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The CTour Process, an option to comply with "zero harmful discharge legislation" in Norwegian waters. Experience of CTour installation on Ekofisk after start up 4'th quarter 2007.

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Abstract

In 1998 the Norwegian Government issued a White Paper (1) requiring the oil industry in the Norwegian sector of the North Sea to develop a strategy of reaching "zero discharges" of produced water within 2005. Operationally, zero discharge has since been defined as "zero harmful discharge" (2). In order to quantify the "harmfulness" of these components, a management tool, the EIF (Environmental Impact Factor), has been developed (3,4,5).

ConocoPhillips originally projected to achieve a combined 95 % reduction in EIF at Ekofisk by introducing Produced Water Re-injection (PWRI). However, after a pilot PWRI test was performed, the conclusion was that re-injection was not cost efficient and most importantly, it became apparent that it introduced a risk of reservoir souring, and could also cause substantial loss of oil produced.

It was then decided to evaluate best available produced water cleaning technologies (7,8,9). Based on previous test data, the results showed that Solvent Extraction (CTour) was the most promising technology for removal of dispersed oil and dissolved aromatic components. Pilot tests of CTour were conducted in 2004-05, and the results showed an 80% EIF reduction, reaching residual oil of <2 mg/l and Naphtalenes and PAH reduction by 80-95%. The CTour Process was successfully scaled up to 300 000 BWPD full field installation, and was started up and commissioned 4'Th quarter 2007. The results from performance testing indicate that the efficiency from the original pilot tests had been successfully reproduced, yielding residual OiW of 1-2 ppm and Naphtalenes and PAH reduction by 86-92%.

It is further concluded that the process yield residual discharge reduction in accordance to the guaranty parameters originally issued upon signing of the licence agreement.

The CTour Process is generally based on using available condensate from suction scrubbers as solvent, but at Ekofisk, NGL is used as extraction fluid.

Introduction and background

The Ekofisk field, operated by ConocoPhillips, is the oldest operating field in the Norwegian sector of the North Sea. It is a carbonate reservoir which has been sea water flooded since 1986. It is currently in a stage of increasing water cut, which is projected to peak at 41000 m3 /day by year 2015.

The Norwegian operators have to comply with the OSPAR discharge legislation which state that over board discharges of hydrocarbons cannot exceed 30 ppm and that the annual total oil discharges cannot exceed 85% of the reported annual discharges of the year 2000. The latter represents a big challenge for an operator experiencing increasing water cut.

In the Norwegian sector of the North Sea, operators must in addition to the OSPAR legislation, comply with specific Norwegian legislation which calls for “zero environmental impact” from overboard discharges. The Environmental Impact Factor (EIF) is used as a tool to quantify the harmful effect of discharges to the environment (3).
The EIF was developed as a management tool based on international agreed procedures for hazard and risk assessment. The tool models the dispersion of produced water accounting for volume, composition of oil and aromatic components (BTEX, Naphtalens, PAHs and Phenols), production chemicals and heavy metals and calculate the PEC/PNEC ratio (Predicted Environmental Concentration versus Predicted No Effect Concentration).

In order to comply with the new discharge legislation, ConocoPhillips originally projected to achieve a 95 % reduction in EIF at Ekofisk by introducing Produced Water Re-injection (PWRI). However, after a pilot PWRI test was performed, the conclusion was that re-injection was not cost efficient and most importantly, it became apparent that it introduced a risk of reservoir souring, and could also cause substantial loss of oil produced.
It was then decided to evaluate best available produced water cleaning technologies (7). Based on literature studies (8,9), previous experience and offshore testing, it was concluded that solvent extraction technology (CTour) was the most promising technology compared to Hydrocyclone-Coalescer and Hydrocyclone- CFU. This was based on the OIW disharges and EIF reductions listed in Table 1. CTour was then tested offshore for two periodes of ca. 2 months in 2004 and 2005, with test flow of about 20-40 m3/h.

