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Report and Executive Summary

Critical Review of Produced Water Sampling, Analysis and Reporting Procedures: Danish Offshore Operations

Maersk Oil Denmark

Our ref ABN1191601/002.001

Lloyd's Register

LIFE MATTERS

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Introduction

During December 2010, Maersk Oil Denmark was subject to allegations published in the Danish newspaper, *Politiken*, regarding the integrity of their produced water management processes, including Oil-in-Water (OiW) analysis and reporting. Maersk Oil Denmark engaged Lloyd's Register EMEA to conduct an independent review of the associated environmental processes and procedures (including implementation). Initial reviews of the Tyra production unit were conducted by Nick Jackson and Amy Annand of Lloyd's Register EMEA, and Stig Stangeland of Lloyd's Register Scandpower. Subsequent reviews of the DUC operations were conducted by Per Christofferson of Lloyd's Register Scandpower and Linda Murray of Lloyd's Register EMEA; they were also supported onshore (Esbjerg) by Amy Annand and Nick Jackson.

Scope of Work

Lloyd's Register EMEA reviewed and determined the degree to which Maersk Oil Denmark's produced water sampling, analysis and reporting (i.e. specifically Oil-in-Water/OiW) processes truly reflected accepted industry practice. The review evaluated existing documented processes and procedures, and compared their implementation onshore and offshore to recognised industry practice, best laboratory practice, and also compliance with the current OiW discharge permits for operating in the Danish sector of the North Sea. The review also included a series of interviews with workforce representatives who developed and used these processes and procedures. Additionally, the review verified a number of samples of reported concentrations, following the path along data transfer points.

The LR EMEA review teams visited:

- Tyra West.
- Tyra East.
- Dan.
- Halfdan.
- Gorm (including Skjold).
- Harald.
- Esbjerg offices.

Findings

Commendations

- Maersk Oil Denmark has established appropriate procedures (specifically OPM 2B Part 3 Rev 9) and associated guidance documents and initiatives which enable operations to meet expectations of the discharge permits associated with the Danish production units. It is noted that in response to the recent changes to the discharge permit, Maersk Oil Denmark has already commenced a review and revision of the OiW procedures and practices.

- Processes are established for employee engagement in procedural change (i.e. the updated Rev 9 of the OiW procedure and Rev 10 that is a work in progress).

- Feedback indicated that the response and reporting culture relating to discharge concentrations greater than 20 mg/l appears to be supportive and reflective of good practice.

- The action level for OiW is 20 mg/l, although the permit defines average monthly discharge limit of 30mg/l. This means that corrective action is often applied before a permit breach occurs. It is also noted that Maersk Oil Denmark has stipulated various internal KPIs, some as low as 5 mg/l for specified discharge points.

- As part of their continual improvement processes, Maersk Oil Denmark has implemented a number of initiatives to improve the efficiency of produced water treatment on board. These have included increasing heating capacity in order to improve separation efficiency, improving flow and skimming properties of the de-gasser, relocating the injection points for the water clarifier, and reducing flow throughput fluctuations.

- Evidence indicated that further improvements to the produced water treatment processes will be introduced. These include exploring the use of online OiW monitoring and investigating the accuracy of overboard flow metering systems.

- Daily production checks are conducted on individual produced water process trains. These checks include levels, pressures and temperatures of specific treatment equipment and processes. This data is then used to troubleshoot and define corrective actions if the 20 mg/l limit is exceeded. Some platforms have also implemented in-line continuous OiW monitoring processes to enhance process control and troubleshooting.

- Evidence obtained from offshore conversations confirmed that employees (e.g. the CCR) are empowered to shut down wells/operations and have done so when necessary.

- Communication with regard to OiW appears to be open and honest, and the workforce is actively encouraged to report on any observed undesired emissions and process deviations. The "eyes and ears" of the workforce were seen to be an important tool in monitoring OiW treatment.

- It is clear that some sound practices have been established and individuals know how to respond and troubleshoot when OiW KPIs are exceeded.

- It is clear that the overwhelming majority of the workforce has great pride in working for Maersk Oil Denmark and cares deeply about their responsibilities. People reported that they did not understand what prompted the newspaper allegations, which they believed did not represent the Maersk Oil organisation that they work for, or the reality of OiW management.

Areas for Improvement

The critical OiW review identified six areas of potential improvement, which are summarised below.

OiW procedure

The OiW Sampling, Analysis and Reporting procedure (OPM 2B, Part 3, Rev 9) enables operations to meet the expectations of the discharge permits. However, the clarity and structure of the procedure can be strengthened. Visibility and understanding of the overall OiW sample collection, analysis and reporting process within the procedure could be improved through the use of Process Mapping.

It is noted that the OiW procedure differs slightly from the reference (OSPAR) method, with examples highlighted below:

- Sample and reagent volumes.
- Sample gas release.
- Sample clean-up.
- Emulsification of sample.
- Blank samples.

The review of the OiW procedure also identified an inconsistent approach to the level of detail contained within the asset specific sections of the procedure. There should be a standardised minimum amount of platform specific data included in all asset specific sections of the procedure. Additionally, there is a lack of platform specific information relating to (where applicable):

- Expectations relating to communication, and how knowledge or data is transferred.
- Details related to the use of in-line and/or continuous monitoring equipment to supplement OiW management.
- Sampling (including when samples should and should not be taken), labelling, packaging, protection, storage and transporting (i.e. sample custody and integrity).
- Determining total volume of re-injected produced water and total volume of overboard produced water.
- Post analysis reporting (i.e. cross-referencing workbooks, production logs and OiW database).

Integrity of data

The Lloyd's Register EMEA reviews could find no evidence that the OiW data had been falsified. However, the lack of robust and transparent sample and data management means that Maersk Oil Denmark is exposed to the potential for error and misconduct. Identified examples of these exposures include the following:

- Existing sample custody practices introduce the potential for samples to be tampered with or to be misplaced; however, there was no evidence that this had taken place.
- Critical data is sometimes verbally transferred.
- There is a lack of written Laboratory Logbooks (denoting sample times, analytical results, anomalies, changes, errors, comments etc.).
- There is a lack of security of data contained within platform specific Excel workbooks.
- When changes are made to data contained within the workbook, there is no record of the original data or documented reason for the change.
- Sense checks (conducted onshore) of reported concentrations did not consistently capture noted data anomalies.
- The first point of verification (using existing practices) is the Excel spreadsheet workbook. This is an issue because the spreadsheet is populated at an advanced stage of the OiW sampling, analytical and reporting process.

Lack of robust verification

The overall process for OiW management should be underpinned by robust verification and Quality Assurance. The review revealed a number of areas where Maersk Oil Denmark did not demonstrate structured processes to assure data quality and compliance with best practice. Examples of these areas include:

- Lack of structured supervisory Quality Assurance.
- Lack of robust verification of On-the-Job training.
- No QC samples analysed to provide assurance of accuracy of results. NB: this is not aligned with good laboratory practice.
- Lack of robust internal audits in order to scrutinise OiW processes.
- The limit of the scope of the Force Technology Audits (i.e. only sampling and laboratory practices and OSPAR correlation) did not enable complete verification of OiW processes.

Degree of variability of reported concentrations

The uncertainty (standard deviation) of reported concentrations and overboard oil volumes is not fully quantified. Variability levels will be associated with:

- The sensitivity of Wilkes Analyzer at lower concentrations (NB: Maersk Oil Denmark has determined the Limit of Detection to be approximately 4mg/l).

- Individual pieces of laboratory equipment (e.g. balances, volumetric flasks, measuring cylinders etc.).
- Differing approaches by individuals with regard to sample collection, storage, extraction and clean-up.
- The OSPAR correlation method.
- Accuracy of overboard flow meters.

The cumulative variability with the aforementioned elements creates an unknown level of uncertainty for the method. Understanding the lower limits of detection is particularly important for reporting lower concentrations, especially those concentrations related to OiW KPIs.

Competency assurance processes

Maersk Oil Denmark is currently establishing a structure for offshore workforce training programmes which includes: training needs analysis, job descriptions, technical training programmes, On-the-Job training programmes etc. This is documented and managed onshore via the Learning Management System (LMS). This framework is still under development and therefore is not fully implemented.

The offshore workforce's individual training programmes are documented in the LMS. It is the expectation that employees will be trained by experienced team members based on tailored role specific training programmes.

Tyra East specific improvements

Some participants on board Tyra East described strong feelings of mistrust towards management both on and offshore. This was supported by perceptions of exclusion and lack of involvement, which are further compounded by stated beliefs that communications between offshore and onshore are ineffective.

Conclusions and Recommendations

OiW procedure

In line with our findings, the OiW procedure (OPM 2B, Part 3, Rev 9) requires a significant update to meet the requirements of the new discharge permit. This upgrade should also address the expectations of OSPAR and strengthen the clarity and structure of the procedure. The platform specific information (e.g. platforms without laboratory facilities, platforms that re-inject produced water etc.) should also undergo a critical review to ensure adequacy. This will enable consistent understanding and application of the overall OiW sample collection, analysis and reporting process.

Integrity of data

The findings indicate that there is a lack of robust and transparent sample and data management meaning that Maersk Oil Denmark is exposed to the potential for error and misconduct. It is therefore recommended that Maersk Oil Denmark implements a number of data integrity control measures in order to reduce the risks associated with inaccurate OiW reporting. These measures include:

- The platform specific instructions should be developed to include a documented sampling plan and procedure.
- Formally document and log verbal transfer of critical information.
- Establish 'Good Laboratory Practice' with the use of written Laboratory Logbooks.
- Introduce data security controls within platform specific workbooks.
- Formalise onshore based sense checks to capture noted data anomalies.
- Introduce robust verification processes that would verify the data trail from sample collection to reporting.

Lack of robust verification

The overall process for OiW management should be underpinned by robust verification and Quality Assurance. The review revealed a number of areas where Maersk Oil Denmark did not demonstrate structured processes to assure data quality and compliance with best practice. These processes should include:

- Structured supervisory Quality Assurance.
- Robust verification of On-the-Job training.
- Analyse QC samples to provide assurance of accuracy of results.
- Robust internal audits.
- Third party audits.
- Update procedures: ensure that the verification processes add value, and are aligned with revised OiW procedures.

Degree of variability of reported concentrations

Inevitably sample collection, custody, analysis and reporting processes will introduce some degree of variability in reported OiW concentrations. The Limit of Detection is likely to be important when the data is utilised for the setting and achieving of internal KPIs, where these are at levels lower than those that can be reasonably detected. It is therefore recommended Maersk Oil Denmark attempts to quantify the lower Limit of Detection for the OiW method and recognises it when setting internal OiW KPIs.

Competency assurance processes

Maersk Oil Denmark is currently establishing a structure for offshore workforce training programmes. They must formalise arrangements to ensure that:

- Existing and new Laboratory Technicians should either complete the newly developed OiW training programme, or verify competency levels of existing Laboratory Technicians against the programme requirements.
- All relevant job descriptions are cohesive and complete. They must accurately reflect produced water management tasks and responsibilities.
- Training programmes are implemented as per identified needs.
- On-the-Job training is formalised, including verification.

Tyra East specific improvements

Critical review findings relating to the Tyra East installation differ from the other DUC assets. Specific recommendations pertaining to this asset are:

- Maersk Oil Denmark has processes to enable individuals to report concerns. It is important that these processes are not only established, but are fully supported and people are encouraged to use them. While recognising that this process is supported by Maersk Oil Denmark, it is clear that some individuals on Tyra East elected to choose a different vehicle to communicate concerns. In support of this recommendation, a culture of openness in reporting and communicating should be further nurtured and embraced within the organisation.

- Maersk Oil Denmark should carefully consider the internal communication and management actions to be taken in the aftermath of these events. This would include communication (i.e. internal/external announcements, lessons learned, and individual response actions) to the workforce and relevant stakeholders. This should clearly define the expectations of onshore and offshore management, and those actively involved in the OiW processes.

1. Introduction and Scope of Work

During December 2010, a series of newspaper allegations raised a number of significant concerns within the Maersk Oil operations in Denmark. As a result, Lloyd's Register EMEA was engaged to conduct a critical review of procedures relating to produced water management. These reviews were carried out via a series of onshore and offshore visits between late December 2010 and February 2011.

The scope of that review examined the adequacy and suitability of the existing Maersk Oil Denmark procedures for sampling, analysis, and reporting of overboard produced water discharges on board DUC installations, including:

- Tyra West.
- Tyra East.
- Dan.
- Halfdan.
- Gorm (including Skjold).
- Harald.

The review also conducted some verification of the procedures as implemented both on and offshore, and commented on the effectiveness of the procedures and how they are applied. Specific elements of the review included:

- A detailed review of the procedures employed for sampling, analysis, and reporting of overboard produced water discharges.
- An independent comparison of the procedures when compared to recognised industry practice (e.g. UK Department of Energy and Climate Change Guidance Notes for the Sampling and Analysis of Produced Water and other Hydrocarbon Discharges).
- The identification of any omissions or inaccuracies within the procedures.
- The review of associated documentation i.e. calibration procedures and certification, historical analytical results, Laboratory Technicians' sampling and analysis notes, competency assurance documentation, maintenance records, audit reports, discharge permits, job descriptions, production logs etc.
- Independent verification of the implementation of the procedures both on and offshore; this would include comment on the effectiveness of the procedures and how they are applied.
- A number of samples of reported concentrations were verified, following the path along data transfer points: from sample collection to analysis to concentration calculations to reported figures.
- Detailed reporting of the Lloyd's Register EMEA findings and recommendations, including the chain of consistency and integrity relating to the Maersk Oil Denmark procedures.

The scope of work for the Tyra East asset varied slightly in focus from the other assets, in that it included an investigative process into the circumstances leading to the publication of the newspaper articles, and detailed discussions with individuals connected with the allegations, as well as the OiW review. As a result, the review that was conducted on board Tyra East had more emphasis relating to the newspaper allegations and did not go into the depth of verification and sampling of the produced water procedure and processes. There was, however, an onshore based review of Tyra East data and reported figures.

