CTour – Simultaneous Removal of Dispersed and Dissolved Hydrocarbons in Produced Water

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Presented at the
16th Annual Produced Water Seminar Nassau Bay Hilton
Houston, Texas
18-20 January 2006

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Abstract

In order to meet tighter and tighter legislation worldwide, a new technology called CTour has been developed, tested and installed on offshore platforms. The CTour process is based on extraction and is one of the only technologies in the world that can cost-effectively remove both dispersed and dissolved hydrocarbons from large volumes of produced water. When operated under optimum conditions, the CTour process yields residual oil discharges of <3 ppm and at the same time removes 90-95% of the dangerous dissolved PAH components.

The CTour process is currently commissioned for full-scale installation at five different platforms in the North Sea. These units will be in operation by 2007 and will in total treat approximately 1.8 million BWPD, which represents two-thirds of the 2007 projected produced water discharges in the Norwegian sector.

CTour represents a step change in produced water management, and the process has served as a vehicle in facilitating "Zero Harmful Discharges" legislation in Norway. It is expected to influence future discharge legislation in other countries as well.

Introduction

It's a fair bet to say that anyone involved in the upstream oil & gas industry knows that where gas and oil are produced, water is almost sure to follow. Typically, the industry does not assign value to produced water, except in cases where the produced water is re-injected for enhanced recovery. As a result, operators want to dedicate as little time and attention as possible to the treatment, handling and disposal of the produced water. Unfortunately, in most cases efficient and effective management of produced water is only a dream as the produced water contains contaminants – oil and solids at a minimum – which often require a substantial investment of time, money and resources. Environmental and operational concerns which necessitate the removal of associated oil and solids provide significant justification for this focus on the treatment of produced waters. Traditionally, produced water treatment has been accomplished through gravity separation, flotation and filtration operations to physically or mechanically remove the contaminants. Through effective utilization of these processes, oil and solid content can be reduced to acceptable levels to meet both environmental and operational criteria.

Governmental agencies, environmentalists and operators who rely on the best available technology as justification to bench mark the resultant discharge criteria often establish environmental discharge requirements through a negotiated process. Generally speaking, these criteria do not include any provision for dissolved hydrocarbons because, until recently, an economical solution has not been demonstrated. The patented CTour process[1] system has been

[1] B. Henriksen et al., "Process For Simultaneous Extraction of Dispersed and Dissolved Hydrocarbons Contaminants from Water," U.S. Patent No. 6,077,433, Assignee Cagniard de la Tour A.S., Stavanger, Norway, Date of Patent 20 June 2000.

proven to remove dissolved hydrocarbons, in addition to the free and dispersed oils. Performance results of the CTour process have demonstrated a reduction of the OiW content in produced water by as much as 80-95% over the currently acceptable industry performance standards. The CTour process has demonstrated a particularly effective ability to remove polycyclic aromatic hydrocarbons (PAH), dispersed oil and phenols[2].

The generally accepted best available technology for de-oiling produced water is a hydrocyclone / degasser-float cell configuration that yields an average discharge concentration of 25 ppm. The CTour process can yield a residual oil discharge as low as 2-3 ppm, and delivers the added benefit of removing dissolved hydrocarbons. In addition to these process benefits, the CTour process has the ability to treat large volumes of produced water, while providing a low weight, height, footprint, CAPEX and OPEX; yielding little or no waste products; and reducing overall chemical use[3].

The CTour Process

History

The CTour process was initially developed 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 Control Authority (SFT).

The CTour process has demonstrated the ability to enhance the performance of traditional produced water treatment systems, including hydrocyclones and flotation cells, operating under the necessary process conditions. 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. The proprietary rights to the process are held by The PURE Group (Stavanger, Norway).

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 to aid in the 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.

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[2] "*Ekofisk cleaning up its discharges*," Upstreamonline.com, 19 August 2004.

[3] B.L. Knudsen, et al., "Meeting the Zero Discharge Challenge for Produced Water," SPE 86671, The Seventh SPE International Conference on Health, Safety and Environment, Calgary, Alberta, Canada, 29-31 March 2004.