	OiW Discharge ppm	EIF %
Hydrocyclon (EIF-reference)	20	100%
Hydrocyclon+ Coalesser filter	8-12	63%
Hydrocyclon +2xCFU	5-8	49%
Hydrocyclon + CTour	1-2	20%

Table 1: OiW discharge and corresponding EIF for representative technologies

The CTour Process

The development of the CTour process was initially conducted at the RF-Rogaland Research Institue, Stavanger and at Norsk Hydro Research Center, Porsgrunn, Norway through a series of Joint Industry Projects. The scope of these projects was to develop a new process to extract dispersed and dissolved hydrocarbon contaminants to reduce the environmental impact of produced water overboard discharge to the sea. The participants in these consortiums included Statoil, Norsk Hydro, BP, Shell, Phillips, Elf, KPS, RF, The Norwegian Research Counsel and The Norwegian Pollution Agency.
The process was named *CTour* in honor of the French scientist *Cagniard de la Tour* who first discovered the phenomena of super critical fluids in 1822.

Process Principle

The principle behind the CTour process is based on the solvent extraction process utilizing liquid condensate. The liquid condensate, often collected from the gas compression train scrubbers, is used to extract the dissolved hydrocarbon components as well as aid in coalescence of finely dispersed oil droplets in the produced water. The CTour process is illustrated in the process flow diagram shown below in Figure 1.

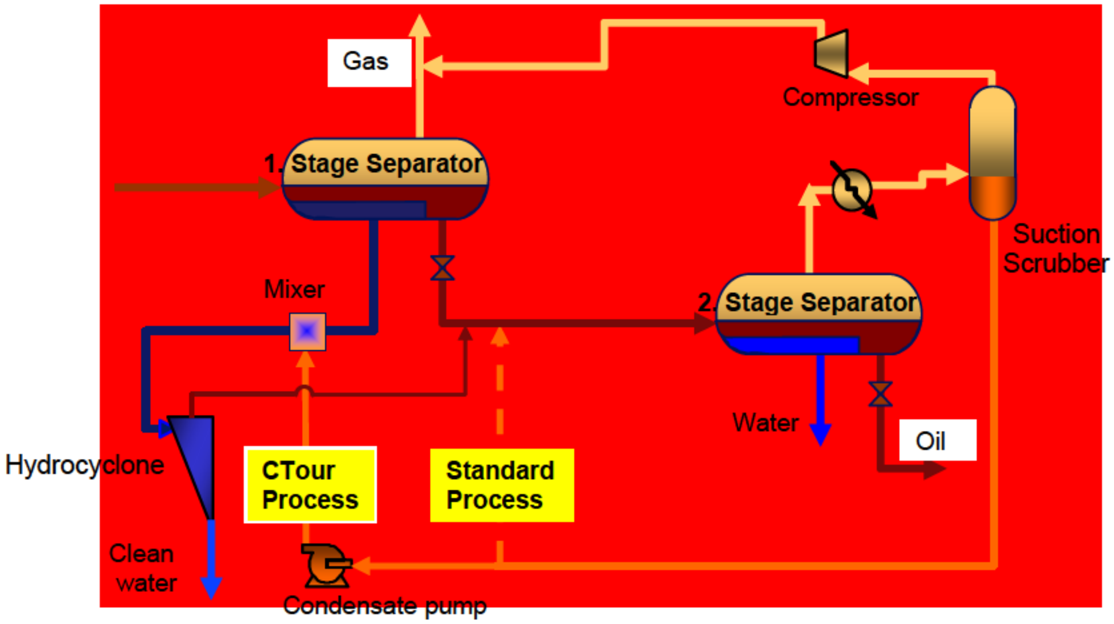

Figure 1. CTour Process Flow Diagram

During development of the CTour process, a number of parameters were investigated to determine their effect on the system operation and performance. These included dissolved gas in both oil and water, free gas in the water, solid particles, and oil-water interfacial tension as influenced by production chemicals. The results of this investigation concluded that none of these parameters had any influence on the process. However, through this investigation it was discovered that the efficiency of the process is very sensitive to the design and operational conditions of the injection system.

In order to successfully put the CTour process into practice, several measures must be achieved,

1. collect sufficient volume of suitable condensate, such that it is in liquid state at the operating pressure and temperature,
2. inject of 0.3-2.0% (volume/volume) liquid condensate in the produced water upstream of the treatment equipment,
3. provide sufficient dispersion and mixing of the condensate to ensure the most favorable conditions for the hydrocarbon components and droplets to contact the injected condensate, (*this is a critical element of the process*),
4. allow the necessary contact time, 3-5 seconds, for the dissolved hydrocarbons to be extracted and the dispersed oil droplets to coalesce,
5. offer a means to separate the condensate and hydrocarbon contaminants from the produced water and
6. recycle the reject back to the hydrocarbon recovery system.