It is noted that at the conclusion of the review, new discharge permit requirements were issued by the Danish Environmental Protection Authority. These new requirements dictate that Maersk Oil Denmark will need to revise their oil in water sampling and analysis procedures and associated practices. Although the scope for this review did not explicitly include an assessment of Maersk Oil Denmark's ability to meet these more stringent permitry requirements, we have included some commentary relating to the new permit requirements in the body of this report. Maersk Oil Denmark have committed to conduct a further OiW review in 6-8 months time to ensure that new discharge requirements have been embedded and that the revised procedure is effective and adhered to.

1.1 Methodology

The critical review process included:

- Review of relevant documentation provided to Lloyd's Register EMEA by Maersk Oil Denmark.
- A series of interviews with relevant personnel on the chosen installations, as well relevant beach based personnel with involvement in produced water management.
- Observations of laboratories and laboratory equipment.
- Observations of water sampling, sample custody and transport, analysis and reporting procedures being performed onsite.
- Visiting and study of water treatment process equipment and sampling points.

Each report from individual installations identifies personnel that were interviewed as part of the onsite reviews. Interviews were also conducted with onshore team members who have produced water management responsibilities. These people included:

- Steffen Fredberg Hansen – Chemistry & Environment Department.
- Joan Jacobsen – Training Coordinator.
- Lars Hvejsel Hansen – Head of Chemistry & Environment Department.
- Hans Henrik Kristensen – Head of Production Operations.
- Britt Gydesen – Chemistry & Environment Department.
- Jette J Østergaard – Chemistry & Environment Department.
- Ole Andersen – Metering Department.

A number of documents were reviewed and are listed in Appendix 7. These documents relate to various aspects of produced water management, including procedures, organisational charts, discharge permits, analytical results contained in spreadsheets, training programmes, job descriptions etc. There were also several other documents that were reviewed onsite. The documents were used as input and planning of the review and the content was followed up by interviews and observations.

2. Key Findings

2.1 Commendations

- Maersk Oil Denmark has established appropriate procedures (specifically OPM 2B Part 3 Rev 9) and associated guidance documents and initiatives which enable operations to meet expectations of the discharge permits associated with the Danish production units. It is noted that in response to the recent changes to the discharge permit Maersk Oil Denmark has already commenced a review and revision of the OiW procedures and practices.
- Processes are established for employee engagement in procedural change (i.e. the updated Rev 9 of the OiW procedure and Revision 10 that is work in progress).
- Feedback indicated that the response and reporting culture relating to discharge concentrations greater than 20 mg/l appears to be supportive and reflective of good practice.
- The action level for OiW is 20 mg/l, although the permit defines average monthly discharge limit of 30mg/l. This means that corrective action is often applied before a permit breach occurs. It is also noted that Maersk Oil Denmark has stipulated various internal KPI s, some as low as 5 mg/l for specified discharge points.
- As part of their continual improvement processes, Maersk Oil Denmark has implemented a number of initiatives to improve the efficiency of produced water treatment on board. These have included increasing heating capacity to in order to improve separation efficiency, improving flow and skimming properties of the de-gasser, relocating the injection points for the water clarifier, and reducing flow throughput fluctuations.
- Evidence indicated that further improvements to the produced water treatment processes will be introduced. These include: exploring the use of online OiW monitoring and investigating the accuracy of overboard flow metering systems.
- Daily production checks are conducted on individual produced water process trains. These checks include: levels, pressures and temperatures of specific treatment equipment and processes. This data is then used to troubleshoot and define corrective actions if the 20 mg/l limit is exceeded. Some platforms have also implemented in-line continuous OiW monitoring processes to enhance process control and troubleshooting.
- Evidence obtained from offshore conversations confirmed that employees (e.g. the CCR) are empowered to shut down wells/operations and has done so when necessary on some occasions.
- Communication with regard to OiW appears to be open and honest, and the workforce is actively encouraged to report on any observed undesired emissions and process deviations. The ‘eyes and ears’ of the workforce were seen to be an important tool in monitoring OiW treatment.
- It is clear that some sound practices have been established and individuals know how to respond and troubleshoot when OiW KPIs are exceeded.
- It is clear that the overwhelming majority of the workforce has great pride in working for Maersk Oil Denmark and care deeply about their responsibilities. People reported that they did not understand what prompted the newspaper allegations, which they believed did not represent the Maersk Oil organisation that they work for, or the reality of OiW management.

2.2 Areas for Improvement

A number of emerging themes or issues were identified during the review, as identified below.

2.2.1 OiW Procedure

The OiW Sampling, Analysis and Reporting procedure (OPM 2B, Part 3, Rev 9) enables operations to meet the expectations of the discharge permits. However, the clarity and structure of the procedure can be strengthened. Visibility and understanding of the overall OiW sample collection, analysis and reporting process within the procedure could be improved through the use of Process Mapping.

It is noted that the OiW procedure differs slightly from the reference (OSPAR) method, with examples highlighted below:

Issue	OiW Procedure	OSPAR reference method
Sample volume.	500ml bottle for 400ml sample.	1 litre bottle, 90% full.
Reagents.	25ml n-pentane.	50ml n-pentane.
Sample gas release.	Shake the sample bottle to release gasses.	Cap the sample, release cap, allow it to cool, and re-tighten.
Sample clean-up.	Use non-activated florisil. No use of sodium sulfate.	Use activated florisil. Use of sodium sulfate.
Emulsification of sample.	No guidance.	Use of centrifuge. Addition of magnesium sulfate.
Blank samples.	No guidance.	Blank tests should be carried out with each series of tests.

There is a potential for these deviations have the potential to introduce a degree of error into the method (e.g. sample clean up may not be as effective when using non-activated Florisil, resulting in potentially higher results). Additionally, shaking the sample could potentially release VOCs, with a resultant reduction in OiW concentrations and errors in reported data.

The review of the OiW procedure also identified an inconsistent approach to the level of detail contained within the asset specific sections of the procedure. There should be a standardised minimum amount of platform specific data included in all asset specific sections of the procedure. Additionally, there is a lack of platform specific information relating to (where applicable):

- Expectations relating to communication, and how knowledge or data is transferred.
- Details related to the use of in-line and/or continuous monitoring equipment to supplement OiW management.

- Sampling (including when samples should and should not be taken), labelling, packaging, protection, storage and transporting (i.e. sample custody and integrity).
- Determining total volume of re-injected produced water and total volume of overboard produced water.
- Post analysis reporting (i.e. cross-referencing workbooks, production logs and OiW database).

Note: the procedure at the time of the review was not aligned with the new discharge permit requirements (in particular relating to extra sampling, verification and according to the principles of 'good lab practice'). Maersk Oil Denmark is currently revising the procedure to meet the expectations of the new permit. This process should also incorporate the principles of 'good lab practice'. Lloyd's Register EMEA has included a summary of 'good lab practice' as Appendix 8 of this document.

This procedural revision reinforces the feedback received from the offshore visit where people recognised the need for an overhaul of the documented processes. Some felt that minor changes are frequently implemented, creating a collection of instructions, rather than a cohesive procedure.

2.2.2 Integrity of Data

The *Politiken* newspaper allegations questioned the accuracy and integrity of the data used to report OiW concentrations. The Lloyd's Register EMEA reviews could find no evidence that data had been falsified. However, a lack of robust and transparent sample and data management means that Maersk Oil Denmark is exposed to the potential for error and misconduct. Examples of these exposures include the following:

- Existing sample custody practices introduce the potential for samples to be tampered with or to be misplaced; however, there was no evidence that this had taken place.
- Critical data is sometimes transferred verbally, in particular OiW concentrations for the Halfdan and the Harald.
- There is a lack of written Laboratory Logbooks (denoting sample times, analytical results, anomalies, changes, errors, comments etc.). NB: the absence of logbooks does not reflect good laboratory practice.
- There is a lack of security of data contained within the workbook, which has open access to all Laboratory Technicians and the Chemistry & Environment Department.
- When changes are made to data contained within the workbook, there is no record of the original data or documented reason for the change.
- Sense-checks (conducted onshore) of reported concentrations did not consistently capture noted data anomalies.
- The first point of verification (using existing practices) is the Excel spreadsheet workbook. This is an issue because the spreadsheet is populated at an advanced stage of the OiW sampling, analytical and reporting process. This leaves a lack of opportunity to verify any of the data that is associated with the early stages of the process. Also see the findings associated with lack of robust verification below.

2.2.3 Lack of Robust Verification

The overall process for OiW management should be underpinned by robust verification and Quality Assurance. The review revealed a number of areas where Maersk Oil Denmark did not demonstrate structured processes to assure data quality and compliance with best practice. Examples of these areas include:

- Lack of structured supervisory Quality Assurance.
- Lack of robust verification of On-the-Job training.
- No QC samples analysed to provide assurance of accuracy of results. NB: this is not aligned with good laboratory practice.
- Lack of robust internal audits in order to scrutinise OiW processes.
- The limit of the scope of the Force Technology Audits (i.e. only sampling and laboratory practices and OSPAR correlation) did not enable complete verification of OiW processes.

In order to ensure that the verification processes add value, they must be aligned with revised OiW procedures and processes (once they are reflective of discharge permit requirements).

2.2.4 Degree of Variability of Reported Concentrations

The uncertainty (standard deviation) of reported concentrations and overboard oil volumes is not fully quantified. Variability levels will be associated with:

- The sensitivity of Wilkes Analyzer at lower concentrations (NB: with an extraction ratio of 1:20 as used in the OiW method, the Wilks Infracal analyser HATR T/T2 has an approximate Limit of Detection of 4mg/l).
- Individual pieces of laboratory equipment (e.g. balances, volumetric flasks, measuring cylinders etc.).
- Differing approaches by individuals with regard to sample collection, storage, extraction and clean up.
- The OSPAR correlation method.
- Accuracy of overboard flow meters.

The cumulative variability with the aforementioned elements creates an unknown level of uncertainty for the method. Understanding the lower limits of detection is particularly important for reporting lower concentrations, especially those concentrations related to OiW KPIs.

2.2.5 Competency Assurance Processes

Maersk Oil Denmark is currently establishing a structure for offshore workforce training programmes which includes: training needs analysis, job descriptions, technical training programmes, On-the-Job training programmes etc. This is documented and managed onshore via the Learning Management System (LMS). This framework is still under development and therefore is not fully implemented.

The offshore workforce's individual training programmes are documented in the LMS. It is the expectation that employees will be trained by experienced team members based on tailored role specific training programmes.

The review also identified the following competency assurance issues related to produced water management:

- A training programme for Laboratory Technicians has been developed (dated 28-06-2010) reflecting laboratory requirements. All existing Laboratory Technicians were trained well before the training programme was developed. The new programme has therefore not been applied to any of the current Laboratory Technicians. It is unclear to the review team if there has been any process applied to compare their knowledge and competency with stated expectations within the training programmes.
- There was evidence that Production Technicians regularly take samples and on board the Harald, the Production Technicians conduct laboratory analyses. The Production Technician job descriptions do not accurately disclose these important produced water management tasks. This will become more of an issue when Production Technicians will be required to take additional samples, as per the 2010-2011 discharge permit. It is also noted that there are other offshore team members with critical roles relating to produced water management (e.g. Production Assistant, Control Room Assistant, and Production Supervisor). The different job descriptions of these team members lack a coherent specification that reflect responsibilities associated with produced water management.
- Although laboratory related training had been identified for Production Technicians who were conducting laboratory operations, there was evidence that this training has not been completed.
- A greater degree of clarity and focus is required in relation to the development and application of Production Operations Guidelines (POGs) that specifically relate to produced water management On-the-Job training. On-the-Job training (again specifically for produced water management) lacks formality, thereby raising questions about the consistency of application.
- There was no evidence that robust verification of On-the-Job training had been carried out for Laboratory and Production Technicians.

2.2.6 Areas for Improvement Specific to Tyra East

Some participants on board Tyra East described strong feelings of mistrust towards management both on and offshore. This was supported by perceptions of exclusion and lack of involvement, which are further compounded by stated beliefs that communications between offshore and onshore are ineffective.

3. Recommendations

3.1 OiW Procedural Recommendation

At the time of the review, the OiW Sampling, Analysis and Reporting procedure (OPM 2B, Part 3, Rev 9) enabled operations to meet the expectations of the existing discharge permits.

In line with our findings, the OiW procedure (OPM 2B, Part 3, Rev 9) requires a significant update to meet both the requirements of the new discharge permit. This upgrade should also address the expectations of OSPAR and strengthen the clarity and structure of the procedure. This will enable consistent understanding and application of the overall OiW sample collection, analysis and reporting process. It is recommended Maersk Oil Denmark adopts a workshop based approach when updating this procedure, with active participation from the Chemistry & Environment Department as well as relevant offshore personnel. The updated procedure would be greatly improved through the use of Process Mapping.

There is also a need to cross-reference relevant procedures and guidelines, such as the spreadsheets used to calculate platform specific OiW concentrations (including the correlated calculations).

The platform specific information (e.g. platforms without laboratory facilities, platforms that re-inject produced water etc.) should also undergo a critical review to ensure adequacy. It is also noted that this procedure, together with associated guidelines (e.g. guidance used to complete statutory reporting of weighted daily average concentrations, monthly average concentrations and total oil overboard) should be brought together to form a suite of Produced Water Management Procedures, as illustrated in the diagram below. An important element of this includes the adoption of 'Good Laboratory Practice' – see Appendix 8 for details.