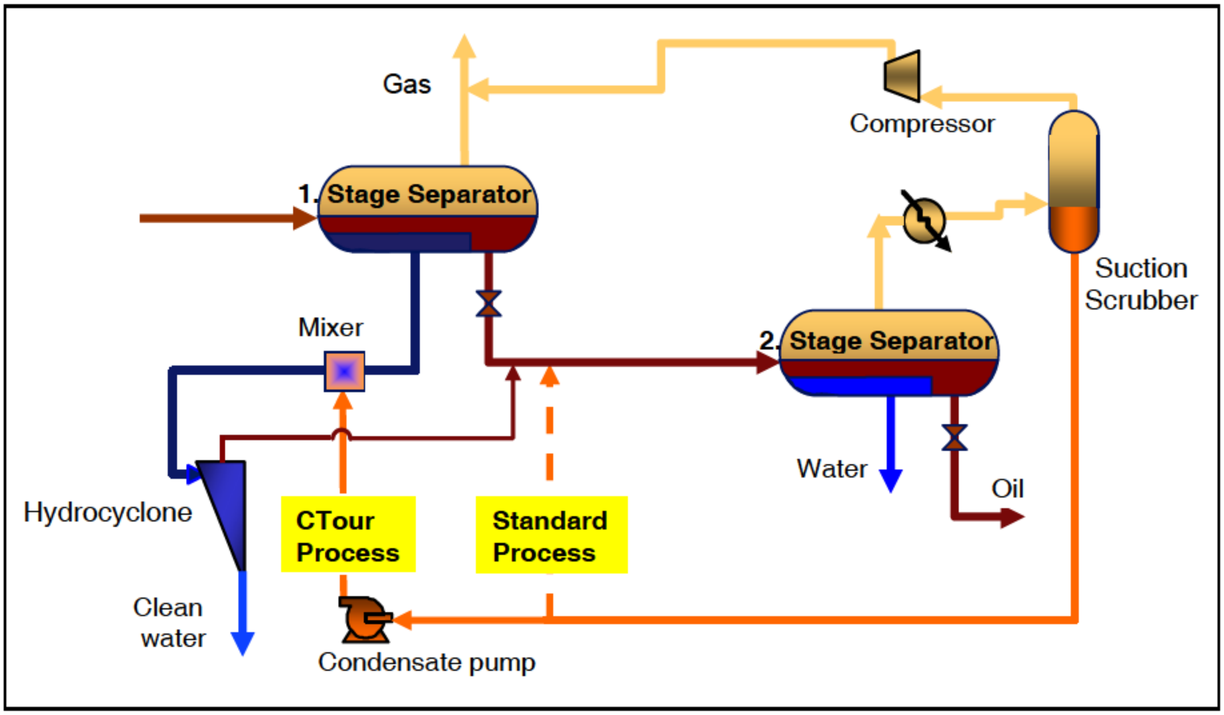

Figure 1. CTour Process Flow Diagram

The developers of the CTour process investigated a number of parameters to determine their effect on 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. This investigation concluded that none of these parameters had any influence on the process. However, this investigation revealed that the efficiency of the process is very sensitive to the design and operational conditions of the injection and mixing system.

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

1. Collect a sufficient volume of suitable condensate, such that it is in liquid form at the operating pressure and temperature.
2. Inject 0.5-2.5% (volume/volume) of the 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.
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 the following:

1. The condensate must be maintained in a liquid phase during the injection and extraction stage, and
2. Any residual condensate not separated from 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 naphthalene. 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 do heavier condensates. If the available condensate has objectionable components, it may need to be conditioned prior to utilization in the CTour process.

Extensive data was 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. The results of this analysis are shown in Figure 2 below.