Condensate Requirements
As noted above, there are specific thermodynamic conditions which must be achieved with the condensate to be used in the CTour process. These are:

1. The condensate must be maintained in a liquid phase during the injection and extraction stage and
2. Any residual condensate not separated with the reject should evaporate completely at atmospheric pressure at the given produced water treatment temperature.

It should be noted that the composition of the raw condensate may contain aromatic components, BTEX – benzene, toluene, ethyl-benzene, and xylene, as well as minor amounts of naphtalenes. These elements, if present in higher relative concentrations in the condensate than in the crude, may actually increase the levels of these contaminants in the discharged produced water. Generally speaking, lighter condensates typically contain lesser amounts of aromatic compounds than heavier condensates. If the available condensate has objectionable components, it may need to be conditioned prior to utilization in the CTour process.

Extensive data has been collected and analyzed to determine the removal efficiency of the CTour process on various hydrocarbon components. Specifically, these included dispersed oil, 2-3 ring PAH, 4-6 ring PAH, Naphthalenes, C_6-C_9 phenols and C_4-C_5 phenols[1]

This data has been utilized to develop a process prediction model for the CTour process based on the condensate compositional analysis

Condensate Properties, Sources and Supply

As illustrated in the CTour process flow diagram shown in Figure 1, a standard source of condensate is from the suction scrubber of the compression train. Figure 2 illustrates the phase envelope of the NGL at EKOJ.

However, if a sufficient quantity of condensate with the correct composition and phase properties for the process conditions is not available; several process adjustments may be considered, including:

1. Increasing the process pressure to match the condensate liquid phase properties,
2. Flashing of the condensate to reduce the bubble point,
3. Flashing of the condensate in a stripper column to remove undesirable components,
4. Recycling of the produced water reject in a reboiler for recovery of the condensate,
5. Cooling of the produced water to match the condensate liquid phase properties,
6. Extract condensate from a HP-gas stream in a JT system (or similar),
7. Remove BTEX components in a rectifying column.

In any potential CTour application, a technical and economic feasibility study of the condensate properties and, if necessary, evaluation of the options above should be conducted to establish the optimal processing scheme.

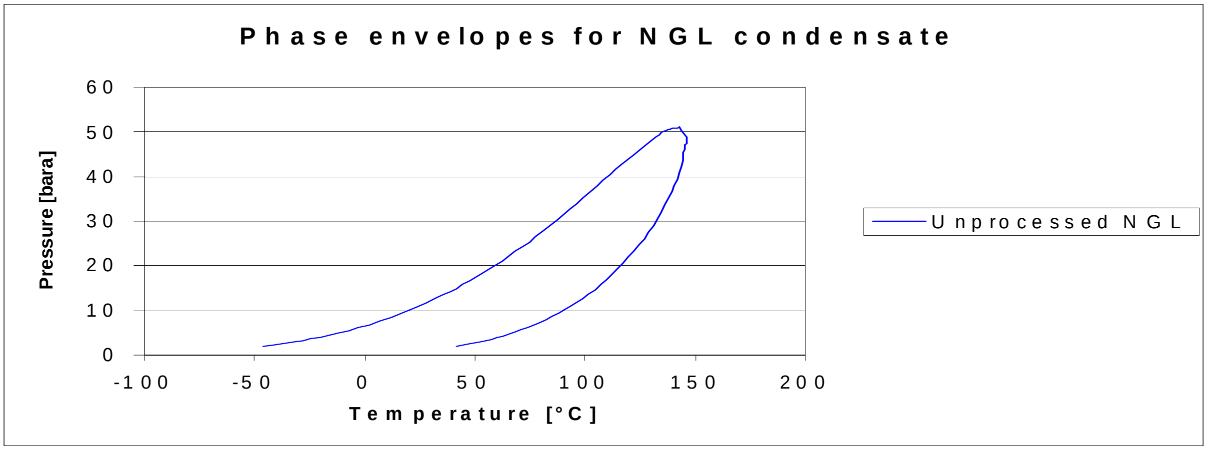

Fig 2 Phase envelope of the EKOJ NGL

Condensate Processing Unit

If the feasibility study indicates a condensate processing unit is required, its principal function is to ensure sufficient volume of condensate with the correct phase properties is available for the anticipated produced water production volumes over the life of the field. Typically, the design condensate volume is set as 2% of the produced water production rate.