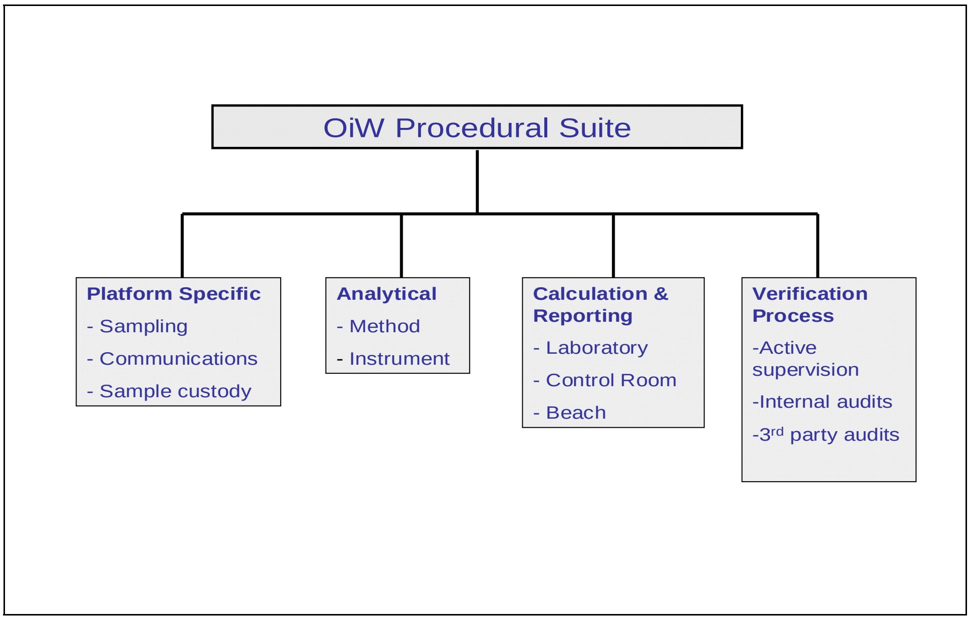


Figure 3-1 Recommended Procedural Suite for Produced Water Management

3.2 Data Integrity Recommendations

The findings indicate that there is a lack of robust and transparent sample and data management meaning that Maersk Oil Denmark is exposed to the potential for error and misconduct. It is therefore recommended that Maersk Oil Denmark implements a number of data integrity control measures in order to reduce the risks associated with inaccurate OiW reporting. These suggested measures include:

- The platform specific instructions should be developed to include a documented sampling plan and procedure which includes specific instructions on sample: collection, labelling, handling, storage and protection, transportation and receipt for normal and abnormal operations.
- The verbal transfer of critical information related to OiW concentrations should be formally recorded and logged.
- Establish a 'Good Laboratory Practice' with the use of written Laboratory Logbooks (denoting sample times, analytical results, anomalies, changes, errors, comments etc.).
- Introduce a process to ensure the security of data contained within the platform specific workbooks. Additionally, when changes are made to data contained within the workbook, ensure there is a record of the original data (i.e. data history) and documented reasons for changes.
- Formalise the onshore base sense-checks of reported data in order to capture potential noted data anomalies.
- Introduce robust verification processes that would verify the data trail from sample collection (as denoted in the written laboratory logbooks) to reporting.

3.3 Robust Verification Recommendations

In addition, the scope of third party audits of the laboratory processes (as currently conducted by Force Technology) should be extended to include reporting. This would provide even more assurance that the calculated figures that are reported to the Danish Government are accurate and traceable to specific samples from specified dates.

At the time of the review, the offshore QA/QC and verification processes relating to OiW sampling, analysis and reporting tend to rely on third party and beach based annual reviews. It is therefore recommended that Maersk Oil Denmark enhances the existing OiW management by the introduction of robust verification processes. These processes should include:

- Structured supervisory Quality Assurance: in order to achieve greater ownership and active quality control, there is an opportunity for line management to engage in skilful conversations while witnessing application of various produced water management processes, including treatment plant troubleshooting, sampling and analysis.
- Processes should be introduced and established to ensure the robust verification of On-the-Job training.
- Analyse QC samples to provide assurance of accuracy of results: planned and *Ad Hoc* quality checks are in line with 'good laboratory practice'.
- Robust internal audits: enhance existing internal auditing processes to ensure that OiW processes are effectively scrutinised.

- Third party audits: expand the scope of the Force Technology audits to enable complete verification of OiW processes (from sample collection all the way to reporting).
- Update procedures: ensure that the verification processes add value, and are aligned with revised OiW procedures and processes (once they are reflective of discharge permit requirements).

3.3.1 Degree of Variability of Reported Concentrations

Inevitably sample collection, custody, analysis and reporting processes will introduce some degree of variability in reported OiW concentrations. Therefore validation of a laboratory method is important (and is Good Laboratory Practice) to determine the suitability of an analysis method for the concentrations to be measured. During the verification there was no evidence that Maersk Oil Denmark has quantified the Limits of Detection (LOD) or the Limits of Quantification of the reported data. The LOD for the OiW method is unlikely to be at a level which will impact on the concentrations set in the permits (20 and 30 mg/L). However, the LOD is likely to be important when the data is utilised for the setting and achieving of internal KPIs, where these are at levels lower than those that can be reasonably detected. It is therefore recommended Maersk Oil Denmark attempts to quantify the lower Limit of Detection for the OiW method and recognises it when setting internal OiW KPIs.

3.4 Competency Assurance Recommendations

When conducting produced water management tasks offshore, teams must rely on each other's competency. Although Maersk Oil Denmark is currently establishing a structure for offshore workforce training programmes, they must formalise arrangements to ensure that:

- Existing and new Laboratory Technicians should either complete the newly developed OiW training programme, or verify competency levels of existing Laboratory Technicians against the programme requirements.
- All relevant job descriptions are cohesive and complete. They must accurately reflect produced water management tasks and responsibilities. This should include troubleshooting, sampling, analysis and reporting.
- Training programmes are implemented as per identified needs.
- On-the-Job training is formalised, including verification.

3.5 Tyra East specific improvements

Critical review findings relating to the Tyra East installation differ from the other DUC assets. Specific recommendations pertaining to this asset are:

- Maersk Oil Denmark has processes to enable individuals to report concerns. It is important that these processes are not only established, but are fully supported and people are encouraged to use them. While recognising that this process is supported by Maersk Oil Denmark, it is clear than some individuals on Tyra East elected to choose a different vehicle to communicate concerns. In support of this recommendation, a culture of openness in reporting and communicating should be further nurtured and embraced within the organisation.

- Maersk Oil Denmark should carefully consider the internal communication and management actions to be taken in the aftermath of these events. This would include communication (i.e. internal/external announcements, lessons learned, and individual response actions) to the workforce and relevant stakeholders. This should clearly define the expectations of on and offshore management, those actively involved in the OiW processes.

Appendices

Appendix 1. Asset Specific Review: Tyra West

Appendix 2. Asset Specific Review: Tyra East

Appendix 3. Asset Specific Review: Halfdan

Appendix 4. Asset Specific Review: Dan

Appendix 5. Asset Specific Review: Gorm (including Skjold)

Appendix 6. Asset Specific Review: Harald

Appendix 7. Documentation Reviewed

Appendix 8. Principles of Good Laboratory Practices

Introduction

During December 2010, Maersk Oil was subject to allegations published in the Danish newspaper *Politiken* regarding the integrity of their produced water management processes, including oil-in-water (OiW) analysis and reporting. Maersk Oil Denmark engaged Lloyd's Register EMEA to conduct an independent review of the associated environmental processes and procedures (including implementation). The review was conducted by Nick Jackson and Amy Annand of Lloyd's Register EMEA, and Stig Stangeland of Lloyd's Register Scandpower.

Scope of Work

Lloyd's Register EMEA reviewed and determined the degree to which Maersk Oil's produced water sampling, analysis and reporting (i.e. specifically OiW) processes truly reflected accepted industry practice. The review evaluated existing documented processes and procedures, and compared their implementation onshore and offshore (on board the Tyra West installation) to recognised industry practice. The review also included a series of interviews with workforce representatives who developed and used these processes and procedures. It is important to note that this was a critical review, which should not be construed as a formal audit. Information was gathered from interviews with representatives of management and of the workforce (both on and offshore), but in-depth verification sampling of the data collected was not carried out.

Key questions (not exhaustive) included:

- How does the current sampling method compare to industry practices?
- Can we confirm it is aligned with requirements?
- Are the procedures adhered to offshore?

The report from this critical review includes both a comparison with accepted and best industry practice, and recommendations on how Maersk Oil Denmark can move towards best industry practice. Findings are reported as commendations, areas for improvement, and observations.

i. Methodology

The review comprised a series of interviews offshore and onshore, as well as reviews of relevant documentation. Maersk Oil Denmark provided Lloyd's Register EMEA with a number of documents prior to commencement of the interviews. These documents included: procedures, organisational charts, copies of newspaper articles and Maersk Oil Denmark's responses to those articles. There were also several other documents that were reviewed onsite. In total, the following Maersk specific documents were provided for review:

- English translation of *Politiken* articles.
- Maersk Oil Denmark's stated response to those articles.
- Danish operation organisational chart.

- Oil in Water Sampling, Analysis and Reporting procedure (OPM 2B, Part 3, Rev 9).
- Job Descriptions: Laboratory Technician, Production Supervisor, Control Room Assistant, Production Technician.
- Daily logs (various dates).
- Daily Production Checklists.
- Daily Operational Highlights Report (various dates).
- Planned maintenance schedules for Tyra West produced water process trains (CBI and IPF).
- Competency matrices, and identified Production Operations Guidelines (POGs) and procedures (both OSPs and OPMs).
- The current Tyra production unit discharge permit, as issued by the Department of Environmental Protection, 20th September 2009.

i. Programme of Work

The following review activities were conducted over five days:

Date	Activity
22 Dec	Onshore (Esbjerg) review of documentation, and offshore visit planning.
27 Dec	Commence offshore review (Tyra West), kick-off meeting with OIM.
28 Dec	Offshore review and interviews.
28 Dec	Evening: return to beach, summarise findings to date with onshore review team.
29 Dec	Further follow-up review onshore and interviews with key personnel.
30 Dec	Analysis and reporting.
30 Dec	Submit Executive Summary, with a formal presentation to the management team.

The following people were interviewed as part of the critical review programme of work:

- Jørgen Juul: Platform Supervisor (Tyra West).
- Frank B Christensen: Production Supervisor (Tyra West).
- Georg Pedersen: Control Room Assistant (Tyra West).
- Carsten Østbo Pedersen: Laboratory Technician (Tyra West).
- Hans Henrik Kristensen: Head of Production Operations (Maersk Oil Denmark).
- Lars Hvejsel Hansen: Manager of the Chemistry and Environment Team (Maersk Oil Denmark).
- Steffen Fredberg Hansen: Production Chemist and reporting specialist (Maersk Oil Denmark).
- Britt Gydesen: Production Chemist and reporting specialist (Maersk Oil Denmark).

Critical Review Findings

i. Commendations

There were several noted positive aspects of produced water management within Maersk Oil Denmark's operations. These included:

- Maersk Oil Denmark has established appropriate procedures (specifically OPM 2B Part 3 Rev 9) and associated guidance documents and initiatives which enable operations to meet expectations of the discharge permit for the Tyra production unit.
- Evidence secured from conversations on Tyra West suggested that the OiW procedures are fully and consistently applied on the installation.
- Processes are established for employee engagement in procedural change (i.e. the updated Revision 9 of the OiW procedure).
- Feedback indicated that the response and reporting culture relating to discharge concentrations greater than 20 mg/l appears to be supportive and reflective of good practice.
- There are a number of verification audits that have been established. These include third party audits of the sampling laboratory OiW processes (Force Technology), ISO14001 certification (DNV), and annual internal audits of OiW reporting processes.
- The action level for OiW is 20mg/l, although the permit defines average monthly discharge limit of 30mg/l. This means that corrective action is often applied before a permit breach occurs. It is also noted that Maersk Oil Denmark has stipulated their own internal KPI as 9.5mg/l for each of the discharge points for the two main produced water treatment process trains on board the Tyra West.
- Evidence indicated that further improvements to the produced water treatment processes will be introduced. These include: exploring the use of online OiW monitoring with improved reliability and improving flow metering systems for overboard discharge volumes.
- Daily production checks are conducted on individual produced water process trains. These checks include: levels, pressures and temperatures of specific treatment equipment and processes. This data is then used to troubleshoot and define corrective action if the 20mg/l limit is exceeded.
- The data trail from analysis to onshore reporting to Danish Environmental Protection Agency is structured and contains numerous sense checks in order to understand any potential anomalies that may occur at data transfer points.
- The OiW sampling, analysis and reporting procedure does include installation specific guidance.
- Evidence obtained from conversations on board Tyra West suggested that employees (e.g. the CCR) are empowered to shut down wells/operations when necessary.