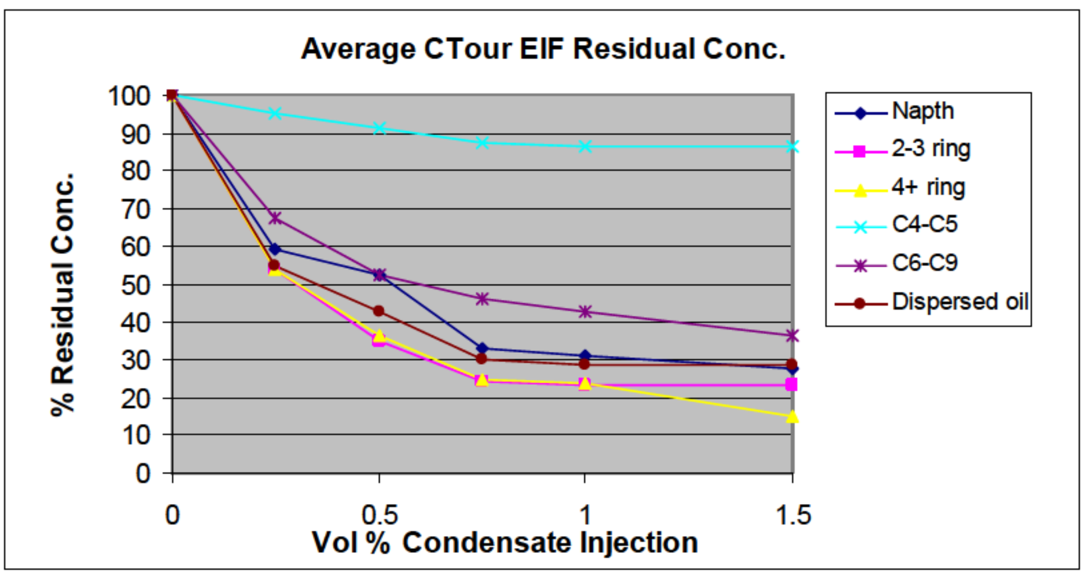

Figure 2. Average CTour Residual Concentration per Environmental Impact Factor Group[4]

This data, along with the condensate compositional analysis which is illustrated in Figure 3, has been utilized to develop a process prediction model for the CTour process.

[4] B.L. Knudsen, et al., "Meeting the Zero Discharge Challenge for Produced Water," SPE 86671, The Seventh SPE International Conference on Health, Safety and Environment, Calgary, Alberta, Canada, 29-31 March 2004.

