Produced Water – Best Management Practices
28 & 29 November 2007

Efficient Produced Water Management through Online Oil-in-Water Monitoring. Case Study: StatoilHydro's Snorre B

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1 INTRODUCTION

Oil and gas (O&G) industry's global water production has increased dramatically over the last decades. This trend is expected to continue. The global water cut is today 75%, a 5% increase over the last decade [1]. In regions like the Norwegian Continental Shelf, the water production is now larger than the oil production. Increasing water production is, consequently, both a major environmental, as well as economic, issue.

These fact call for immediate action from the O&G industry in order to increase water processing capacity and to improve management of produced water. Actions taken to meet this challenge may vary between production installations, fields, regions and operators, but will, however, fall into two categories: Modification and optimisation of current process systems or design and implementation of new process systems. In any case, improved process monitoring will be important in meeting these operational challenges.

Online oil in water (OiW) instrumentation is expected to play an important role in future produced water management. Implementation of such technology may result in:

- Efficient (real time) process monitoring and optimisation (throughout the process)
- Increased throughput where oil production is bottlenecked by water processing system
- Meeting mandated HSE goals for the reduction of oil in water discharges
- Cost reductions from improved water treatment (chemicals, etc.)
- Reduced costs of buying (traded) discharge quotas (UK)

This paper describes the ProAnalysis' Argus® Environment OiW monitor technology platform as well as installation and implementation of the instrument for environmental monitoring at StatoilHydros's Snorre B platform. Emphasis is put on calibration of the Argus Environment instrument towards current methods (manual sampling and analysis). Additionally, the paper describes and documents the online OiW monitor as a valuable tool for produced water management at Statoil's Snorre B operations and an efficient tool to meet the operator's ambitious environmental (HSE) targets – zero harmful discharges to the environment.

In conclusion, data from this StatoilHydro-operated offshore installation clearly demonstrates that implementation of online OiW monitoring technology have had substantial impact on produced water management.

2 THE ARGUS OIW MONITORING TECHNOLOGY

2.1 Fluorescence

ProAnalysis' OiW monitor technology platform is based on the measurement principle fluorescence. This well established optical measurement principle has over the last decades found numerous applications in the O&G industry, both for process and environment monitoring. The widespread use of fluorescence can be accredited to a number of important system characteristics:

- High sensitivity for aromatic hydrocarbons
- High selectivity for aromatic hydrocarbons
- Wide dynamic detection range

- Low sensitivity for variations in physical and chemical environment

A more detailed discussion of fluorescence and its application in OiW monitoring can be found in [2].

2.2 The Argus Technology Platform

Figure 1: The Argus Environment OiW monitor.

The Argus technology platform takes full advantage of the fluorescence measurement principle. All elements of the classic fluorescence system design are engineered into a unique technology platform including an inline probe design, which isolates the light source, the optical system (filters and sensors) and electronics from a *harsh* process environment. The Argus design is made possible through the use of laser (as light source) and fibre optics (as light guides both for excitation [UV light] and emission [visual light]). Figure 1 illustrates the main elements of Argus Environment: Field enclosure (Eex de) connected via an optical fibre cable to the inline optical sensor probe mounted into an insertion- and retraction tool.

A measurement cycle includes the following:

Excitation – a UV laser pulse is transmitted from the laser to the aqueous sample via an optical fibre. Fluorescence is induced in aromatic hydrocarbons dispersed in water.

Emission – visual fluorescence is collected by another optical fibre and transmitted through optical filters to the sensor unit. Each measurement cycle has duration of a few milliseconds. Sampling rate (configurable) is set to 10 Hz resulting in real time monitoring of oil in water.

Another basic characteristic of the Argus technology platform is a proprietary integrated system for maintenance of the optical interface (“window”) towards the process environment. Depending on the application, laser-based or ultrasound-based cleaning technologies significantly reduce the need for manual inspection and maintenance.

3 SNORRE B

Located in the Tampen area of the Norwegian North Sea, the Snorre field has been producing oil and gas since August 1992. The Snorre development embraces two platforms, A and B. The Snorre B platform, a submersible PDQ floater came on stream in June 2001. Oil from Snorre B is piped to Statfjord B for storage and export. The gas can be injected back into the reservoir, or (partly) transported by pipeline via Snorre A to the Statpipe/Norpipe system.