Areas for Improvement

- The time of sample collection is recorded at the same time (i.e. 07:30), as printed out on the Daily Log pro forma. There was no evidence to suggest that sampling times varied widely from 7:30, but it is still highly unlikely that samples are collected at the same time every day. It is important that the exact sample time should be recorded because the weighted daily average oil/water concentration is based upon time between samples.
- Offshore QA/QC and verification processes relating to OiW sampling, analysis and reporting tend to rely on third party and beach based annual audits. In order to achieve greater ownership and active quality control, there is an opportunity for line management to engage in skilful conversations while witnessing the application of various produced water management processes, including treatment plant troubleshooting, sampling and analysis. In addition, the scope of third party audits of the laboratory processes (as currently conducted by Force Technology) should be extended to include reporting. This would provide even more assurance that the calculated figures that are reported to the Danish Government are accurate and traceable to specific samples from specified dates.
- The OiW Sampling, Analysis and Reporting procedure (OPM 2B, Part 3, Rev 9) enables operations to meet the expectations of the discharge permit for the Tyra production unit. However, the clarity and structure of the procedure can be strengthened. Visibility of the overall OiW sample collection, analysis and reporting process could be improved through the use of Process Mapping. It was unclear what the 'chemical slip' was and there was little guidance within the procedure on determining total volume of re-injected produced water and total volume of overboard produced water. There is also a need to cross-reference relevant procedures and guidelines, such as the spreadsheets used to calculate platform specific OiW concentrations (including the correlated calculations). The platform specific information (e.g. platforms without laboratory facilities, platforms that re-inject produced water etc.) should also undergo a critical review to ensure adequacy. It is also noted that this procedure, together with associated guidelines (e.g. guidance used to complete statutory reporting of weighted daily average concentrations, monthly average concentrations and total oil overboard) should be brought together to form a suite of Produced Water Management Procedures.
- A greater degree of clarity and focus is required in relation to the development and application of Production Operations Guidelines (POGs) that specifically relate to produced water management On-the-Job training. On-the-Job training (again specifically for produced water management) lacks formality, thereby raising questions about the consistency of application.

i. Observations

There were a small number of observations that Maersk Oil Denmark should consider. These included:

- To provide (comparative) verification of onsite analytical results, consideration should be given to conducting duplicate/triplicate sampling through an accredited third party laboratory. This is not a requirement of the discharge permit, but it may provide additional assurances of reported oil in water concentrations.

- To ensure sample integrity of any samples that are sent onshore for third party analysis, clear guidance should be provided relating to sample handling and labelling, anti-tampering methods, sample custody paperwork etc. It is noted that people felt comfortable with guidance relating to the actual transport of samples, but were unsure if there was guidance relating to maintaining sample integrity.
- The organisational chart for Tyra West shows the Laboratory Technicians reporting directly to the Platform Supervisor, when in reality they report to and work closely with the Production Supervisor.

Conclusions

From an overall produced water management perspective, Maersk Oil Denmark has established suitable tools, processes, systems and competencies which enable compliance with overboard discharge permit expectations. Evidence gathered during conversations suggested that the response and recording culture on board Tyra West relating to produced water management was supportive and reflective of good practice. Going forward, it is clear that Maersk Oil Denmark intends to continue improvement of its overboard discharge performance processes by the further introduction of enhanced systems and technology. However, there are a few areas which require attention, including:

- Ensuring that sample times are accurately recorded on the Daily Log.
- Improving the structure and clarity of the Sampling, Analysis and Reporting procedure (OPM 2B, Part 3, Rev 9).
- Enhancing ownership and active quality control offshore via line management (e.g. engage in skilful conversations while witnessing application of various produced water management processes, such as sampling, analysis and troubleshooting).
- Formalising the On-the-Job training and mentoring programmes with regard to produced water management.

Introduction and Scope of Work

During December 2010, Maersk Oil Denmark was subject to allegations published in the Danish newspaper *Politiken* regarding the integrity of their produced water management processes, including Oil-in-Water (OiW) sampling, analysis and reporting on board the Tyra East offshore installation. Maersk Oil Denmark engaged Lloyd's Register EMEA to conduct an independent review of the associated environmental processes and procedures (including implementation). This review was based on information gathered from conversations and documentation obtained on board the Tyra West installation and Maersk Oil Denmark offices in Esbjerg. The review was conducted between the 27th and 30th of December 2010 by Nick Jackson and Amy Annand of Lloyd's Register EMEA, and Stig B. Stangeland of Lloyd's Register Scandpower. On the 3rd of January 2011, Lloyd's Register EMEA issued a full report and executive summary entitled 'Independent Critical Review of Produced Water Sampling, Analysis and Reporting Procedures'.

Maersk Oil Denmark then requested a follow-up independent review and offshore visit to the Tyra East offshore installation to assess the application and effectiveness of the OiW procedures. Maersk Oil Denmark also verbally requested a review into the circumstances and causal factors that led to an individual's supplying of information to the *Politiken* regarding the organisation's OiW processes and reporting. These reviews were conducted between the 4th and 6th of January 2011 by Stig B. Stangeland. Participants engaged in the interviews included three Laboratory Technicians, one Production Supervisor, and two Platform Supervisors. It is important to note that this independent review was not meant to be a complete investigation or inquiry into the root causes of these allegations, nor was there any objective to apportion individual responsibility or blame.

Independent Review Findings and Participant Feedback

i. Relating to OiW procedure (OPM 2B Part 3, Rev 9)

- The initial Lloyd's Register EMEA critical review of the OiW Sampling, Analysis and Reporting procedures identified that Maersk Oil Denmark have established appropriate procedures (specifically OPM 2B part 3, Rev 9) and associated guidance documents and initiatives which enabled operations to meet expectations of the discharge permit for the Tyra production unit. However the review also identified that the structure and clarity of the procedure could be improved, and should be subject to review and enhancement.
- Feedback from participants on board the Tyra East supported these aforementioned findings and suggested that the procedure left too much room for interpretation, opportunities for misunderstandings and the potential for inconsistent work practices.
- The initial review of the OiW process identified that processes are established for employee involvement in procedural change (i.e. the updated Revision 9 of the OiW procedure). Information from the Tyra East participants indicated that the OiW procedural update did not involve the on board Laboratory Technicians.

ii. Relating to participant feedback

- Interview feedback indicated a lack of both formal and informal interaction and communication between the Laboratory Technicians on board the Tyra East and their colleagues, both onshore and offshore. Furthermore the Laboratory Technicians felt excluded from internal decision making processes which influence their roles and responsibilities. One stated example was the recent update (13th of September 2010) to the OiW procedure, which did not include any input from or consultation with the Tyra East Laboratory Technicians. When Laboratory Technicians requested clarification on procedural details, they felt they were being ignored. A further example indicated a lack of interaction and appropriate response from management when dealing with issues relating to poor personnel performance.
- Some individuals felt that it would be possible to manipulate the Oil-in-Water data (e.g. within the Excel spreadsheet), although no evidence of any malpractice was presented, and no direct suggestion of manipulation was made.
- Feedback from one participant also suggested that the existing OiW procedure does not comply with OSPAR requirements. This individual believed that the OSPAR requirements mandated that a minimum of 30 samples per month shall be analysed with an equal time lag. This perception is incorrect; OSPAR requirements only actually require a minimum of 16 samples per month, taken at equal time intervals. Procedure OPM 2B Part 3, Rev 9 describes the OiW discharge sampling requirements, as defined in the Permit to Discharge, issued by the Danish Environment Protection Agency, which requires a minimum of one sample per day. As previously mentioned, the existing OiW procedure should enable the Tyra production unit to fully meet the obligations of the discharge permit.

iii. Relating to circumstances leading to allegations

Feedback from participants in this review suggested that the basis for the supply of information to *Politiken* and the subsequent published allegations was due to a number of complex perceptions and circumstances, including:

- Different interpretations and varying levels of understanding of the OiW procedure created the potential for inconsistent work practices. This particularly related to the number of samples to be taken and the process to be followed when analysed samples exceeded 20 mg/l, as per Maersk Oil Denmark's requirements.
- One of the participants demonstrated a lack of understanding of the OiW procedure (OPM 2B, Part 3 Rev 9). This may be due to a lack of clarity within the procedure itself or a lack of communication or awareness. These reasons clearly could have added to the frustration and dissatisfaction that contributed to the reasons for release of information to the press.
- Some participants described strong feelings of mistrust towards management both on and offshore. This was supported by perceptions of exclusion and lack

of involvement, which are further compounded by stated beliefs that communications between offshore and onshore are ineffective.

- The perceived lack of clarity in the OiW procedures has led to varying degrees of confidence and trust in the work processes. This was further compounded by a stated but incorrect belief that the OiW procedure did not meet the OSPAR sampling requirements, as well as unaddressed requests for procedural clarification.
- Some participants believed that there was insufficient sampling, analysis, and reporting Quality Assurance to support or challenge reported OiW concentrations.
- Some participants were unaware of a formal confidential and anonymous internal reporting system for raising concerns and issues.
- It was also evident that the individuals who responded to the request for information from the freelance journalist did so because they believed that the processes to address their concerns on the Tyra East installation were not effective. They indicated that this was their last resort of action.

Conclusion from the Independent Review and Recommendations

The reasons, behaviours and perceptions which led to the supply of sensitive information to *Politiken* are complex, and this high level review identifies some of the causes and can only speculate on others. The review, however, did not identify any evidence that any Maersk Oil Denmark employee or contractor had deliberately attempted to falsify any information or data relating to OiW discharges.

Based solely on information and feedback gained from the interview processes, it is recommended that the following activities are considered:

- The OiW Sampling, Analysis and Reporting procedure (OPM 2B, Part 3, Rev 9) enables operations to meet the expectations of the discharge permit for the Tyra production unit. However, the clarity and structure of the procedure can be strengthened. Visibility of the overall OiW sample collection, analysis and reporting process could be improved through the use of Process Mapping. There is also a need to cross reference relevant procedures and guidelines. The platform specific information should also undergo a critical review to ensure adequacy.

- Offshore QA/QC and verification processes relating to OiW sampling, analysis and reporting tend to rely on third party and beach based annual audits. In order to achieve greater ownership and active quality control, there is an opportunity for line management to engage in skilful conversations while witnessing application of various produced water management processes, including treatment plant troubleshooting, sampling and analysis. In addition, the scope of third party audits of the laboratory processes (as currently conducted by Force Technology) should be extended to include reporting. This would provide even more assurance that the calculated figures that are reported to the Danish Government are accurate and traceable to specific samples from specified dates. Maersk Oil Denmark has processes to enable individuals to report concerns. It is important that these processes are not only established, but are fully supported and people are encouraged to use them. While recognising that this process is supported by Maersk Oil Denmark, it is clear that some individuals on Tyra East elected to choose a different vehicle to communicate concerns. In support of this recommendation, a culture of openness in reporting and communicating should be further nurtured and embraced within the organisation.

- Maersk Oil Denmark should carefully consider the internal communication and management actions to be taken in the aftermath of these events. This would include communication (i.e. internal/external announcements, lessons learned, and individual response actions) to the workforce and relevant stakeholders. This should clearly define the expectations of onshore and offshore management, and those actively involved in the OiW processes.

Introduction

On the 26th January 2011, the Critical Review of Produced Water Sampling, Analysis, and Reporting procedures were conducted on board the Halfdan installation by Linda Murray (Lloyd's Register EMEA) and Per Christofferson (Lloyd's Register Scandpower). The scope of work was conducted, as described in Section 1 of this report. Documentation reviewed as part of this process is listed in Appendix 7. The following people were interviewed as part of the critical review programme of work:

- Jimmy Johansen, Platform/Production Supervisor (Kombimester).
- Ib L. Pedersen, Production Supervisor.
- Nils Bo, Maintenance Supervisor.
- Erik B. Johansen, Control Room Assistant.
- Jonny W. Pedersen, Production Technician.

Overview of Produced Water Management

The water treatment process was described and demonstrated to the review team by the on-shift Production Technician. The treatment train includes the separator (V3402), three hydrocyclones (V5012 – 14) and two degassers (V5016 A/B). Although the daily sampling had been completed, the two sampling points were viewed and the sampling process discussed. The continuously flowing sampling points are located after the final degasser treatment process (see Figure A3.1 below) and before discharge to the caisson. Individual samples collected from each treatment train are analysed and reported as a mean concentration. Halfdan does not have laboratory facilities; therefore daily samples are collected and sent by helicopter or boat to the Dan for analysis.

Figure A3.1 Post Treatment Sampling Points

Some aspects of the treatment train are subject to continuous monitoring and the results are displayed in the Control Room on the Scada System. In addition to this monitoring, for the past month the discharge point from each degasser (adjacent to each sampling point) has been monitored by a continuous in-line Laser Induced UV florescence monitor (Argus type by ProAnalysis); see Figure A3.2 below.

Figure A3.2 Continuous in-line Laser Induced UV Florescence Monitor

The values from the in-line monitoring are available online (soon to be available on the Scada), and the Control Room is notified when a sample is taken. The results from the in-line monitoring are compiled by the Control Room Assistant to provide a basis for correlation with the OiW analytical results from the official samples. The comparative results were reviewed for the month it has been in use and no correlation has been established yet. There is a limited amount of data gathered to date from the in-line concentrations. Therefore the data is currently used by the Control Room Assistant only to gather information on the OiW trend (i.e. rising or falling) for fine tuning the produced water treatment process.

The samples are collected in 500ml glass bottles (with Teflon insert) that have been cleaned by the Dan Laboratory Assistant who also adds 5ml of 6M hydrochloric acid to each bottle. The process for labelling, packaging and transporting samples was observed. Printed labels are attached to individual sample bottles with elastic bands and the bottles are then packaged in a sample box, prior to transport to Dan (see Figure A3.3 overleaf). No details were obtained regarding storage of samples prior to transport.

Figure A3.3 Oil in Water Sample packaged for transport to the Dan

Timely transfer of the Halfdan samples is dependent on the frequency and availability of helicopter flights. It is noted that samples that are considered to be urgent (i.e. to confirm potential treatment problems) can be sent by boat to the Dan laboratory for expedited analysis in 5 to 6 hours. Flight delays have resulted in several days' accumulation of uncollected samples. It was not clear how the samples were stored during these periods in order to maintain sample integrity and custody whilst preventing cross-contamination. It is noted that some samples from the Halfdan have gone missing, specifically on 22/04/10.

Control Room operations were also observed, and the application of the OiW procedure was discussed. The Control Room Assistant frequently monitors the produced water treatment through the Scada System read-outs, and the OiW continuous in-line monitoring read-outs. At the time of the review, the trigger level for extra sampling, as defined in the discharge permit, was 20 mg/l. It is also noted that the Halfdan has an internal KPI of 5 mg/l for 2011. Operating conditions are monitored and fine-tuned to enable corrective actions to be taken in order for Halfdan to meet its internal KPI. Therefore it is critically important for the Control Room Assistant to have frequent communication and discussions with other team members (i.e. Kombimester, Production Supervisor and Production Technicians) who are involved in the water treatment process. Typically, the Kombimester and the Production Supervisor decide together on the corrective measures required to return to acceptable levels. This can be complicated by the lag time in receiving OiW sampling results from the Dan Laboratory. The issue is further compounded by the absence of an on board Laboratory Assistant who, on other platforms, provides invaluable information and support, in particular during troubleshooting.