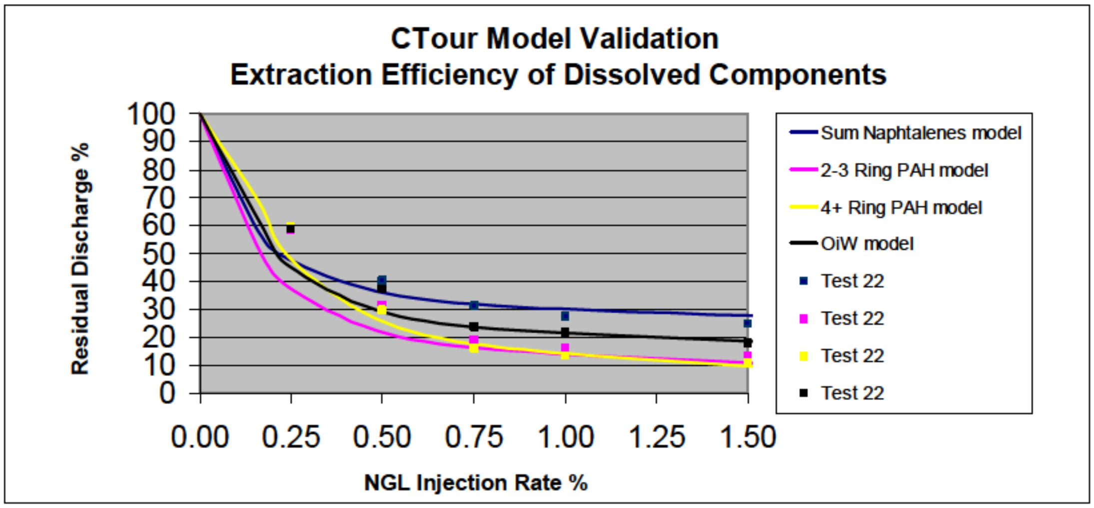

Figure 3. CTour Performance Prediction Model Confirmation

Condensate Properties, Sources and Supply

As illustrated in the CTour process flow diagram shown in Figure 1, the suction scrubber of the compression train is a standard source of condensate. 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 the condensate to reduce the bubble point,
3. Flashing the condensate in a stripper column to remove undesirable components,
4. Recycling the produced water reject in a reboiler for recovery of the condensate,
5. Cooling the produced water to match the condensate liquid phase properties,
6. Extracting condensate from a HP-gas stream in a JT system (or similar), and
7. Removing BTEX components in a rectifying column.

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

Condensate Processing Unit

If the feasibility study indicates a condensate processing unit is required, then the unit's principal function would be 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 CTour process does not significantly improve efficiency at condensate injection concentrations over 0.5% (v/v) for low inlet concentrations. This is illustrated in a graph of removal efficiency (% residual concentration) versus condensate injection rate shown in Figure 4.

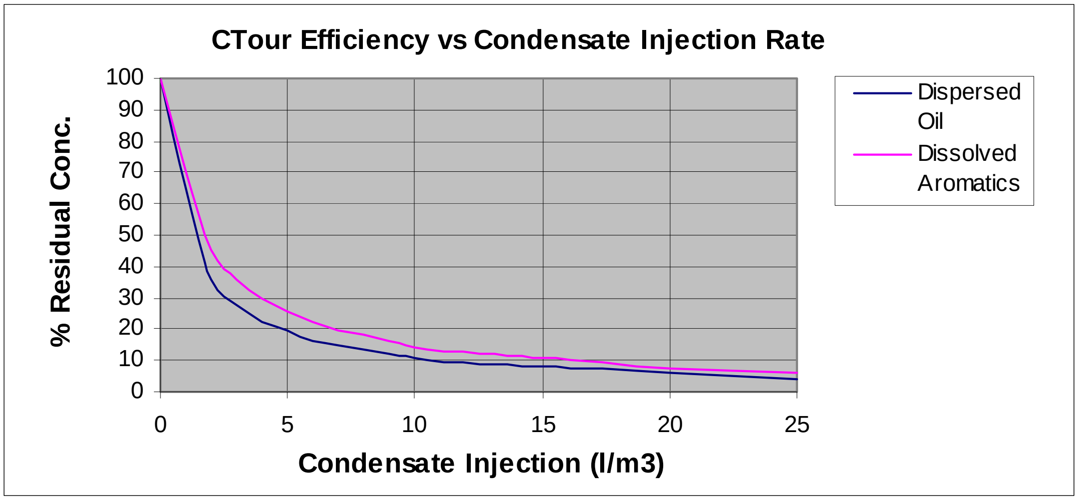

Figure 4. CTour Efficiency vs Condensate Injection Rate for Dispersed and Dissolved Components

<u>Condensate Injection and Mixing System</u>

The design and operation of the condensate injection and mixing system significantly influences the efficiency of the CTour process. The injection and mixing system serves three critical functions to ensure maximum efficiency of the system:

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 indicate that these conditions are met when a pressure drop across the injector and mixing system is above 1.5 bar. This is illustrated in Figure 5 where the removal efficiency of naphthalene is plotted against the pressure drop across the mixers at 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.