Figure 2: StatoilHydro’s Snorre B (Photo: StatoilHydro).

Table 1 - Technical data, Argus Environment at Snorre B

Parameter	Value
Process temperature (nominal)	65°C
Process pressure (nominal)	< 1 barg
Process flow velocity (nominal)	1-2 m/s
Position, OiW monitor	Outlet to sea

3.1 Water Processing System at Snorre B

Figure 3 illustrates the main elements of current water processing system at Snorre B.

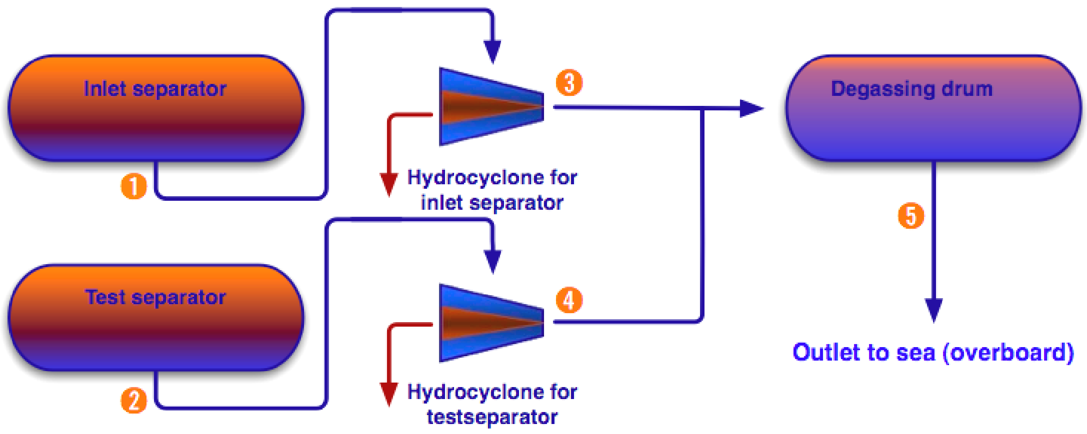

Figure 3: Water processing system at Snorre B (main elements).

The water processing system at Snorre B consists of hydrocyclones downstream the inlet and test separators, followed by a degassing drum. From the degassing drum the produced water can be routed either to sea, or re-injected to the reservoir via water injection booster pumps and water injection pumps. During normal operation the produced water is routed to sea. Produced water re-injection (PWRI) has been stopped due to potential reservoir souring. However, PWRI is performed during cleanup of new wells. The Argus online OiW monitor has been placed between the degassing drum and the water injection booster pumps. Hence, online measurements are possible both when routing produced water directly to sea, and when performing PWRI.

3.2 Argus® Environment OiW Monitor at Snorre B

Early 2006 StatoilHydro's Snorre B operations decided to conduct offshore testing and verification of two different online OiW monitors. One of the selected instruments, Argus Environment, was installed and commissioned in February 2006. After completing an internal test program (StatoilHydro), the instrument was integrated into the normal operation setup of Snorre B.

As one of the first offshore installations of the Argus technology platform, the Snorre B offshore team collected and communicated valuable information from both OiW measurements and the daily use of the instrument.

3.3 Day to day operation of Argus Environment at Snorre B

Data from Argus Environment are directly implemented into Snorre B's control system and accessible for the operator in real time. *Argus Manager* (software included) is installed at local PCs in order to e.g. monitor and control the instrument (via a IP network).

Due to hard scaling in the water process, it is advised to retract, inspect and clean (manually) the sensor probe (see picture) weekly. Duration, inspection: 15 – 20 minutes.

Figure 3: Inspection of inline sensor probe (Photo: StatoilHydro).

4 ONLINE OIW MONITORING AT SNORRE B

4.1 Initial Phase: Confidence Building (February – December 2006)

The initial phase after commissioning of Argus was characterised by technology verification and validation. How to operate this new tool, how to implement the new flow of real time data into the produced water management system, how to relate Argus' data to data from standard manual sampling and laboratory analysis and how to establish procedures for periodic maintenance of the instrument. Minor technical challenges were solved during this phase.

4.2 Next Phase: Calibration, Accuracy and Stability (December 2006 – Today)

Results from the initial phase led to a program for a more detailed evaluation of Argus' characteristics with the ultimate objective to replace manual sampling and laboratory analysis with online monitoring. An offshore calibration program initiated this phase. Reproducible manual sampling and laboratory analysis, well coordinated with logging of the online OiW monitor output, resulted in data illustrated in figure 4.

