 1998 a total of 25 mbd of water was being discharged.

The quality of the water discharged from the installation began to deteriorate during early 1998. Average discharge quality was maintained within the 40 parts per million of oil consent, however with monthly averages typically around 30 ppm Andrew performance was clearly far short of the objective to be ‘best in class’ for the North Sea.

Throughout 1998 a number of initiatives were implemented to improve Andrew effluent quality. These were all partly successful in preventing the consent level being breached, they included:

- Optimisation of demulsifier blend and injection rates.
- Support from hydrocyclone vendor to optimise unit operation.
- Transfer of best practice from other BP North Sea assets.
- Use of external consultants to perform a produced water characterisation study
- Engagement of the Offshore Operations Team to provide daily focus on effluent quality

Other options that were tried but subsequently discarded were:

- Water clarifier chemical injection trials (this gave a small improvement but the environmental benefit was more than offset by the high toxicity of the chemical, a low toxicity deoiler was subsequently found to give no improvement)
- Field trials using hydrocyclone liners from an alternative supplier (no significant improvement over the performance of the existing liners was found).

The studies performed on the system operation by a leading third party consultancy indicated that one of the key factors limiting hydrocyclone performance on the platform was the oil droplet size in the feed stream to the hydrocyclone packages. Median oil droplet sizes in the feed to the HP, LP and Cyrus hydrocyclones were found to be 14, 7 and 9 m respectively. In all cases, a significant part of the feed comprised of droplets below 10 m in diameter. This is generally accepted as the cut off for most hydrocyclone units, the separation efficiency for droplets smaller than this is often poor.

These results were backed up when an alternative hydrocyclone liner was tested on the installation. The observed separation efficiency during these tests was not significantly better than the performance of the existing units. This indicated that some of the problem was being caused by the quality of the feed, rather than the operation of the equipment.

Several features of the Andrew/Cyrus development could explain the existence of small droplets in the hydrocyclone feed. However these features were related primarily to the wells and would therefore be difficult to influence.

Incentive to Investigate Novel Technology Option

For Andrew the recent trend has been of gradually improving water effluent quality. This is due to a number of factors, the key one being the positive engagement of the Offshore Operations Team so that daily operating parameters are continually optimised to give best quality discharge water. Although this improvement has been welcomed, it is clear however that continued incremental improvements in quality were unlikely to deliver enough of an improvement to meet the Teams environmental aspirations.

To become consistent with the top quartile North Sea performance, a step change improvement in effluent quality is required. This is difficult with the existing technologies that are available in this sector of the industry. One of the key drawbacks of the technologies that are available is the requirement to make significant modification to the existing facilities. This is always expensive, both in terms of capital spend and the losses incurred during the production shutdowns that are required to carry out the work.

In late 1998, Cyclotech approached BP Amoco with a proposal for the PECT-F Deoiling Hydrocyclone Performance Enhancing System. It was clear that this offered a strategic fit as a potential solution to the Andrew problems.

Firstly the technology was focused on improving droplet size which was the suspected limiting factor inhibiting Andrew performance. Secondly this was seen as a low cost retro-fit option, modifications to existing equipment would not be required and the shutdown requirements would not be onerous, the scheme could potentially be fitted during a planned maintenance outage.

Single Liner Field Trial

Cyclotech constructed a fully rated PECT-F single liner field test system which comprises of a fully certified 300# 316L SS coalescer unit and a 300# 316L SS single liner test unit. The two units are separate for ease of construction and test practicalities but the coalescer test unit has sufficient flexibility to ensure that it models the flow regime within the inlet chambers of various types of full scale deoiling hydrocyclone vessels. Local pressure gauges, sample points and valving are included which will enable control and sampling of each stream (coalescer inlet, hydrocyclone inlet and hydrocyclone water outlet) for both oil-in-water and drop size analysis.

This test unit was used for a field trial which took place on Andrew in late April 1999 to fulfil two objectives, namely:

1. To prove the technical viability of the PECT-F system on the produced waters from the Cyrus and LP separators.
2. To optimise the configuration of the PECT-F media.

The test equipment was installed in parallel with the existing Cyrus deoiling hydrocyclone system. The inlet conditions of the existing Cyrus hydrocyclones were characterised in terms of inlet drop size distribution and oil concentration. This was then benchmarked against the Cyclotech hydrocyclone test unit, without the PECT-F coalescer on-line, and found to be comparable.

Approximately six coalescer configurations were tested over three/four pressure drops and the coalescer performance was monitored using drop size analysis and by changes in hydrocyclone deoiling performance.

A Malvern 3600Ec drop sizing system was used to carry out the drop sizing analysis. The sampling procedure used a pressurised sample container or “bomb”. The sample stream was run into the bomb, the flowrate controlled by a downstream needle valve. The bomb was then isolated, vented and drained, a small fraction of which was directed into a measuring cylinder for dilution and stabilisation, before being poured into the sample cell for analysis.