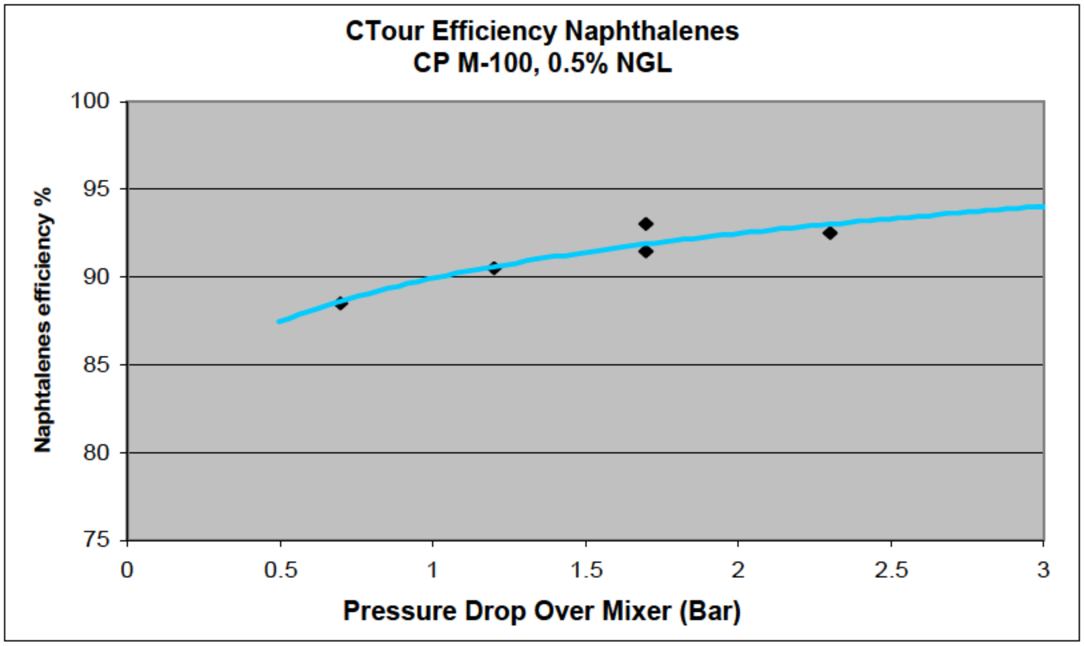

Figure 5. CTour Naphthalene Removal Efficiency as a Function of Mixer Pressure Drop

CTour Performance, Test Results and Enhancements

The CTour process has been extensively field-tested in the Norwegian sector where these facilities have a readily available supply of condensate and the produced water treatment system operates at a pressure and temperature condition suited for the available condensate. These fields include Statfjord B, Ekofisk 2/4J, Troll C, Aasgard and Snorre TLP.

As a result of these field trials, the following production facilities have implemented full-scale systems:

- Statfjord C (2004)
- Statfjord B (2005)
- Statfjord A (2005/2006)
  - Total Water Volume Treated at Statfjord facilities 1,400,000 BWPD
- Snorre A (2005/2006)
  - Water Volume Treated 150,000 BWPD
- Ekofisk 2/4-J &M (2005/2006)
  - Water Volume Treated 300,000 BWPD

The total produced water treated at these facilities accounts for two-thirds of the total volume of produced water in the Norwegian sector. Figure 6 presents the typical results from several of these installations. Note that the CTour performance % indicated is the **additional** removal efficiency yielded by the addition of the CTour process. For example, the NSA 1 with a NGL injection rate of 1% of the produced water rate achieved a 90% reduction in the OiW discharge level. Assuming the pre-CTour OiW discharge level to be at the legislated maximum acceptable value of 30 ppm, the post-CTour performance would result in a 3 ppm discharge level.