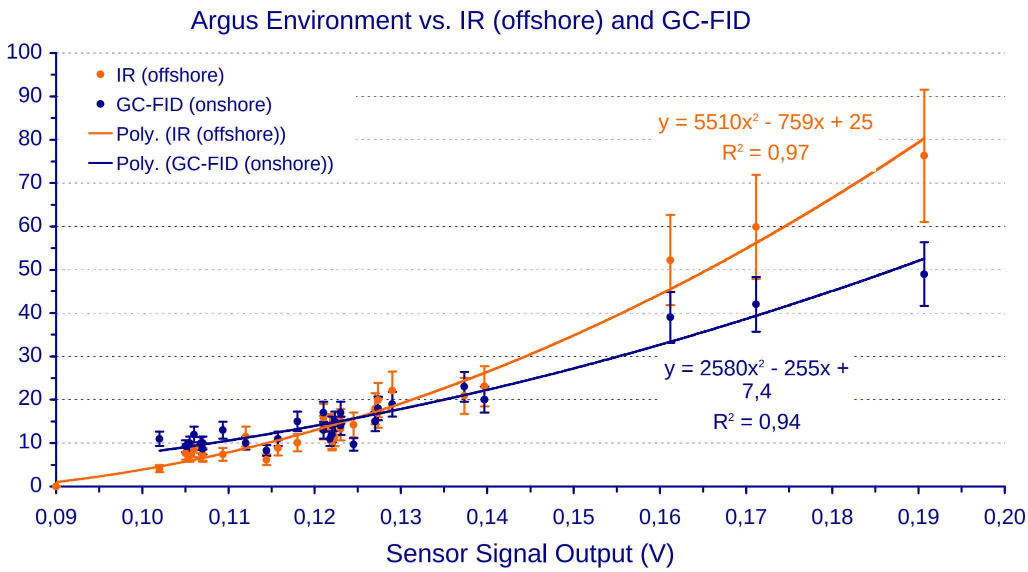

Figure 4: Calibration: Argus Environment sensor output vs. IR and GC-FID analyses. Error bars: ±15% for GC-FID and ±20% for IR lab analysis methods (source: West Lab).

Figure 4 displays sensor output versus corresponding values from offshore laboratory IR absorption analyses (InfraCal [Wilks Enterprise, Inc.]) and onshore GC-FID analyses (NS-EN ISO 9377-2 method) performed by Intertek West Lab (third party). Data from the calibration program was processed in line with Department of Trade and Industry's (UK) regulations for calibration of online OiW monitors [3].
The graph illustrates a high degree of correlation between sensor output (Argus Environment) and both lab methods. R^2-values for 2. order polynomial regression: 0,94-0,97 (GC-FID values are lower than corresponding IR values, due to the fact that some classes of hydrocarbons are removed before the GC-FID quantification of oil (compared to the IR method)). For practical reasons, calibration factors derived from the Argus Environment vs. IR data were integrated into the instrument (despite the fact that the GC-FID method represents the standard method).

StatoilHydro's governing documents (working requirements) specify that online oil in water measurements can be used as a reporting tool towards the Norwegian authorities, providing acceptable calibration of the instrument. Snorre B is working towards implementing online measurements for reporting.