The performance data collected to date indicate that the efficiency of the CTour process is not significantly improved at condensate injection concentrations over 0.5 Vol% for low feed concentrations (i.e. 100 ppm). This is illustrated in a graph of removal efficiency (% residual concentration) versus condensation injection rate shown in Figure 3.

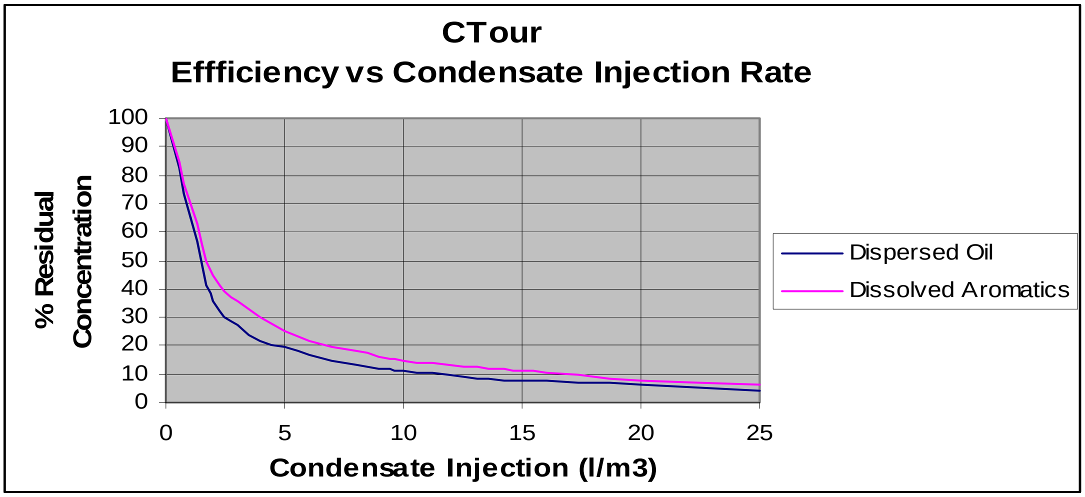

Figure 3. CTour Efficiency vs Condensate Injection Rate for Dispersed and Dissolved Components

Condensate Injection and Mixing System

The efficiency of the CTour process is significantly influenced by the design and operation of the condensate injection and mixing system. The injection and mixing system serves three critical functions to ensure maximum efficiency of the system. These are:

1. Ensure homogeneous dispersion of the condensate throughout the produced water volume
2. Provide high surface area and turbulence to facilitate mass transfer of the dissolved components between the aqueous and condensate phases
3. Promote coalescence and absorption of condensate and oil droplets by thorough dispersal of the hydrocarbon phases

Testing and operational data indicates that these conditions are met when a pressure drop across the injector and mixing system is above 1.1 bar. This is illustrated in Figure 4 where the removal efficiency of naphthalene's is plotted against the pressure drop across the mixers as a constant condensate addition of 0.5%. All the CTour systems in operation utilize the ProPure WT200 Injector / Mixer (C100 injection mixer and M100 in-line mixer) system for optimized performance and efficiency.