Samples were analysed for oil-in-water content using the established Freon solvent extraction / MIRAN IR method currently employed by Andrew.

The results of the trial were very encouraging. The inlet drop size distribution to the Cyrus hydrocyclones agreed with the results of an earlier investigation and showed that the distribution was bimodal with the larger peak at around 15μm and the smaller peak at around 5μm giving an overall d_{50}~ 7μm. The water outlet quality was approximately 22 mg/l from an inlet of 70 to 130 mg/l implying that the existing hydrocyclone system could effectively separate the larger size peak but could not separate the smaller peak.

Fig 9 illustrates the effect of the optimally configured PECT-F system. The drop size distribution was increased to a d50 in excess of 30 m which resulted in a substantial water discharge quality improvement to ~ 5 mg/l (best result achieved was only 3 mg/l). A water quality of <10 mg/l was maintained even a very low pressure drops (0.5 bar inlet to underflow) implying that the turndown of the system had been increased to over 10:1 and confirmed the trend found during the prototype trial. The pressure drop across the coalescer at the maximum pressure drop across the hydrocyclone (inlet to reject) of 10 bar was less than 0.3 bar.

The media was visually inspected following 24 hours of continuous operation and was found to have limited oil hold up and was free of solids. However, a 24 hour period is too short to draw any firm conclusions so the unit was left to operate for five weeks continuously prior to the second phase of the trial which answered the following questions:

Can the Phase I results be repeated – is the performance enhancement a long term effect?

Has the unit experienced any solids fouling?

Has the media suffered any form of degradation?

The results of the Phase II trial proved to be positive. The Phase I results were repeated to within 2 mg/l, the solids hold up was negligible and the media had suffered no form of degradation. It is now planned that a Pilot PECT-F system will be retro-fitted into the Cyrus hydrocyclone vessel. Since this vessel handles approximately half of Andrew’s produced water production, it is hoped that this will improve the overboard discharge quality significantly.

Due to the success of the Andrew trial, to date four further trials have been confirmed on other North Sea installations.

Conclusions

There is no doubt that the PECT-F technology has shown real potential to become a viable low cost alternative to the conventional chemical approaches to produce a step change in the level of overboard hydrocarbon discharge. The benefits of the PECT-F technology can be summarised as follows:

- Enable deoiling hydrocyclone systems which operate outside the required overboard water discharge limit (40 mg/l) to meet specification.
- Significantly improve the performance of existing deoiling hydrocyclone systems to meet the stretched targets imposed by operators for overboard water discharge specifications (20~30 ppm).
- Maintain or improve the performance of existing hydrocyclone systems while reducing or eliminating the reliance on chemicals such as water clarifiers.
- Significantly increases the turndown of hydrocyclone systems by maintaining deoiling performance at low hydrocyclone pressure drops.
- The viability of the technology to a particular application can be confirmed relatively quickly and at low cost with a single liner field trial.
- Extend applicability of hydrocyclone based solutions to both heavy oil and condensate applications where there is a history of poor performance.
- Lower Capital and Operating Expenditure solution when compared to alternatives such as chemical or tertiary treatment based solutions
- Can be easily retrofitted into existing deoiling hydrocyclone systems without the need for any major vessel or pipework modifications.
- Open structure, multi media and surface treated design of coalescing internal ensures optimal performance while being insensitive to solids fouling.
- Pressure drop across coalescer limited to less than 0.5 bar.
- The technology is passive – it requires no control or external power requirement.

Acknowledgements

The authors extend their thanks to BP Amoco for permission to publish this paper.