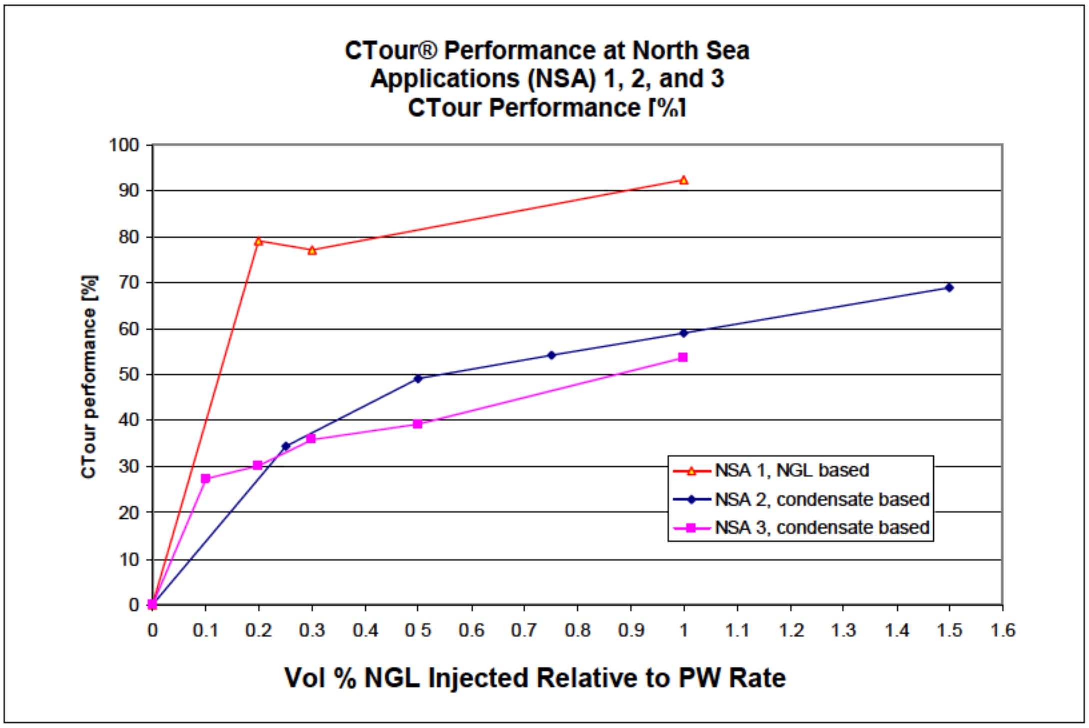

Figure 6. CTour Typical Full-Scale Performance at Several North Sea Installations

CTour Enhancements

In a continuous improvement process, moving the installation of the CTour system to a downstream produced water treatment system would realize several possible advantages. These include 1) substantially reducing the amount of condensate, 2) even further reducing the discharge OiW levels, 3) achieving more consistent performance and 4) yielding a cost-effective alternative to produced water re-injection.

A flow diagram of this "downstream" approach is illustrated in Figure 7, and the net performance is shown in Figure 8.