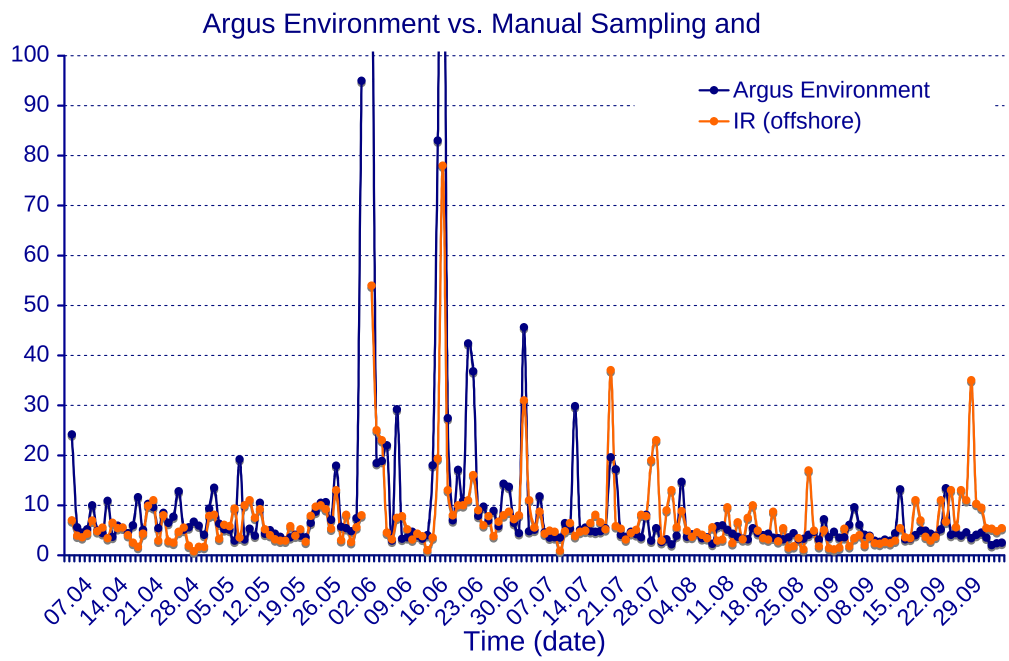

Figure 5: Online versus manual sampling and analysis over a period of 6 months.

After almost one year of operation, Statoil initiated a new test to evaluate the (technical) stability of the system. Figure 5 illustrates 6 months of data (April 1 to October 1, 2007). At Snorre B, manual samples for regulatory purposes are taken 4 times each 24h period (day), mixed and analysed to give the daily value. Data from Argus Environment are sampled each 15 minutes (i.e. 96 samples/day), averaged and given as the corresponding value. Although Argus Environment can provide data every second (user configurable), the MIKON software tool at Snorre B was set up to sample at this frequency. Comparison of these data sets represents a semi-quantitative approach. No synchronised manual vs. optical sampling, different number of data points averaged for each value and operator-related errors in manual sampling and analysis represent non-quantified sources of error. Despite this, figure 5 clearly illustrates that independent measurements for most data points fall within narrow concentration ranges (mg/l). For most periods of higher oil concentrations (as determined by the IR-method), we also find (qualitatively) good correlation between the online and offline measurements. For future analyses, improved (coordinated) sampling will make more accurate statistical analyses possible.

5 EFFICIENT PRODUCED WATER MANAGEMENT

The following chapters describe cases where Argus Environment has been used for optimisation of Snorre B's produced water system.

5.1 Case 1: Optimisation of Production Chemical Use – Flocculant

Operational challenge: Sudden increase in produced water oil concentration.

Definition, flocculant: Flocculants, or flocculating agents, are chemicals that promote flocculation by causing colloids and other suspended particles in liquids to aggregate, forming a floc. Flocculants are used in water treatment processes to e.g. improve the sedimentation of small particles like solids and oil droplets.

Day N: Significant increase in produced water oil concentration observed immediately due to online measurements. Spot samples at 0810h and 1115h show 24 mg/l and 27 mg/l, respectively (samples analysed in the offshore laboratory). More samples were taken to further characterise the problem:

- At exit, 1. level separator (at 1600h): 60 mg/l
- At exit, 1. level hydrocyclone (at 1715h): 12 mg/l
- At exit, test separator (at 1600h): 16 mg/l
- At exit, test hydrocyclone (as 1715h): 2.1 mg/l
- Spot sample, at online OiW monitor (at 1640 h): 6.6 mg/l

All tests indicated a problem at 1. level separator. Some days earlier concentrations at this point were close to 5 mg/l! Test samples verified no problems at the hydrocyclones. The produced water system should, however, easily handle 60 mg/l at exit of 1. level separator.
Increase in produced water oil concentration coincided with bad weather coming up (Snorre B is a submersible floater). From weather conditions and water sampling, operators suspected deposited sand particles to suspend into the liquid phases in the 1. level separator. High levels of sand were later confirmed by thermograph. Increased slugging frequency was also observed.

Daily manual sample the day before: 16 mg/l.