Figures

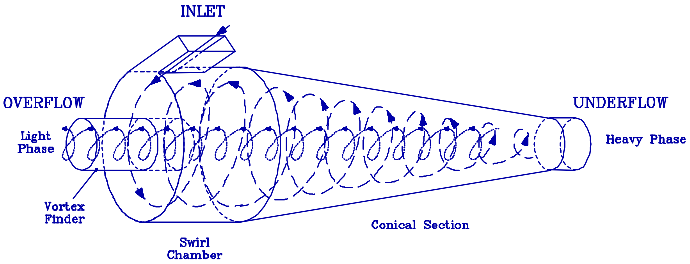

Fig 1 – Main Cyclone Features

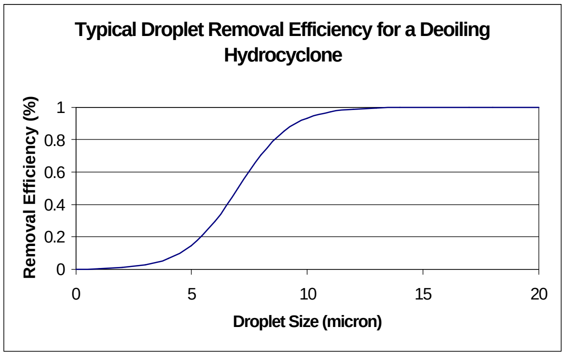

Fig 2 – Typical Deoiling Hydrocyclone Cut Size Curve

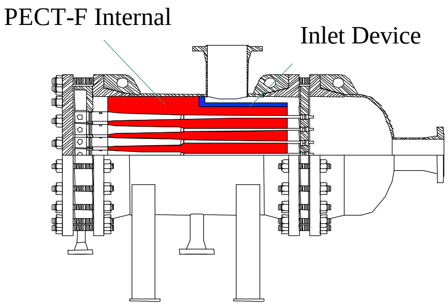

Fig 3 – Conventional Deoiling Hydrocyclone Vessel

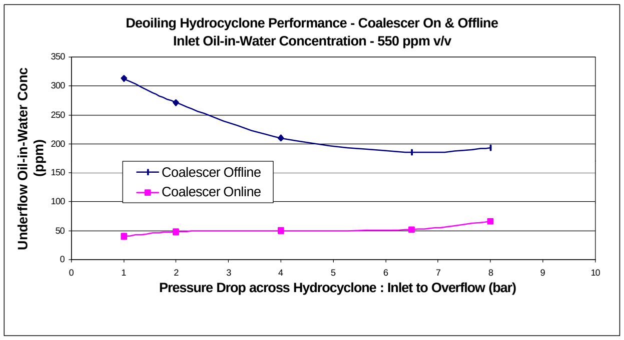

Fig 4 – PECT-F Separation Efficiency Enhancement

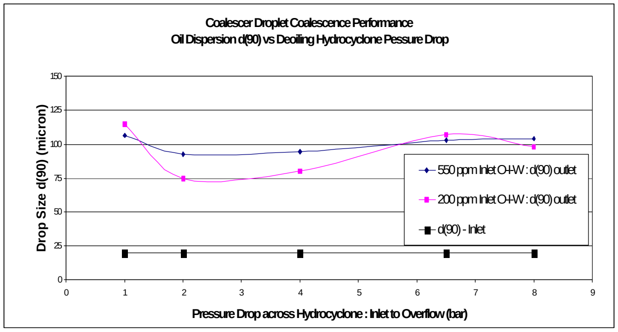