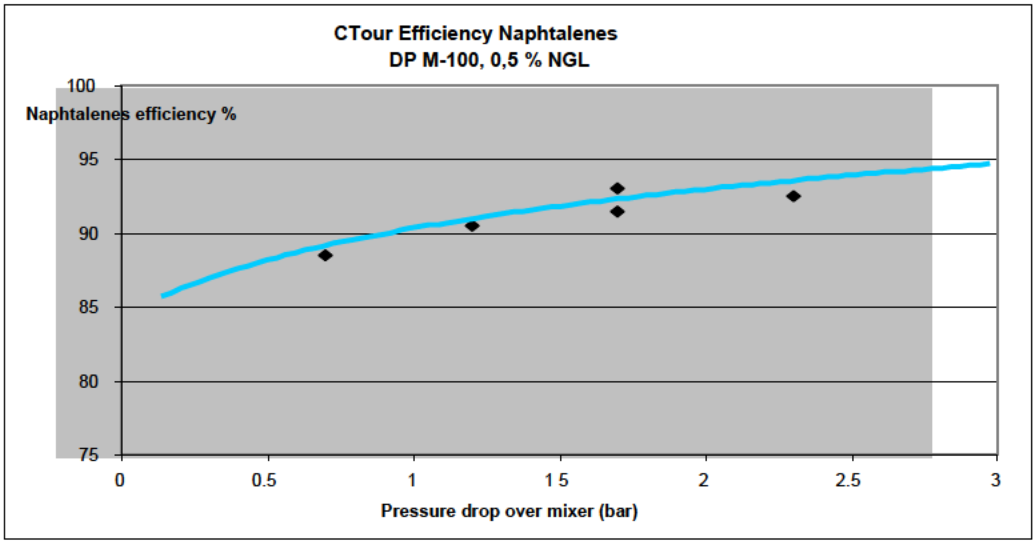

Figure 4 CTour Removal Efficiency as a Function of Mixer Pressure Drop

EKOJ Produced Water System description

The CTour Produced Water System (PWS) reduces the dispersed and dissolved hydrocarbon content in the produced water by injecting condensate into the produced water.

Fig. 5 illustrates a snapshot of the produced water system at EKOJ were produced water from the HP and LP Separators is routed to the old hydrocyclone package, consisting of 3 hydrocyclones, one for the HP process, one for the LP process and one for common use (both HP and LP). These cyclones are upgraded with new liners and reject system. The reject from these hydrocyclones is routed to the CTour Flash Tank via the old Flash Tank, and produced water to the new CTour PWS.

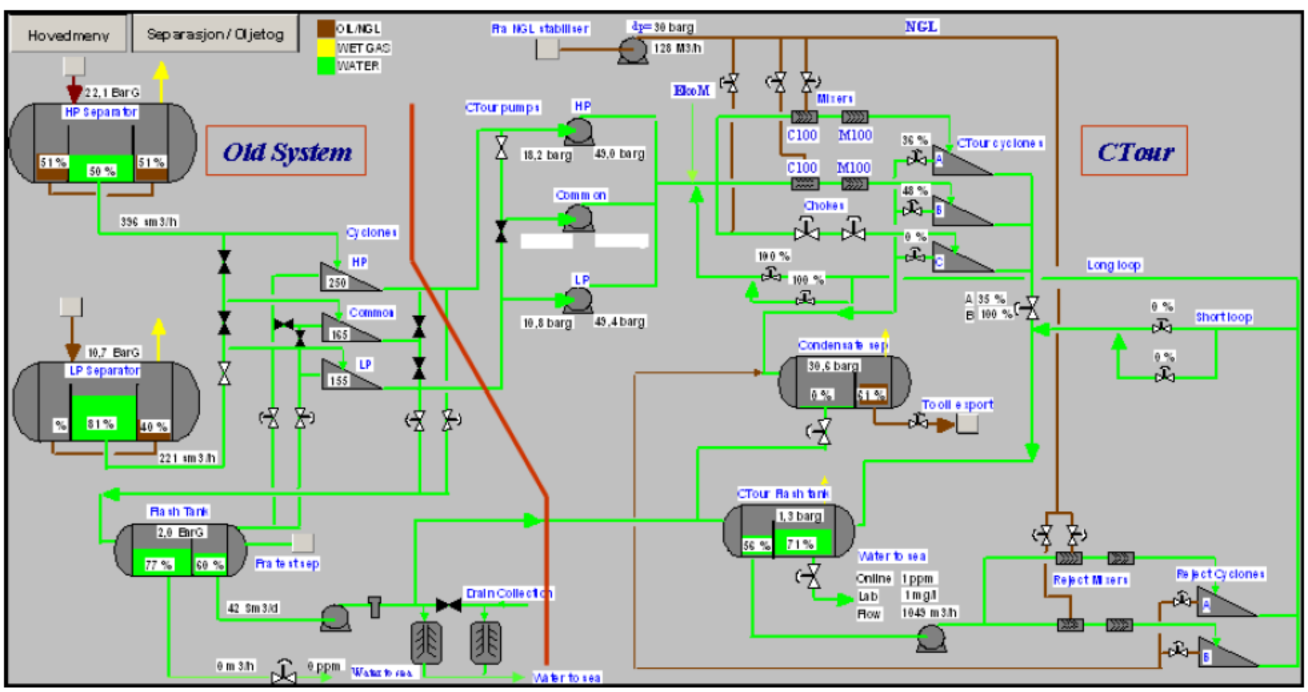

Figure 5: Snapshot of a CTour Process Flow Diagram at EKOJ (Test series 1 to 6)