The reporting of sample results is completed by the Control Room Assistant. The results from the sample analysis are received from the Dan Laboratory Assistant electronically (and copied to Danish Operations Control Centre (DOCC) onshore). These are entered into the produced water results page in the EBJ-OBJ database. The deadline to enter OiW results is 1.00 am the following day. If the results are not received until the next day (or even later) the previous day’s results are supposed to be entered into the comments section for the specified day.

Overboard volumes are measured by flow meters. Calibration and preventative maintenance of the flow meters was discussed with the Maintenance Supervisor. Although the P&ID and tag numbers were available and viewed, the management of flow meters with respect to calibration and maintenance is the overall responsibility of the onshore Metering Department.

The review process also included a cross-check of workbook data from specific dates in the Halfdan spreadsheet against what was reported in the produced water database (EBJ-OLS); specified dates included: 02/02/10, 26/02/10, 22-23/04/10, 06/05/10, and 16/06/10. These 2010 dates were selected from database entries that indicated having either higher OiW results, missing data or other potentially abnormal conditions.

Critical Review Findings

i. Commendations

The overall impression when visiting the Halfdan is that the personnel interviewed were highly focused on produced water management and several positive aspects were noted. These included:

- The produced water process train is frequently monitored via the Scada read-outs, specifically: levels, pressures and temperatures and also read-outs from the in-line continuous OiW monitoring. This enhances control of both the process and troubleshooting actions, when required.
- The action level for collection of additional samples is 20mg/l OiW, and the permit defines an average monthly discharge limit of 30mg/l. On the Halfdan, the 2011 KPI is 5mg/l. This means that corrective action is usually applied long before a permit breach occurs. The Halfdan reservoir is reported to be relatively stable and its conditions are well understood. This, coupled with the corrective action trigger levels and KPIs, means that the Halfdan produced water quality is well controlled, with low OiW concentrations.
- It is clear that the Halfdan workforce has great pride in working for Maersk Oil Denmark. They are proud of their operation and their achievements in relation to produced water management.
- Communication on the Halfdan appeared to be open and honest, and the whole workforce is actively encouraged to report any unplanned emissions and process deviations. The “eyes and ears” of the workforce were seen to be an important OiW management tool.
- There is no documented procedure for process troubleshooting on the Halfdan when OiW KPIs or permitted discharge concentrations are exceeded. However, it is clear that sound practices are well established and the individuals involved in produced water management have the knowledge and the experience to respond in a timely and efficient manner.
- Evidence obtained during interviews suggested that operators are empowered by management to shut down wells/operations in the event of high OiW concentrations. Evidence was provided for the occasions when this had occurred.

Areas for Improvement

- Samples were well packaged, but potential problems with sample custody were apparent. A single pre-printed label is attached to the bottle with an elastic band. Although the label contains the correct information, it could easily become detached, with the potential for lost or misidentified samples. This also introduces the potential for samples to be tampered with or misplaced. Additionally, it was unclear how samples were stored prior to transport (i.e. in such a way as to maintain sample integrity).
- The platform specific information in the OiW procedure (OPM 2b Section 3.2) provides some information on sampling and reporting for the Halfdan and OSP26 provides some information on packaging for transport. However there is a lack of detail in the following areas:
    - Sample custody assurances relating to sample labelling, packaging and documentation. These control measures are critical to prevent misplaced samples and loss of identity during abnormal conditions such as delays and sample backlog.
    - Storage of samples to maintain sample integrity. This is particularly important when there are extended delays in transport to the Dan Laboratory. Although the samples have already been acidified, in order to ensure integrity, they should be stored in a refrigerator (at 4^{0}C to 8^{0}C) and analysed within seven days.
    - The utilisation of the on-line monitoring equipment to supplement the OiW management processes.
    - Recording and logging critical information passed verbally, specifically to and from the Control Room.
    - Instruction for reporting delayed analytical results. When the Control Room Assistant has not been able to update Halfdan overboard OiW concentrations in the EBJ-OLS database on that day, there is evidence of unnoticed missing data.
- A Sample Logbook is not maintained. There is therefore no method to verify and confirm: who took the sample, when it was collected, where it was collected, experienced anomalies and changes to the procedure, observations, comments etc. This does not reflect Good Laboratory Practice. NB: The Danish Authorities will require verification against Good Laboratory Practice as indicated in the 2011 discharge permit.
- The uncertainty (standard deviation) of the reported concentrations is not fully quantified. The cumulative variability associated with the sample collection, storage, extraction and clean-up is particularly important in the reporting of concentrations when related to the Halfdan KPI (5mg/l for 2011).
- Team members' job descriptions lack a coherent specification that reflects their responsibilities associated with produced water management, for example the Production Assistant taking the samples.

- There was no evidence of a structured process to assure data quality assurance or compliance with procedures and best practice. Specifically, there was no evidence of:
    - Structured supervision and verification of On-the-Job training.
    - Quality control or blank samples provided for analysis.
    - Internal audits of Halfdan sampling and reporting processes.
    - The inclusion of Halfdan sampling, sample custody and reporting in third party audit scopes.

Conclusions and Recommendations

The overall impression of the Halfdan platform is that produced water management is well controlled, with low OiW concentrations. The OiW team has a high focus on and an understanding or knowledge of the water treatment processes. Furthermore, evidence from the interviews and observations indicated that the team is well aware of how to handle unanticipated situations and upset conditions. Halfdan does not have an on board laboratory and this has implications for specific elements of produced water management, namely: sample custody, sample integrity, results reporting and troubleshooting. The following recommendations are based upon the review findings:

- The Halfdan platform specific instructions should be expanded to include a documented sampling plan and procedure which includes details relating to:
    - Sample labelling, storage, packaging and transport to ensure sample custody and integrity.
    - The inclusion of planned and *Ad Hoc* Quality Control checks and blanks (i.e. distilled water) to provide assurance of accuracy of results and the absence of contamination in the complete method.
    - The use of in-line monitoring equipment and correlation with OiW analytical results.
    - The formal recording and logging of critical information and the use of Logbooks (see comment below).
    - Results reporting for normal and abnormal operations, including receipt of delayed analytical results.
- Implement Good Laboratory Practice via the use of sample Logbooks (section 5.7 (f) DECC guidance) for recording the name of the sampler, location of sample, date and time of collection, anomalies and any deviations from the procedure, observations and comments. Records should be made accurately at the time, be legible, indelible and signed and dated. Changes should be initialled with reasons and should not obscure the previous entry.
- The principals of Good Lab Practice recommend the use of method validation. This includes determination of accuracy, precision, detection limit, quantitation limit, linearity, range and robustness. It is therefore recommended that validation of the complete OiW method (specifically the determination of lower limits of

detection / quantitation) is carried out with respect to setting and meeting the Halfdan KPI (5mg/L).

- The onshore based sense checks of reported data should be formalised in order to ensure that data anomalies are captured.
- Job descriptions for all Halfdan personnel should accurately reflect their produced water tasks and responsibilities. Where associated training needs have been identified, the workforce training programme should be implemented, and the On-the-Job training formalised and verified as having been completed.
- OiW management can be enhanced by introducing more robust verification processes. This should include the:
    - Use of structured supervisory quality assurance of the Halfdan produced water management process.
    - Implementation of internal audits scrutinising the implementation of the complete OiW procedure on the Halfdan.
    - Inclusion of the Halfdan OiW processes in the scope of third party verification audits.
- The level and effectiveness of the cooperation between Production Technicians and Laboratory Assistants is fundamental when troubleshooting and fine-tuning OiW processes. The Laboratory Assistant on board the Dan should be recognised as a vital part of the Halfdan produced water management team. The recommendation is to enhance levels of cooperation between the production team on board the Halfdan and the Laboratory Assistant on board the Dan to enable better level of support to the production team.
- The accuracy of individual flow meters in recording overboard volumes is unknown at the present time. It is noted that this is an area identified by Maersk Oil Denmark and the Danish authorities for investigation.

Introduction

On the 27th January 2011, the Critical Review of Produced Water Sampling, Analysis, and Reporting procedures were conducted on board the Dan installation by Linda Murray (Lloyd's Register EMEA) and Per Christofferson (Lloyd's Register Scandpower). A return visit was made on the 30th January 2011 in order to cover some aspects of the OiW procedure in more depth, follow-up on some queries from the first visit and take the opportunity to speak to another Laboratory Assistant during the handover period. The scope of work was conducted following the format as described in Sections 1 and 2 of this report. Documentation reviewed as part of this process is listed in Appendix 7. The following people were interviewed as part of the critical review programme of work:

- Kim V. Nielsen, Platform Supervisor.
- Daniel Sandberg, Laboratory Assistant.
- Hanne Lykke, Laboratory Assistant.
- Gunnar Bjørnstad, Production Supervisor.
- Steen Pedersen, Production Assistant.
- Tommy Bonde, Control Room Assistant.
- Peter Hansen, Control Room Assistant.

Overview of Produced Water Management

The produced water treatment process on the Dan production unit is more complex, due to the number of platforms. There are a total of three permitted discharge points located on the Dan FC, Dan FF and the Dan FG. The produced water treatment trains were observed by the Lloyd's Register EMEA team, and described by the Laboratory Assistant. The Dan FC produced water treatment train is comprised of: three separators, four sand hydro-cyclones, four de-oiling hydro-cyclones and two degassers, before discharge to a caisson. Dan FC also has the availability of produced water re-injection pumps, if required. The Dan FF produced water train varies slightly in that there are two separators, four sand hydro-cyclones, six de-oiling hydro-cyclones and a single degasser prior to discharge into a caisson. For Dan FG, the produced water train includes: a single separator, two sand hydro-cyclones, two de-oiling hydro-cyclones and then onto a flotation unit prior to discharge into a caisson. The sampling points for each of these platforms are continuously flowing and located after the exit end of final treatment. It is noted that Dan FC has two sampling points, depending on which degasser is in operation; under normal operations, one sample is collected from Dan FC, depending on which degasser is operation. The sampling points from Dan FC, FF, and FG were all viewed; see Figures A4.1, A4.2 and A4.3 below.

Figure A4.1 Sampling Point and Online Monitor Discharge, Dan FF

Figure A4.2 Sampling Point, Dan FG

Figure A4.3 Sampling Point, Dan FC

Approximately one year ago, the Dan FF installed a continuous OiW monitoring system at the exit end of the degasser; please refer to Figure A4.4 below.

Figure A4.4 Continuous OiW Monitoring System EX1000 (Advanced Sensors), Dan FF

The EX1000 (Advanced Sensors) uses a full scan spectrometer which can record the OiW concentration, temperature and full optical spectrum of the oil fraction. It employs an ultrasonic self-cleaning unit in order to improve reliability of the monitoring equipment. However, at the time of the first visit, the EX1000 was reading "0" and was subsequently discovered to be inoperable on the second visit. Previous to this, the system had been considered robust; it was thought that the ultrasonic cleaning mechanism was responsible for weakening the glass window of the monitoring device.

Although sampling had been completed at the time of the review, the samples were being extracted in the laboratory. The sampling process was discussed with the

Laboratory Assistant. Scaling is considered to be a significant problem both in the treatment process and sampling tubes, especially on board the Dan FF where the sample tubes are longer and have more acute bends.

Prior to sampling, the 500 ml sample bottles with Teflon insert are cleaned and pre-prepared in the laboratory with 5 ml (6M) of hydrochloric acid. The Dan Laboratory Assistant is also required to complete additional sampling duties (i.e. for H_2S) which are performed at the same time as the OiW sampling, and this sampling routine typically takes 1.5 hours to 2 hours to complete given the distances covered. If there are known problems with OiW treatment and additional samples must be collected overnight, the Laboratory Assistant will leave pre-prepared sample bottles for the Production Assistants, who collect night-shift samples.

The Dan Laboratory extracts and analyses the samples from the three Dan discharge points, as well as the samples collected and transported from the Halfdan platform. Implementation of the procedure (OPM 2b, Part 3, Rev 9. 2010-09-13) was witnessed in the laboratory for the two morning samples (Dan FF and FG discharge points). This specifically included Section 5.1 (Extraction), Section 5.2 (Chromatography), Section 5.3 (Setting and Adjustment of the Wilks Infracal) and Section 5.4 (Analysis and Calculation). Additionally, laboratory practices relevant to Section 7 (Glassware Cleaning and Rinsing) were observed. It is noted that hand and eye protection was not worn throughout analytical procedures.

The Dan Laboratory Assistant analyses the Halfdan samples in a separate batch on the day that they are received and reports on the same day. On the day of the site visit at 11:30 am, the Halfdan sample was delivered to the laboratory from the heli-admin. It was unclear when it was transported from the Halfdan to the Dan.

The LR EMEA review team observed the preparation of the standards and the subsequent analysis on the Wilks OiW analyser for the monthly calibration (Section 6 of the OiW procedure). This included the development of calibration graphs which are used to determine the line slope formula which is sent onshore to the Chemistry & Environment Department for input to the workbook of the formula; this in turn, is used to calculate the concentration from absorbance. It is noted that the Laboratory Assistant completed performance checks on the scales prior to conducting calibration. Some time was also spent reviewing the procedure, and cross-checking graphs and calculations relating to the correlation of the Wilks OiW method with the OSPAR reference method for Dan, and all the platforms.