Later, day N: Jetting of 1. level and test separator – as well as degassing drum to remove sand. Estimated 230 kg sand removed. Regular skimming of degassing drum performed. New samples were taken after jetting (day N+1):

- At 0000h: 34 mg/l
- At 0600h: 32 mg/l
- At 0800h: 17mg/l
- At 1106h: 47mg/l

Preliminary conclusion: OiW concentrations increased rather that decreased following jetting. Samples were also taken upstream:

- At exit, 1. level separator (at 0750h): 38mg/l
- At exit, 1. level hydrocyclone (at 0805h): 19mg/l
- At exit, 1. level hydrocyclone (at 1110h): 2.9 mg/l

From these data, it was concluded that the problem was restricted to the degassing drum.
In fact, oil concentrations seem to *increase* in degassing drum. Problems at the electrostatic coalescer were ruled out.

Laboratory tests were carried out in order to study the effect of increasing concentrations of flocculant (levels 2 ppm, 6 ppm and 20 ppm). Effect of flocculant was only observed at lower concentrations (in line with earlier experience; earlier 9-12 ppm flocculant was injected (with varying degrees of success)).

Injection of 4 ppm of flocculant upstream 1. level separator was started at 1724h.
Argus online OiW monitor responded immediately – and stabilised at 5-8 mg/l.
Skimming was performed shortly after addition of flocculant, to remove flocculated particles.

Conclusion: Higher oil in water values were caused by fine particles in degassing drum.

In order to verify measurements from Argus online OiW monitor, a spot sample was taken at 1853h: 9.3 mg/l. The figure compared well with 5 – 8 mg/l from Argus Environment.

Operator decided to inject flocculant (4 ppm) until the process stabilised.

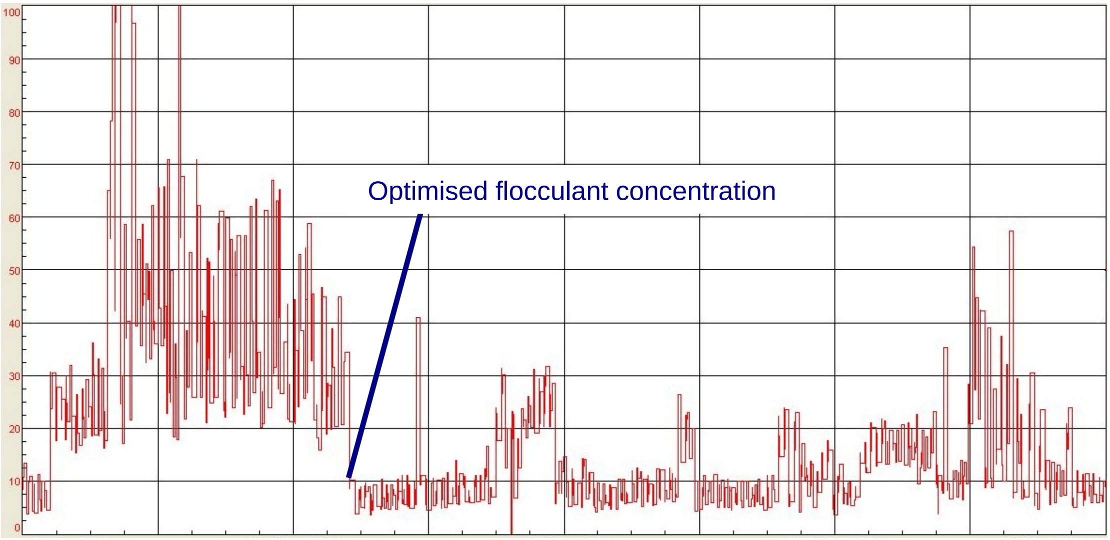

Figure 6: Online OiW monitor output during and after optimisation of flocculant.

5.2 Case 2: Optimisation of Emulsion Breaker

Operational challenge:

- Observed increased water in oil concentration due to one new oil-rich production well put on stream, and another one coming up.
- Optimisation of emulsion breaker concentration
- Balancing oil and water quality

Definition, emulsion breaker: Emulsion breakers are chemicals that are used to accelerate and improve oil – water separation in oil treatment processes.

This production chemical has previously, at optimal concentration, resulted in improved water and oil quality (oil in water and water in oil) at Snorre B. However, overdosing has given pronounced separation problems.

Emphasis was on identifying the optimal concentration of the emulsion breaker – both to improve separation (water and oil quality) and to minimise deterioration of water quality (environmental impact). Earlier testing had indicated that at emulsion breaker concentrations above 1 ppm reduced water quality significantly.