Produced water from the HP and LP system is boosted up to a pressure in excess of 40 bar (exceeding the bubble point of the NGL by 10 bar) to enable the NGL to be in a liquid state at the hydrocyclone reject pressure and further transported to the CTour PWS. The produced water is routed through alternate mixing systems, either the ProPure, C100 injection mixer and a M100 re-mixer, or two choke mixers. The NGL (0,5Vol%) is taken downstream of the NGL stabilizer and pressurized up to a fixed set point above the water pressure by the NGL injection pumps, and injected through the C100 injection mixer and remixed in the M100 mixer, or in the line upstream the choke mixers. After the mixer system the water is routed through hydro cyclones, where water and oil/NGL is separated. PW is routed to the CTour PW flash tank and the reject liquid is routed to the CTour condensate separator.

In the CTour PW flash tank water and gas is separated, and oil is separated from the PW by gravity separation and leaded over the weir into the reject oil chamber. Clean PW is routed to the sea, and liquid from the reject oil chamber is routed to a separate CTour cleaning process. If the PW from this cleaning process have acceptable quality, the water is routed back to the CTour PW flash tank, clean side. If not, the PW is routed back to the main process for a second CTour treatment.

The CTour condensate separator is a three-phase separator where water, oil and gas are separated.
Gas is routed to the HP Flash gas compressor suction cooler. The NGL/oil is routed to the main export line. PW from the waterside is routed to the CTour PW flash tank reject oil chamber.

The operating premises for the CTour PWS are that the produced water is routed to old produced water system if there is a shutdown on the platform or at the CTour PWS. The system must be manually switched back in order to resume the CTour treatment.

Results and discussion

ProPure AS, the licensor of the CTour Technology, issued a performance guaranty rooted on a dedicated process simulation tool developed specifically for Ekofisk. The simulator was developed to predict the discharge of dispersed and dissolved hydrocarbons under a given set of operating conditions for the CTour Process.

The operational conditions for the guaranty were:

- Reference discharge w/o CTour <100 ppm
- Condensate injection rate <0,5Vol %
- Condensate (NGL) density <550 kg/m3
- Pressure drop over injection mixers(bar) 1,1<DP<3,0
- Condensate is in liquid state at HC reject
- OiW and SVOC analysed OLF Recommended Guidelines (6)

The discharge guaranty, as presented in Table 2, yields an overall reduction in EIF in excess of 80% based on the discharge of natural hydrocarbon components under standard operating conditions excluding eventual EIF contribution from production chemicals.

EIF Component Group	CTour Process guarantee %	Average* Removal Efficiancy %	+/-SD %
Naphthalenes	78	86	1,9
2-3 ring PAH	86	89	2,4
4+-ring PAH	89	92	2,5
C0-C3 phenols	0	0	4,4
C4-C5 phenols	41	29	9,1
C6-C9 phenols	60	82	4,4
BTEX	35	36	7,2
OiW	<2,2 ppm	<1,3 ppm	

Table 2: CTour Process guaranty and corresponding actual removal efficiency at full scale performance testing.
*SVOC composition of a 22,4 ppm OiW sample was used as reference

It is apparent from Table 2 the removal efficiency for all components exceed the guarantee, except for C4-C5 Phenols, which has 12% lower removal than expected. The reason for this might be due to analytical variations as illustrated Fig 6, and it should be noted that the contribution to EIF from C4-C5 Phenols is relatively small because these components are water soluble with low bioaccumulation potential. The excess removal of the more toxic heavy components, like 4+Ring PAH and C6-C9 Phenols, will most probably compensate for the 12% higher concentration of C4-C5 Phenols.

The performance test includes ten test series as illustrated in Table 3 which also presents the corresponding OiW discharges. Each test series comprises three data sets:

1. OiW and SVOC (Solvable Volatile Oil Components including naphthalene's, PAH's, phenols) and BTEX composition with out CTour
2. OiW, SVOC and BTEX composition with CTour using two alternate condensate injection and mixing systems.