The LR EMEA review process also included a cross-check of workbook data from specific dates in the Dan spreadsheets against what was reported in the produced water database (EBJ-OLS); specified dates included: 20/01/10, 06/04/10, 19/04/10, 11/10/10 and 20-24/05/10. These 2010 dates were selected from the workbook entries that indicated higher OiW results, missing data or other potentially abnormal conditions.

In addition to gathering information about OiW management processes, additional interviews took place with the Platform Supervisor, Production Supervisor, Production Assistant as well as the Laboratory Assistant that was coming on rotation. These interviews focused on the different roles and responsibilities with regard to OiW treatment and touched on training and competency, cooperation, communication and troubleshooting. During discussions there was no evidence of any verification having been implemented through supervision or internal audits.

An important aspect of communication was the degree of inclusiveness and engagement between the team members with OiW management responsibilities. This included the morning meeting that addresses production related matters. The Laboratory Assistant participates in this meeting as it is considered to be an important pre-requisite to the OiW sampling and analysis. It was also an opportunity for team members to share experiences and for the Laboratory Assistant to advise and inform the production personnel with regard to the water treatment system. Information gathered from interviews also suggested that this level of engagement also applied to their approach to troubleshooting and problem solving.

The Production Supervisor and Technician frequently perform simple indicative tests (e.g. "white paper" tests and visual checks) of the OiW at different process points. During daylight hours, the seawater surface in the vicinity of the platform is regularly observed to detect oil sheens. Any abnormal observation or test results are immediately reported to the Control Room and onwards to the Laboratory Assistant and platform management. Additionally, the Laboratory Assistant is routinely consulted to discuss the processes and potential adjustments or solutions.

The Control Room Operators use the OiW values together with trends from Scada read-outs to fine tune the water treatment processes. When a 20mg/l overboard concentration is detected, a troubleshooting response is applied. This involves team based approaches which include communication, reporting, fault tracing, problem solving, and further sampling and analysis. As previously mentioned, the Dan FF installed a continuous OiW monitoring system at the exit end of the degasser. Information obtained from this monitoring supplement the data obtained from collected samples and the Scada read-outs. It is noted that there is no established correlation between the concentrations measured from collected samples versus the results from the continuous monitoring; the data from the continuous monitoring is used to understand trends in OiW concentrations.

Members of the production team who are involved in the produced water treatment process have documented task descriptions which are reflected in a training matrix. Training is applied in accordance with the matrix, which is signed off by the Platform Supervisor and the appointed trainer. Training related to sampling and analysis processes are supplemented by production team members spending half a day working with the Laboratory Assistant. Additionally, feedback stated that the OiW processes are the subject of frequent discussions during daily meetings and this was seen as an important aspect of the learning and information transfer process.

Overboard volumes are measured by various flow meters. The calibration and preventative maintenance of the flow meters is the overall responsibility of the onshore Metering Department.

Critical Review Findings

i. Commendations

The overall impression from the visit to the Dan installation is that produced water management is seen as important and has the attention of platform management. Furthermore, evidence from the interviews and observations indicated that the produced water team are highly competent in all aspects of produced water management, including troubleshooting. Several positive aspects relating to produced water management were noted during the visit. These included:

- Laboratory practices complied with Sections 4 to 7 of the OiW procedure (i.e. equipment, analysis, calibration, glassware). Additionally, some commendable practices went above and beyond what was specified in the procedure (i.e. performance checks on the scales prior to conducting calibration).
- Laboratory Assistants were knowledgeable with the procedure and the theory behind the processes, and demonstrated a good awareness of potential problems.
- The extended two day rota handover period for Laboratory Assistants gives plenty of time for a thorough handover of information on problems encountered and forthcoming issues. It also enabled one Laboratory Assistant to conduct the more time-consuming procedures, such as instrument calibration, whilst the other Laboratory Assistant took samples and dealt with operational issues.
- The recorded data that is transferred from Excel spreadsheet workbooks to daily reports on the EBJ-OLS database (from which the official reports are derived) appears to be largely accurate.
- Daily production checks are conducted on individual produced water trains. These checks include: levels, pressures and temperatures of specific treatment equipment and processes. This data is used to troubleshoot and define corrective actions if the 20mg/l limit is exceeded. The Dan FF treatment train has a continuous monitor which is used to trend the OiW levels and enhance process control and troubleshooting.
- The effective management of the OiW treatment processes is achieved by teamwork and the application of individual skills and knowledge.
- On-the-Job training (including awareness) of the OiW sampling, analysis, and associated water treatment processes is provided by the Laboratory Assistant for relevant team members. As these tasks and operations are frequently performed, the knowledge and expertise is retained through custom and practice. This includes different approaches to troubleshooting and fine-tuning the treatment processes, where necessary.
- The Laboratory Assistant attends the morning (production) meeting; this helps to maintain a focus on the produced water management. Furthermore, the interviews indicated that the skills and knowledge of the Laboratory Assistant are highly appreciated amongst the workforce and they are consulted on a daily basis regarding specific elements of the OiW treatment processes.

- Maersk Oil Denmark's ongoing commitment to improving produced water treatment performance was demonstrated on the Dan platform, where a trial of ceramic filters for Membrane filtration was being initiated.

Areas for Improvement

The following were identified as areas for improvement:

- The OiW procedure has minor differences from the reference OSPAR method in:

  - The volumes of sample bottle (500 ml) and reagents (n-pentane 25 ml) (OSPAR is 1l bottle and 50 ml n-pentane).
  - The activation of the Florisil and storage in a desiccator.
  - The use of sodium sulphate for removal of water in the clean-up column.
  - Actions to be followed in the event of emulsions (no guidance in the OiW procedure).
  - Shaking the sample (not in the OSPAR method).
  - Blank tests (i.e. a method blank (water containing no analyte) which is subjected to the complete OiW method using the same reagents as the samples).

  There is potential for these deviations to introduce a degree of error into the method (e.g. sample clean-up may not be as effective when using non-activated Florisil, resulting in potentially higher results). Additionally, shaking the sample could potentially release VOCs with a resultant reduction in OiW concentrations and errors in reported data. Emulsions are described as rare on the Dan; however if these do form, there is no guidance relating to dealing with emulsions, as specified in OSPAR guidance.

- There are no Quality Control (QC) samples or blanks with the OiW water samples as a quality assurance check. The analysis of known concentration QC samples can monitor any variation and drift (and highlight problems) in the performance of the method by using QC charts and setting limits. Without these contamination or problems with equipment, reagents or interferences during sampling, analysis, and clean-up may go unnoticed and therefore reported in the Dan results. This is not aligned with Good Laboratory Practice, nor does it provide any degree of assurance relating to the accuracy of reported results. NB: The Danish Authorities will require verification against Good Laboratory Practice as indicated in the 2011 discharge permit.

- An electronic logbook is completed by Laboratory Assistants on the Dan. They do not however keep sample logbooks or official laboratory notebooks to trace back to raw data, or to reference sample times, analytical results, changes from the procedure, errors or actions taken i.e. treatment of emulsions resulting from production chemicals. This compromises the transparency and traceability of the sampling and analysis method, and does not reflect Good Laboratory Practice.

- The first point of verification is the raw data recorded in the Dan electronic Excel workbook, which could be subject to manipulation, such as:

  - When changes are made to data contained in the workbook, there is no record of the original data or documented reasons for changes.
  - There is a lack of security in the data contained in the Dan Excel workbook, which has open access to all Laboratory Assistants (and potentially visitors) on other platforms and the Chemistry & Environment Department.

- The platform specific information in the OiW procedure (Section 3.2) provides some information on sampling and reporting for the Dan. However there is a lack of detail in the following areas:

  - Sample custody and integrity for sample received from the Halfdan. There is no guidance for the receipt, storage and analysis of the Halfdan samples. There is known potential for the samples to go missing (as occurred on 22/04/10) during abnormal conditions such as transport delays and sample backlogs.
  - The use of the continuous monitoring equipment on the Dan FF to supplement the OiW management process.
  - Expectations relating to communications associated with pre-sampling, process activities, troubleshooting etc.
  - Sampling times, and locations and labelling. Also protection, storage, and transportation when necessary for onshore analysis.
  - The use of PPE during analytical procedures.
  - Actions in the event of samples to be taken overnight by Production Assistants.
  - Reporting of Dan and Halfdan results, with reference to the use of the Excel workbooks, production logs and the EBJ OLS database.

- The results from the OSPAR analysed samples and the Wilks Infracal analysed samples displayed varying degrees of linearity in the correlations for the individual platform calibration curves. The September 2010 R^2 values varied from 0.9982 for the Dan FC to 0.8347 for the Gorm F. This has the potential to introduce considerable error into the reported results. The Chemistry & Environment Department is aware of this and the procedure is currently under review using guidance notes and guidance from produced water engineers.

- Some of the cells in the current Dan Excel workbook contain obsolete data. This has arisen through data (January to April 2010) being re-calculated retrospectively by the Chemistry & Environment Department using an improved OSPAR correlation. This was highlighted when data in the EBJ-OLS daily screen did not match with workbook recorded values with no explanation. Using multiple versions of documents and worksheets increases the potential for the use of incorrect data in calculations and reporting values.

- The uncertainty (standard deviation) of the reported concentrations is not fully understood. The cumulative variability associated with the analyser, laboratory equipment, sample collection, storage, extraction, clean-up and calculation using the OSPAR correlation creates an unknown level of uncertainty. Understanding the degree of uncertainty is particularly important in the reporting of lower concentrations related to the Dan KPIs. The Dan KPIs are FC 7 mg/l, FF 6 mg/l, and FG 9mg/l.

- There was no evidence of a structured process to assure data quality assurance or compliance with procedures and best practice. The Laboratory Assistants on the Dan at the time of the review are long serving (over twenty years). As a consequence, there was no documented evidence of structured supervision and verification of On-the-Job training being carried out for Laboratory Assistants. There was also no evidence of verification of On-the-Job training for Production Assistants required to take samples. In addition, during discussions, there was no evidence that any formal internal audits had been carried out on the OiW process on the Dan.
- There may be production instances that necessitate the collection of additional OiW samples by night-shift Production Technicians. In most cases, the Laboratory Assistant will pre-prepare sample bottles for this purpose. On some occasions, samples may be required at short notice and bottles may not be pre-prepared. Technicians are currently not trained to pre-prepare cleaned sample bottles with 6M HCl.

Conclusions and recommendations

The overall impression of the Halfdan platform is that produced water management is well controlled. The OiW team has a high focus on and an understanding of knowledge of the water treatment processes. Furthermore, evidence from the interviews and observations indicated that the team is well aware of how to handle deviating situations and upset conditions. The Laboratory Assistant is highly appreciated amongst the workforce and is consulted on a daily basis regarding specific elements of the OiW treatment processes. The following recommendations are based upon the review findings:

- The extraction and analysis sections of the OiW procedure, based on DECC guidance and the OSPAR reference method, have a good level of detail which is being followed in the laboratory. In the areas where the OiW procedure method differs from the OSPAR recommended method, the deviations should be assessed for any significance in the measurement of OiW concentrations, and if necessary the OiW procedure amended accordingly.
- The implementation of good laboratory practice and the use of laboratory Logbooks for recording sampling times, observations, any deviations from the procedure and who carried out the sampling. This should also include raw data from the extraction, clean-up, analysis, any problems encountered and actions taken. Records should be made accurately at the time, be legible, indelible and signed and dated. Changes should be initialled with reasons and should not obscure the previous entry.
- Introduce a process to ensure the security of data contained within the platform specific workbook, ensure there is a record of the original data (i.e. data history) and documented reasons for changes.
- The principals of Good Lab Practice recommend the use of method validation. This includes determination of accuracy, precision, detection limit, quantitation

limit, linearity, range and robustness. It is therefore recommended that validation of the complete OiW method (specifically the determination of lower limits of detection / quantitation) is carried out with respect to setting and meeting the Dan KPIs.

- The OiW procedure should include the analysis of Quality Control (OSPAR method section 6.8.3) samples and blanks (OSPAR method section 9.1) to provide assurance of accuracy of results and the absence of contamination in the complete method. The use of planned and *Ad Hoc* quality checks are in line with Good Laboratory Practice, and can be developed using purchased or in-house known concentration quality control samples.
- The method for establishing a correlation between the OSPAR and Wilks Infracal analysed samples is currently under review by the Chemistry & Environment Department. A detailed formal procedure should be developed to cover the production of standards, analysis and the statistical treatment of the received results. Determining the most appropriate method and formalising it will ensure transparency in data calculation and reporting.
- The OiW management can be enhanced by introducing more robust verification processes. This should include the:
    - Application of quality assurance via Supervisors.
    - Implementation of internal audits scrutinising the implementation of the complete OiW procedure from sampling through to reporting on the Dan platform.
    - Expand the scope of the Force Technology audits to enable complete verification of OiW processes (from sample collection all the way through to reporting).
- Job descriptions for all Dan personnel (Laboratory Assistants as well as Production and Control Room personnel) should accurately reflect their produced water tasks and responsibilities. Where associated needs have been identified, the workforce training programme should be implemented, and the On-the-Job training formalised and verified as having been completed.
- The accuracy of individual flow meters recording overboard volumes is unknown at the present time. It is noted that this is an area identified by Maersk Oil Denmark and the Danish Authorities for investigation.

Introduction

On the 28th January 2011, the Critical Review of Produced Water Sampling, Analysis, and Reporting procedures were conducted on board the Gorm installation by Linda Murray (Lloyd's Register EMEA) and Per Christofferson (Lloyd's Register Scandpower). The scope of work was conducted following the format as described in Section 1 of this report. The scope of work was conducted following the format as described in Sections 1 and 2 of this report. Documentation reviewed as part of this process is listed in Appendix 7. The following people were interviewed as part of the critical review programme of work:

- Ken H. Feddersen, Laboratory Assistant.
- Stefan Andersen, Control Room Assistant.
- Ole Thomsen, Control Room Assistant.
- Bjørn Otte, Production Supervisor (Gorm F).
- Steen Claus Valentine, Production Assistant (Gorm F).
- Thomas Bjørn, Production Supervisor (Gorm A, C, D, E).
- Morten Frank, Production Assistant (Gorm A, C, D, E).