Solution: Optimal dosage of production chemical.

The challenge of taking new wells into production and keeping oil and water quality at its highest level was met by active use of online instrumentation, the Argus Environment, as well as manual sampling and analysis. Optimisation of the separation system was completed within a few days (as illustrated in figure 7) resulting in excellent water quality.

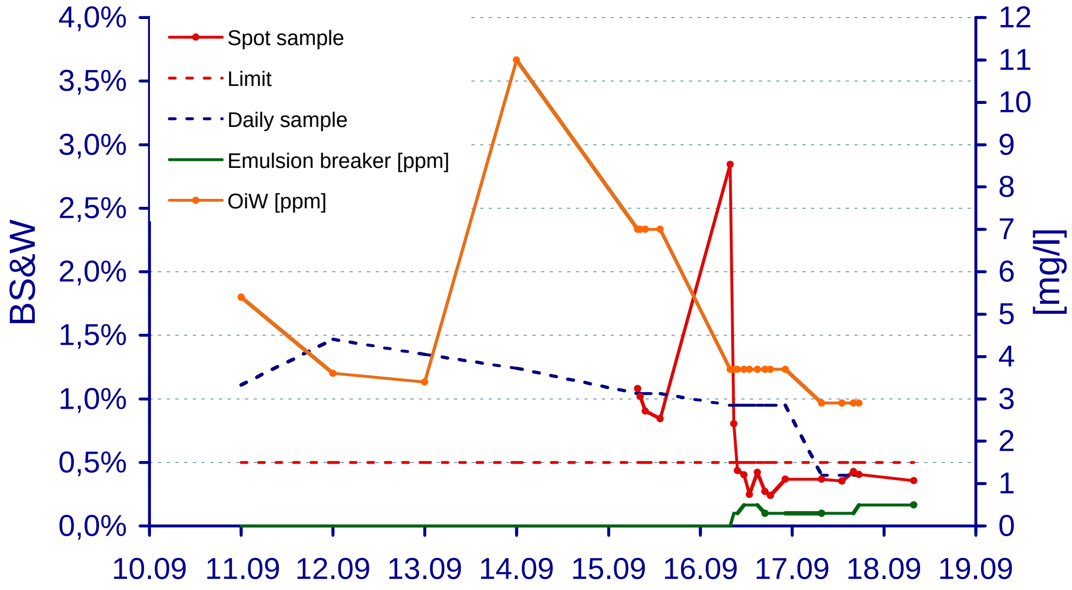

Figure 7: Optimisation of emulsion breaker.

6 PRODUCED WATER MANAGEMENT – THE SNORRE CASE

Accumulated data and experience from 20 months of operation clearly documents the online OiW monitor as an efficient tool in produced water management at Snorre B. This paper describes a few of many ways to optimise water processing at this specific oil production platform.
A complete list of applications where online OiW monitors can optimise O&G operations is difficult to give, but from experience in the North Sea over the last 2-3 years, the following are essential:

- Improved performance of the produced water system (online OiW monitors are installed throughout the process system)
- Effective optimisation (and potential reduction) of production chemical consumption
- Immediate detection of irregular process conditions
- Immediate alarm at acute discharges (HSE)
- Reduced personnel exposure to potentially harmful substances (from significant decrease in manual sampling and laboratory analysis) (HSE)
- Maintenance only when appropriate. Reduced energy consumption, man-hours, and replacement parts
- Reduced downtime

The economic effects of an optimised produced water system are clear but often difficult to quantify. The nature and magnitude of these effects will, by nature, vary with process system:

- Increased oil production due to optimised flow
- Increased oil production due to reduced OiW concentrations
- Reduced use of chemicals
- Optimisation of personnel resources (manual sampling and laboratory analysis, etc.)

In conclusion, results from Snorre B demonstrate that implementation of online OiW monitoring technology have had a substantial impact on produced water management.

At Snorre B, the daily use of Argus Environment OiW monitor has contributed to a 40% reduction in oil in water concentrations over the last 12 months (6,3 vs. 10,5 mg/l).

7 REFERENCES

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[3] Department of Trade and Industry (UK). Guidance Notes for The Sampling and Analysis of Produced Water and Other Hydrocarbon Discharges, version 1.0 (September 2006).