The OiW discharges as presented in Table 3 illustrate that for all the three lines comprising separate condensate injection/mixing systems and hydrocyclones the average discharge is in the range 1-2 ppm, with only one measurement exceeding the guaranteed value of 2,2 ppm. The minor differences observed represent typical variations caused by different setting and operations of the individual hydrocyclones. The results confirm successful scale-up of the CTour process from 5 000 (4" pipeline) to 150 000 BWPD (14" pipeline).

With the respect to operation the choke system has suffered from scale deposition whereas this has been alleviated for the ProPure mixers. The ProPure mixers are mechanically designed so that the risk for deposition is reduced, and possible deposits are efficiently removed by an automized mixer operation from mixing position to full-bore position and back again.

Test series	W/O CTour Sampled in Header Upstream mixers ppm	Line A Propure A+HC A o-i-w downstr HC ppm	Line B Propure B+HC B o-i-w downstr HC ppm	Line C Chokes + HC C o-i-w downstr HC ppm
1	15	1	1	
2	15	1	1	
3	12	2	1	
4	17	2	1	
5	13	1	1	
6	17	1	2	
7	22		3	1
8	68		1	1
9	18		1	1
10	27		1	1

Table 3: OiW discharge with and without CTour at EKOJ for parallel mixer-hydrocyclone configurations

The corresponding removal efficiencies of SVOC and OiW is illustrated in Figure 6, where for instance "Sample #" 1 and 2 refers to Test series 1, "sample # 2 and 3 refers to Test series 2 ,- and so on.

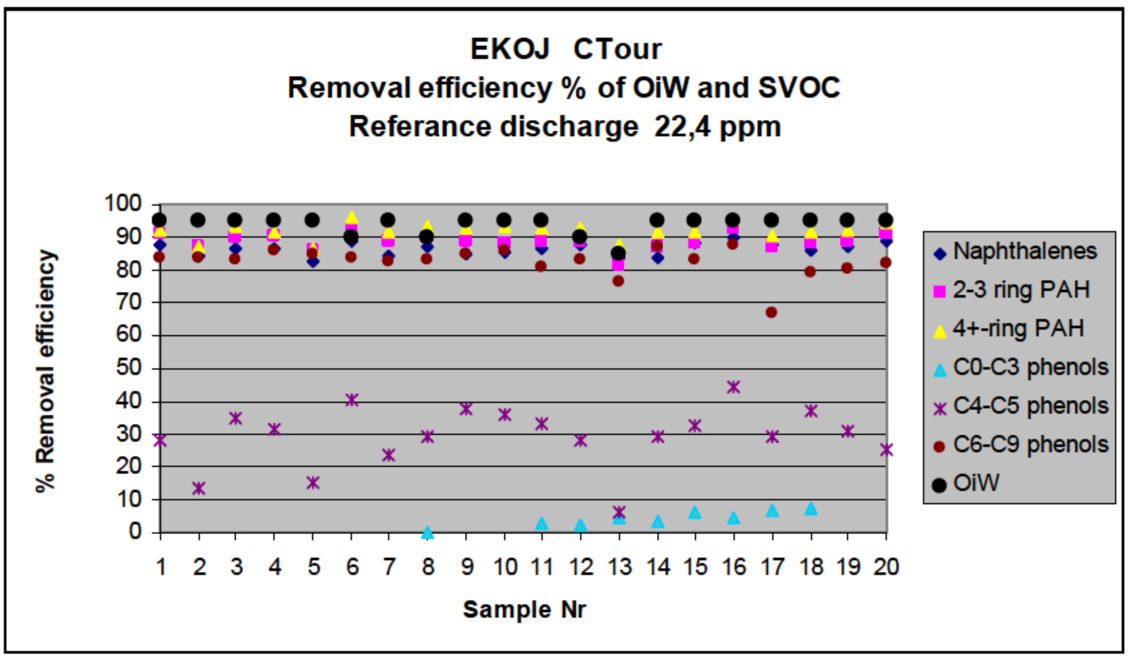

Fig 6: Relative OiW and SVOC (Naphtalenes, PAH's, Phenols) ,discharges with and with out CTour.

Conclusion

With reference to the above performance tests of CTour at EKOJ, it is concluded that the process is successfully scaled up, yielding residual discharge reduction in accordance to the guarantee parameters originally granted by ProPure AS in the licence agreement.

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