Overview of Produced Water Management

The produced water treatment processes on the Gorm platforms are relatively complex and include produced water re-injection activities. The produced water treatment trains were observed by the Lloyd's Register EMEA team, and described by the Laboratory Assistant. The final treatment degassers and sampling points for the three discharge points on the Gorm F and C were also viewed.

Gorm C receives fluids from the Rolf and Halfdan. This has a separator, hydro-cyclone and degasser (V5002) to discharge in a caisson. The Rolf was shut-in and there was no hydrocarbon processing at the time of the review but the sample point (Figure A5.1) was viewed, as this would normally be continuously flowing.

Gorm F receives fluids from Gorm A, B, F and Skjold and the oil is exported to shore via Gorm E. Gorm F produced water from the separator is treated by five de-oiling hydro-cyclones and a degasser. The Gorm F also has available a stage one and two flotation unit which is not currently used due to the need for fuel gas. The Skjold produced water treatment consists of two separators, five hydro-cyclones and two degassers. Gorm F and Skjold sampling points from degassers (V5021 and V5005) were viewed. These sample points (Figures A5.2 and 5.3) were not continuously running due to the presence of relatively high concentrations of sulphurous compounds in the water and the potential for odour. Both produced water trains go to re-injection.

Figure A5.1 Sampling Point on Gorm C

A5.1 Sampling Point on Gorm F

The morning samples had already been collected at the time of the review, and were cooling in the fridge (reservoir temperatures 50°C to 65°C for Gorm F and Skjold). However, during the observations, the sampling process was discussed with the Laboratory Assistant, including indicative checks on the sample point temperature to determine whether the sample to be taken is at process temperature.

Scale accumulation is a problem in the Gorm F and Skjold production process, and the separator V-3401 was undergoing maintenance (PVI) at the time of the review, requiring acid cleaning every other day. Other problems result from slugging and variability in the fluids on the Skjold produced water treatment caused by the length of pipeline (12 km) from the well. A 30 minute backwash is frequently required on the Skjold treatment train (sometimes two or three times daily).

There is no continuous OiW monitoring for any of the treatment trains on the Gorm platforms. The variability in the Skjold water treatment process is monitored by the production team during the night by taking samples and analysing them using the portable Fluorescence OiW monitor (Turner TD500D). The samples taken are left with the time and result written on the side (Figures A5.3 and A5.4 overleaf). This enables the Laboratory Technician to view the water treatment performance overnight, and determine whether additional samples and corrective measures are required.

Figure A5.3 Sampling Point for Skjold

Figure A5.4 Quick Analysis of Skjold OiW using Turner TD5000

Prior to sampling, clean sample bottles are pre-prepared in the laboratory with the addition of 5 ml (6M) hydrochloric acid. Implementation of the procedure (OPM 2b, Part 3, Rev 9. 2010-09-13) was witnessed in the laboratory for the two morning samples (Gorm F and Skjold discharge points). This specifically included Sections 5.1 (Extraction), Sections 5.2 (Chromatography), Sections 5.3 (Setting and Adjustment of the Wilks Infracal) and Sections 5.4 (Analysis and Calculation). In addition laboratory practices relevant to Section 7 (Glassware Cleaning and Rinsing) were observed. It was noted that eye and hand protection was not worn throughout the analytical procedure.

The temperature of the sample is taken to ensure it is below 20^{0}C, and then the extraction was performed without the use of a water bath in the laboratory. The Skjold sample was analysed first in order to be able to pass the information to the Production Department as soon as possible. The result for this was 23 mg/L which (at the time of the review) required extra samples to be taken. The production team back-flushed the system and the next sample was taken (and witnessed).

The review process also included a cross-check of workbook data from specific dates in the Gorm and Skjold spreadsheets against what was reported in the produced water database (EBJ-OLS); specified dates for the Gorm F included: 04/02/10, 14-24/08/10, 19/04/10, 21 and 22/09/10, 31/10-01/11/10, 04 and 05/12/10. For the Gorm C, 07/01/10, 24/02/10, 08/03/10, 28/05/10, 03/09/10 sampling points. For Skjold, 12/06/10, 07/01/10, 21/03/10, 30/03/10, 23/07/10 and 24/08/10 sampling points. These 2010 dates were selected from the workbook data that indicated higher OiW results, missing data or other potentially abnormal conditions.

The Lloyd's Register EMEA review team also conducted additional interviews with the Production Supervisors, Production Assistants, Control Room and Laboratory Assistants on the Gorm platforms. The interviews focused on the skill requirements and the role responsibilities with regard to the OiW treatment process. Communication and cooperation was also observed between and within departments whilst conducting troubleshooting activities.

Because OiW treatment processes on the Gorm are relatively complex, two teams are required to manage the production processes. One team, consisting of a Production Supervisor and Production Assistants, is dedicated to production activities associated with Gorm A, C, D, E, Rolf and Halfdan. A second team is dedicated to production operations for the Gorm F, Skjold A and B. Both teams work closely with the Control Room Assistants.

The Gorm F and Skjold production team works from a Control Room on the Gorm F platform, which is separate from the main Control Room. The Laboratory Assistant works very closely with the Gorm F and Skjold production teams, partially due to the location of the laboratory. Due to fluctuations in the OiW treatment process for the Skjold process, the portable OiW monitor is used frequently (four to five times per shift) by the production team in order to trend and track the fluctuations in the OiW values.

There is a second production team devoted to Gorm A, C, D, E, Rolf and Halfdan operations. They work from an office which is adjacent to the main Gorm Control Room on the Gorm C platform. The OiW treatment processes from these wells are relatively stable. Treatment processes and OiW values are frequently discussed between the production team, the Control Room Assistant and the Laboratory Assistant. It is noted that this production team does not utilise the handheld OiW monitors. This means that the majority of information relating to OiW process control is obtained from the Scada read-outs in the Control Room and the OiW sample results.

Observations and interviews indicated that there is a high level of awareness for the need to manage OiW processes, and that all team members are encouraged to “be the eyes and ears” to assist in identifying potential problems. Troubleshooting and fine-tuning involves a collaborative approach with the Production and Control Room teams and the Laboratory Assistant, who is considered to play a critical role in these activities.

Overboard volumes are measured by various flow meters. The calibration and preventative maintenance of the flow meters is the overall responsibility of the onshore Metering Department.

Critical Review Findings

i. Commendations

- Laboratory practices followed the procedure as described in Sections 4 to 7 of the OiW procedure (equipment, analysis, calibration, glassware).
- The Laboratory Assistant was knowledgeable with the procedure and the theory behind the processes, and demonstrated a good awareness of potential problems.
- Despite the complexity of the Gorm platforms, collaboration and communication within and between the production teams and the Laboratory Assistant was excellent. The Laboratory Assistant was consistently involved in the relevant decision making and problem solving processes; he was considered to be an important production team member.
- Evidence from observations and interviews indicated that there is a widespread focus on the OiW treatment processes, and the workforce is encouraged to observe and report any unplanned emissions and process deviations. The "eyes and ears" of the workforce were seen to be an important OiW management tool.

- Production and Control Room personnel appeared knowledgeable about the various approaches to reduce the OiW concentrations and fine-tune the production and OiW treatment processes.
- There was a general awareness of the OiW KPI values by the production and Control Room teams, and they are considered to be an important factor in the adjustment and fine-tuning of the production and OiW treatment processes.
- The quick analysis of the Skjold water treatment process by the production team during the night shift (using the portable OiW monitor) enables closer monitoring and hence control of treatment efficiency. This provides an indication to the Laboratory Assistant as to whether additional samples and measures will need to be taken during the day.

Areas for Improvement

- The OiW procedure has minor differences from the reference OSPAR method in:
    - The volumes of sample bottle (500 ml) and reagents (n-pentane 25 ml) (OSPAR is 1l bottle and 50 ml n-pentane).
    - The activation of the Florisil and storage in a desiccator.
    - The use of sodium sulphate for removal of water in the clean-up column.
    - Actions to be followed in the event of emulsions (no guidance in the OiW procedure).
    - Shaking the sample (not in the OSPAR method).
    - Blank tests (i.e. a method blank (water containing no analyte) which is subjected to the complete OiW method using the same reagents as the samples).

  There is potential for these deviations to introduce a degree of error into the method (e.g. sample clean-up may not be as effective when using non-activated Florisil, resulting in potentially higher results). Additionally, shaking the sample could potentially release VOCs with a resultant reduction in OiW concentrations and errors in reported data. Emulsions are described as rare on the Gorm; however if these do form, there is no guidance relating to dealing with emulsions, as specified in OSPAR guidance.
- There are no Quality Control (QC) samples or blanks with the OiW water samples as a quality assurance check. The analysis of known concentration QC samples can monitor any variation and drift (and highlight problems) in the performance of the method by using QC charts and setting limits. Without these contamination or problems with equipment, reagents or interferences during sampling, analysis, and clean-up may go unnoticed and therefore reported in the Gorm results. This is not aligned with good laboratory practice, nor does it provide any degree of assurance relating to the accuracy of reported results. NB: The Danish Authorities will require verification against Good Laboratory Practice as indicated in the 2011 discharge permit.
- An electronic logbook is completed by Laboratory Assistants on the Gorm. They do not however keep sample logbooks or official laboratory notebooks to trace back to raw data, or to reference sample times, analytical results, changes from

the procedure, errors or actions taken i.e. treatment of emulsions resulting from production chemicals. This compromises the transparency and traceability of the sampling and analysis method, and does not reflect good laboratory practice.

- The first point of verification is the raw data recorded in the Gorm electronic Excel workbook, which could be subject to manipulation, such as:
  - When changes are made to data contained in the workbook, there is no record of the original data or documented reasons for changes.
  - There is a lack of security in the data contained in the Gorm Excel workbook, which has open access to all Laboratory Assistants (and potentially visitors) on other platforms and the Chemistry & Environment Department.

- The platform specific information in the OiW procedure (OiW procedure Section 3.2) provides some information on sampling and reporting for the Gorm and Skjold. However there is a lack of detail in the following areas:
  - Expectations relating to communications in relation to pre-sampling, process activities, troubleshooting etc. On the Gorm F, sample taking is strongly linked to the need for OiW information for process control therefore good communication with the production team is a necessity.
  - In the use of the Turner TD500D OiW portable monitor to supplement the OiW management process, by both the Production teams and Laboratory Assistants.
  - Sampling times, locations and labelling. Also protection, storage, and transportation when necessary for onshore analysis.
  - Actions in the event of samples to be taken overnight by Production Assistants.
  - Reporting of Gorm and Skjold results, including the requirement for any explanations, with reference to the use of the Excel workbooks, production logs and the EBJ-OLS database.
  - Reference to platform specific risk assessment for the OiW procedure (i.e. sampling, chemicals etc.), and controls (i.e. PPE and H_2S controls) required.

- The uncertainty (standard deviation) of the reported concentrations has not been fully quantified. The cumulative variability associated with the analyser, laboratory equipment, sample collection, storage, extraction, clean-up and calculation using the OSPAR correlation creates an unknown level of uncertainty. Although the KPIs for the Gorm are not as low as for other platforms (Gorm F, 10 mg/l, Gorm C 8 mg/l and Skjold 20 mg/l), understanding the lower limits of detection is still important in the reporting of concentrations related to KPIs.

- The results from the OSPAR analysed samples and the Wilks Infracal analysed samples displayed varying degrees of linearity in the correlations for the individual platform calibration curves. The September 2010 R^2 value for the Gorm F was 0.8347. This relatively poor linearity has the potential to introduce considerable error in the reported results. The Chemistry & Environment Department are aware of this and the procedure is currently under review using guidance notes and advice from produced water engineers.

- Some of the cells in the current Gorm Excel workbook contain obsolete data. This has arisen through data (January to April 2010) being re-calculated retrospectively by the Chemistry & Environment Department using an improved OSPAR correlation. This was highlighted when data in the EBJ-OLS daily screen did not match with workbook recorded values, with no obvious explanation. Using multiple versions of documents and worksheets increases the potential for the use of incorrect data in calculations and reporting values.

- The data and associated information entered into the workbook and EBJ-OLS daily screen varied in the level of detail between different Laboratory Assistants. Minor data entry errors were found in the workbook. Produced water concentrations for discharged volumes were entered into the EBJ-OLS daily screen when no samples had been taken (estimated from mean or previous sample concentration). The lack of explanations, cross-checking or robust data entry procedures contribute to a lack of transparency and the potential for errors in reported data.

- Although a check is performed on the Wilks OiW analyser before use (confirming the zero reading) and samples are repeated, there was no evidence of regular performance checking of the OiW analyser against known concentrations. There was also no evidence of maintenance records or actions carried out in the event of problems. Good Laboratory Practice requires equipment to be calibrated, checked, maintained and records of repairs, routine and non-routine maintenance to be retained. A method from InfraCal was provided for checking energy levels as an indicator of instrument performance, but this is not detailed in the procedure.

- Continuous OiW monitoring is not conducted on any of the Gorm and Skjold produced water treatment processes. The time lag from sampling to receipt of results can result in delays relating to identifying and initiating troubleshooting actions. This is particularly relevant for the Gorm C process where there is no other method of determining real-time OiW values, and for the Skjold which experiences highly variable OiW conditions.

- Team members' job descriptions lack a coherent specification that reflects their responsibilities associated with produced water management, for example the Production Assistant taking the samples.

Conclusions and Recommendations

- The extraction and analysis sections of the OiW procedure, based on DECC guidance and the OSPAR reference method, have a good level of detail which is being followed in the laboratory. In the areas where the OiW procedure method differs from the OSPAR recommended method, the differences should be assessed for any significance in the measurement of OiW concentrations and if necessary, the OiW procedure amended accordingly.