Fig 5 – PECT-F Inlet Drop Size Enhancement

Fig 6a – PECT-F Inlet

Fig 6b - PECT-F Outlet

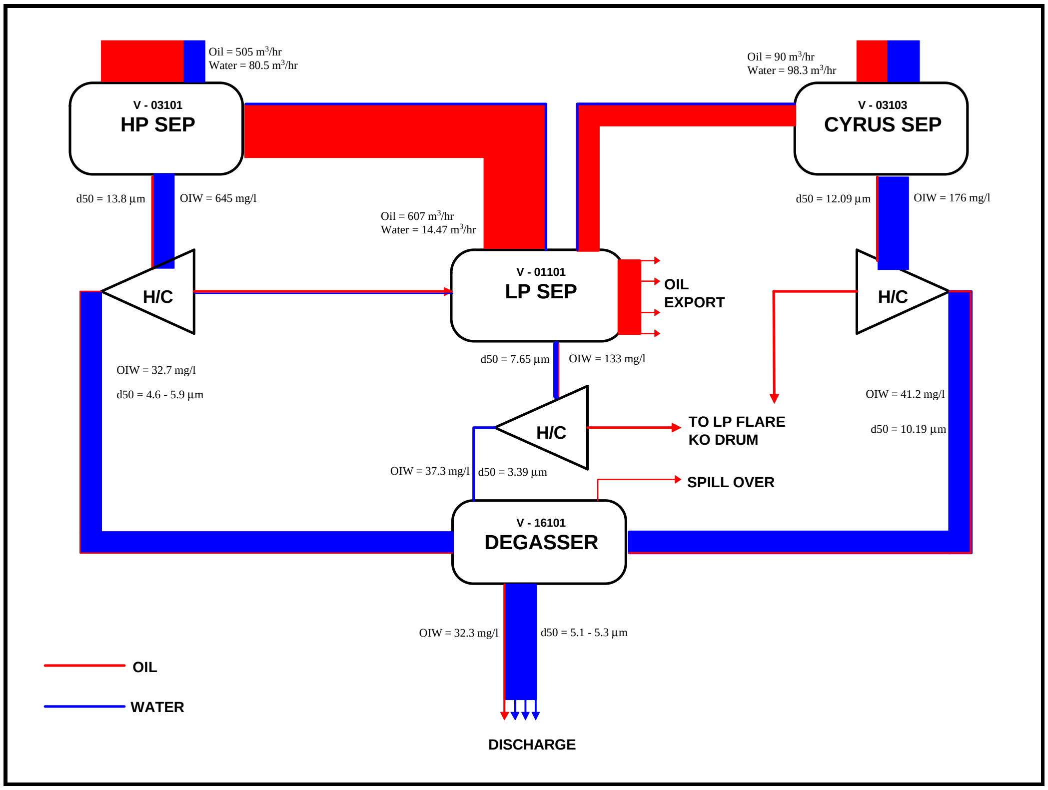

Fig 7 – Schematic of BP Amoco Andrew Water treatment Facilities

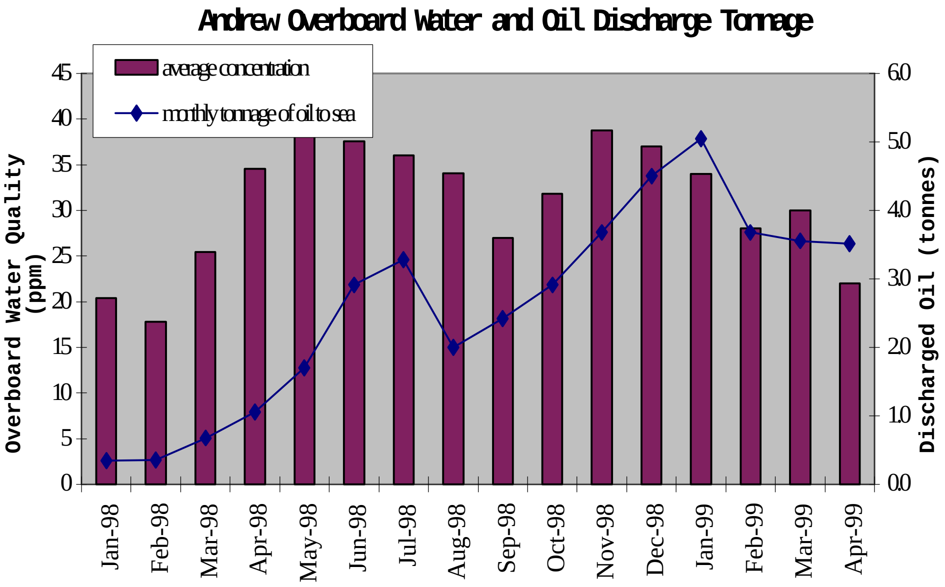

Fig 8 – BP Amoco Andrew : Monthly Average Overboard Water Quality

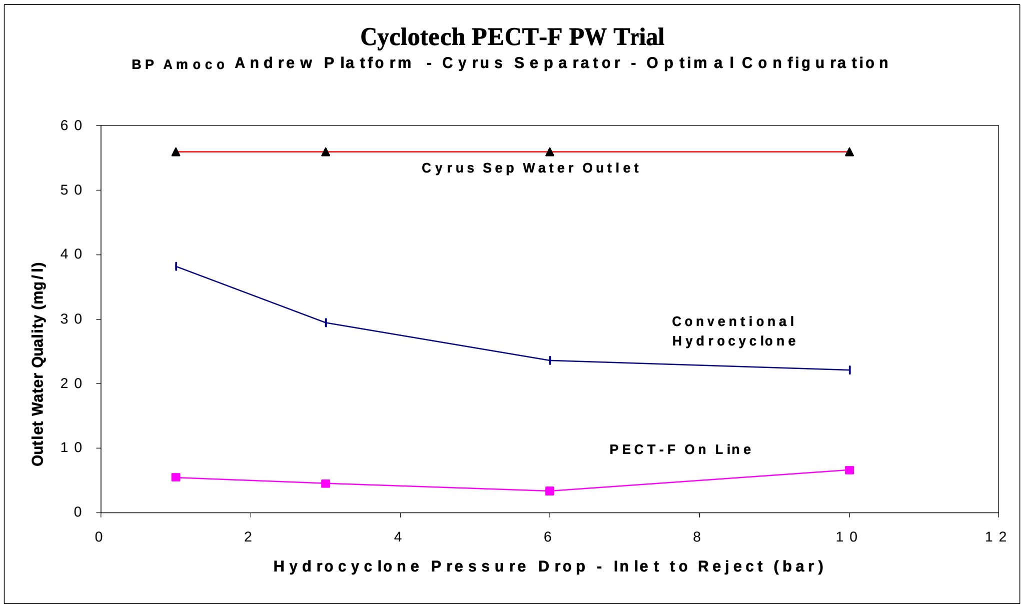

Fig 9 – Results of PECT-F Field Trial on BP Amoco Andrew