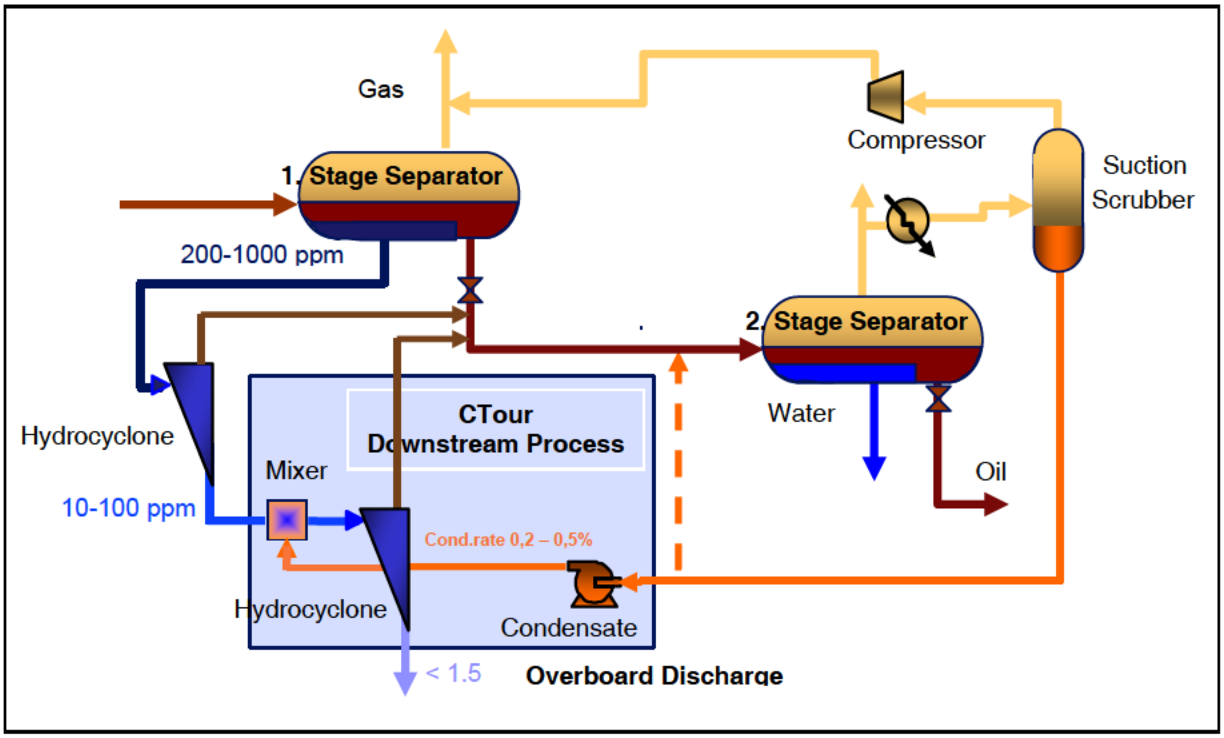

Figure 7. CTour Process Implementation "Downstream" Process Flow Diagram

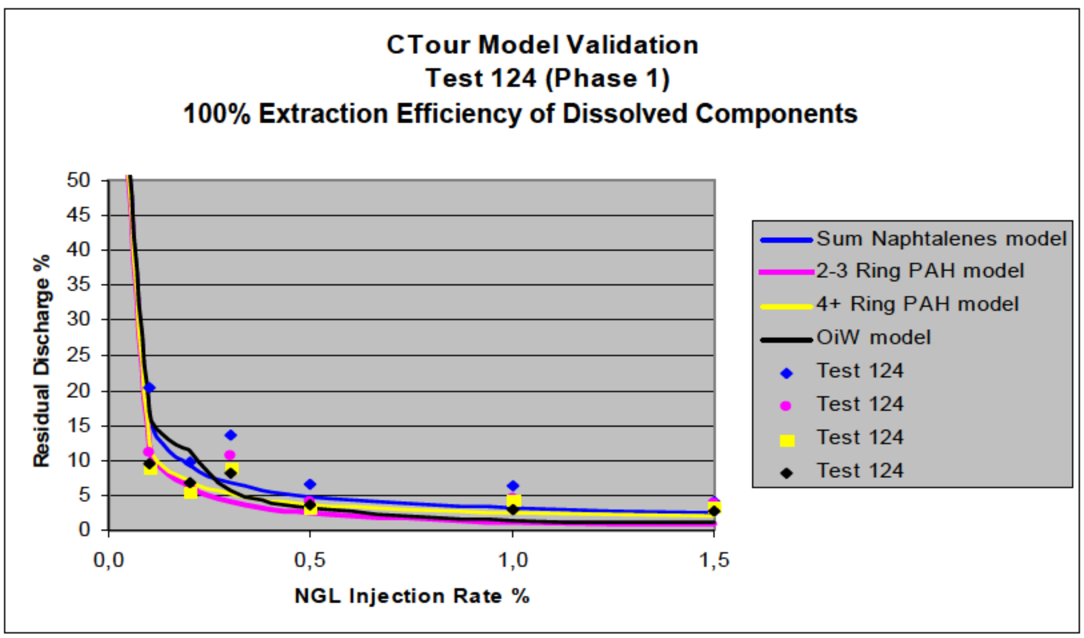

Figure 8. CTour Process Performance "Downstream" Configuration

Conclusions

The CTour process has proven to be a viable, reliable and efficient means of removing dispersed and dissolved hydrocarbons in produced water that has been embraced by the Norwegian producers. By the end of 2007, at least two-thirds of the produced water volumes in the Norwegian sector will be treated by the CTour process.

Several test skids have been built and utilized to demonstrate and verify applicability and performance of the CTour process. In addition, a performance prediction model has been developed which accurately predicts full-scale performance of the CTour system.

The CTour process breaks ground as a step change in the treatment approach for produced waters. It is the new “best available technology” in specific markets.