- The implementation of good laboratory practice, and the use of laboratory Logbooks for recording sampling times, observations, any deviations from the procedure, and who carried out the sampling. This should also include raw data from the extraction, clean-up, analysis, any problems encountered and actions taken. Records should be made accurately at the time, be legible, indelible and signed and dated. Changes, and the reasons for changes, should be initialled, and should not obscure the previous entry.

- The introduction of a process to ensure the security of data contained within the platform specific workbook (i.e. locking cells after data entry, restricting access etc.). Ensure there is a record of the original data (i.e. data history) and documented reasons for changes.
- The principals of Good Lab Practice recommend the use of method validation. This includes determination of accuracy, precision, detection limit, quantitation limit, linearity, range and robustness. It is therefore recommended that validation of the complete OiW method (specifically the determination of lower limits of detection / quantitation) is carried out with respect to setting and meeting the Gorm KPIs.
- The OiW procedure should include the analysis of Quality Control (OSPAR method section 6.8.3) samples and blanks (OSPAR method section 9.1) to provide assurance of accuracy of results and the absence of contamination in the complete method. The use of planned and *Ad Hoc* quality checks are in line with Good Laboratory Practice, and can be developed using purchased or in-house known concentration quality control samples.
- The method for establishing a correlation between the OSPAR and Wilks Infracal analysed samples is currently under review by the Chemistry & Environment Department. A detailed formal procedure should be developed to cover the production of standards, analysis and the statistical treatment of the received results. Determining the most appropriate method and formalising it will ensure transparency in data calculation and reporting.
- Although checks are performed on the OiW analyser before use (checking the zero reading) and samples are repeated, the instrument standard operating procedure should include additional routine performance checks using a secondary reference material to check the OiW analyser performance in terms of drifting, faults and to ensure the calibration is valid. The InfraCal check on energy levels could be incorporated into this procedure.
- Continuous OiW monitoring has already been identified as a potential improvement measure for the Gorm OiW treatment processes by Maersk Oil Denmark and the Danish authorities. This will be an important tool in understanding OiW concentrations, and fine-tuning of the Gorm treatment processes. An additional portable OiW monitor for use on the Gorm C platform would provide more information to production teams in the interim period.
- Job descriptions for all Gorm personnel should accurately reflect their produced water tasks and responsibilities. Where associated training needs have been identified, the workforce training programme should be implemented, and On-the-Job training formalised and verified as having been completed.

- The accuracy of individual flow meters recording overboard volumes is unknown at the present time. It is noted that this is an area identified by Maersk Oil Denmark and the Danish authorities for investigation.

Introduction

On the 29th January 2011, the Critical Review of Produced Water Sampling, Analysis, and Reporting procedures were conducted on board the Harald installation by Linda Murray (Lloyd's Register EMEA) and Per Christofferson (Lloyd's Register Scandpower). The scope of work was conducted following the format as described in Sections 1 and 2 of this report. Documentation reviewed as part of this process is listed in Appendix 7. The following people were interviewed as part of the critical review programme of work:

- Olof Larsson, Platform/Production Supervisor (Kombimester).
- Leon Jacobsen, Production Technician.
- Henning Bygvraa, Production Assistant.
- Kim Olsen, Control Room Assistant.
- Chris Tennig Jensen, Production Assistant.

Overview of Produced Water Management

The produced water management on the Harald is a relatively straightforward process, and the quantity of water discharged is relatively low (400 m^3 in 24 hours). Harald produces from six wells which include condensate and heavy oil (Lulita well) from three different reservoirs which are mixed and exported 85 km to the Tyra platform. A new higher pressure well (Trym) was scheduled to come online from the Norwegian sector at the beginning of February 2011. It will be processed and exported to Denmark via the Tyra West. A new compressor and booster have been installed for this purpose.

The treatment process is designed for a higher capacity. From the separator, further OiW treatment is provided by two hydro-cyclones (different sizes) and a degasser (V-5019); from here, the water goes overboard to a caisson. The sampling point was viewed and is downstream of the degasser (Figure A6.1).

Figure A6.1 Sampling Point on Harald

Figure A6.2 Laboratory Analysis of OiW Sample

There is a limited need for corrective actions in the event of high OiW due to low throughput. Required corrective actions have included altering the differential pressure, changing the interface height and overflow in the degasser, and cleaning the hydro-cyclones. As a worst case, produced water can be exported to Tyra untreated. The KPI for Harald is 5 mg/l.

There are no Laboratory Assistants on board the Harald. Sampling and analysis is therefore conducted by the Production Technician on the day shift. Sampling and analysis can also be performed by the night-shift, if required. The morning sampling had been collected at the time of the review. However, during the observations the sampling process was discussed with the Production Technician. Although not continuously running (due to odour issues), the sampling point is left to run for several minutes whilst the Production Technician continues his checks and returns to collect a sample. The sample is taken at approximately 7.30 am every day, using clean bottles that are pre-prepared with 5 ml of 6M Hydrochloric Acid. The bottles are labelled if required (as there is usually only one sample) using a marker pen, and extracted soon afterwards. On a weekly basis, the Production Technician is required to undertake further sampling and analysis for additional parameters e.g. Hydrogen Sulfide, Carbon Dioxide, viscosity, pH and iron.

Implementation of the OiW procedure (OPM 2b, Part 3, Rev 9. 2010-09-13) was witnessed in the laboratory for the morning sample (Figure A6.2 above). This specifically included Sections 5.1 (Extraction), Sections 5.2 (Chromatography), Sections 5.3 (Setting and Adjustment of the Wilks Infracal) and Sections 5.4 (Analysis and Calculation). In addition, laboratory practices relevant to Section 7 (Glassware Cleaning and Rinsing) were observed.

The extraction was performed without the use of a water bath in the laboratory. The only deviation observed from the OiW procedure was the use of a 10 ml graduated test tube in place of a volumetric flask. The test tube was used for the collection of the extract from the clean-up column. The absorbance readings from the Wilks OiW analyser are entered into the Excel workbook, and then the calculated concentration is communicated to the Control Room via the radio. The Control Room then records this onto a daily log sheet. All of the recorded data on the sheet is entered into the EBJ-OLS database at the end of the day (before 1.00 am). This was confirmed by an interview with the Control Room Assistant, which also covered OiW troubleshooting.

The review process also included a cross-check of workbook data from specific dates in workbooks against what was reported in the produced water database (EBJ-OLS); specified dates included for the Harald: 10/06/2010; 18 – 20/05/2010; 14/11/2010; 05/12/2010; 30/12/2010. These 2010 dates were selected from the workbook data that indicated higher OiW results, missing data or other potentially abnormal conditions.

The Lloyd's Register EMEA review team also conducted additional interviews with the small team working with OiW treatment processes; this included the Kombimester, Production Technicians, and Control Room Assistants. The interviews focused on the skill requirements and the role responsibilities with regard to the OiW treatment process. Communication and cooperation were also observed between and within departments whilst conducting troubleshooting activities.

The situation on the Harald is unique in that the platform has a laboratory but lacks the accommodation and volume of work to warrant a full time Laboratory Assistant. The

Production Technicians therefore perform the analyses in addition to their other duties. OiW training and competency requirements for the Production Technicians have not been formalised.

Practices and approaches to troubleshoot OiW treatment issues are discussed and agreed between the Kombimester, the Production Team, and the Control Room Assistants. If OiW concentrations exceed 20 mg/l, the Kombimester and Control Room is immediately contacted by the Production Technician and corrective actions are agreed.

Critical Review Findings

i. Commendations

- It is clear that the Harald workforce has great pride in their platform and their achievements in relation to produced water management.
- Communication within the team (16 to 30 people) is excellent.
- Laboratory practices largely followed the OiW procedure as described in Sections 4 to 7 (equipment, analysis, calibration, glassware).
- The Production Technician was clearly careful and thorough when completing the laboratory extraction and analysis. He wore the correct PPE at all times.
- The standard of OiW analysis did not appear to be compromised by the lack of formal training received by the Production Technician, and his knowledge with regard to the production process was particularly beneficial during abnormal operations.

Areas for Improvement

- The OiW procedure has minor differences from the reference OSPAR method in:
    - The volumes of sample bottle (500 ml) and reagents (n-pentane 25 ml) (OSPAR is 1l bottle and 50 ml n-pentane).
    - The activation of the Florisil and storage in a desiccator.
    - The use of sodium sulphate for removal of water in the clean-up column.
    - Actions to be followed in the event of emulsions (no guidance in the OiW procedure).
    - Shaking the sample (not in the OSPAR method).
    - Blank tests (i.e. a method blank (water containing no analyte) which is subjected to the complete OiW method using the same reagents as the samples).

  There is potential for these deviations to introduce a degree of error into the method (e.g. sample clean-up may not be as effective when using non-activated Florisil, resulting in potentially higher results). Additionally, shaking the sample could potentially release VOCs with a resultant reduction in OiW concentrations and errors in reported data. The Production Technician on the Harald had never encountered a problem with emulsions.

- There are no Quality Control (QC) samples or blanks with the OiW water samples as a quality assurance check. The analysis of known concentration QC samples can monitor any variation and drift (and highlight problems) in the performance of the method by using QC charts and setting limits. Without these contamination or problems with equipment, reagents or interferences during sampling, analysis, and clean-up may go unnoticed and therefore reported in the Harald results. This is not aligned with Good Laboratory Practice, nor does it provide any degree of assurance relating to the accuracy of reported results. NB: The Danish Authorities will require verification against Good Laboratory Practice as indicated in the 2011 discharge permit.
- The Production Technician on the Harald does keep a personal notebook however, there is no official sample or laboratory Logbook. A lack of raw data and information potentially compromises the transparency and traceability of the sampling and analysis method, and does not reflect Good Laboratory Practice.
- The first raw data recorded is in the Harald electronic Excel workbook, which could be subject to manipulation. Specifically:
    - When changes are made to data contained in the workbook, there is no record of the original data or documented reasons for changes.
    - There is a lack of security in the data contained in the Harald Excel workbook. Although the Harald laboratory is remote, the workbook has open access to all Laboratory Assistants (and potentially visitors) on other platforms and the Chemistry & Environment Department.
- The platform specific information in the OiW procedure (OiW procedure Section 3.2) provides some information on sampling and reporting for the Harald. However there is a lack of detail in the following areas:
    - Expectations relating to communications related to pre-sampling, process activities, troubleshooting etc. As the Production Technician is also performing OiW sampling and analysis, there should already be a good awareness of the operating conditions.
    - Sampling times, locations and labelling. Also protection, storage and transportation when necessary for onshore analysis.
    - Actions in the event of samples to be taken overnight.
    - Reporting of Harald results, with reference to the use of the Excel workbooks, production logs and the EBJ-OLS database, including the importance of formally recording and logging any verbal radio communications.
    - Reference to platform specific risk assessment for the OiW procedure (i.e. sampling, chemicals etc.) and controls (i.e. PPE) required.
- The uncertainty (standard deviation) of the reported concentrations is not fully quantified. The cumulative variability associated with the analyser, laboratory

- The results from the OSPAR analysed samples and the Wilks Infracal analysed samples displayed varying degrees of linearity in the correlations for the individual platform calibration curves. The September 2010 R^2 values varied from 0.9982 for the Dan FC to 0.8347 for Gorm F. This has the potential to introduce considerable error into the reported results. The Chemistry & Environment Department is aware of this and the procedure is currently under review using guidance notes and advice from produced water engineers.
- The data and associated information entered into the workbook and EBJ-OLS daily screen contained some errors. Time entries did not correlate with Excel workbook entries (10.06.2010 and subsequently other dates) and explanations were missing for elevated OiW results (14/11/2010). The lack of explanations, cross-checking and robust data entry procedures potentially contribute to a lack of transparency and the potential for errors in reported data. The verbal transfer of OiW data may also be a contributory factor.
- Although a check is performed on the Wilks OiW analyser before use (confirming the zero reading) and samples are repeated, there was no evidence of regular performance checking of the OiW analyser against known concentrations. There was also no evidence of preventative or corrective maintenance records. Good laboratory practice requires equipment to be calibrated, checked, maintained and records of repairs, routine and non-routine maintenance to be retained. An InfraCal methodology was applied to check energy levels as an indicator of instrument performance, but this is not detailed in the procedure.
- Continuous OiW monitoring is not conducted on the Harald. The time lag from sampling to receipt of results can result in delays relating to identifying and initiating troubleshooting actions. This is particularly relevant as there is no other method of determining real-time OiW values. The addition of the Trym well may impact on the current stability of the treatment process and create more of a need for quick information.
- In line with other installations, there is no provision of a formal training and competence development programme for Production Technicians who conduct OiW sampling and analysis tasks. A programme of OiW training and competency development has been created for Laboratory Assistants in the Dansk Undergrunds Consortium, and this should also be adopted by the Harald to support development and consistency in this area.

Conclusions and Recommendations

- The extraction and analysis sections of the OiW procedure, based on DECC guidance and the OSPAR reference method, have a good level of detail which is being followed in the laboratory. In the areas where the OiW procedure method differs from the OSPAR recommended method, the differences should be

- The implementation of Good Laboratory Practice and the use of laboratory Logbooks for recording sampling times, observations, any deviations from the procedure and who conducted the sampling. This should also include raw data from the extraction, clean-up, analysis, any problems encountered and actions taken. Records should be made accurately at the time, be legible, indelible, and signed and dated. Changes should be initialled with reasons and should not obscure the previous entry.
- The introduction of a process to ensure the security of data contained within the platform specific workbook (i.e. locking cells after data entry, restricting access etc.) ensures there is a record of the original data (i.e. data history) and documented reasons for changes.
- The principals of Good Lab Practice recommend the use of method validation. This includes determination of accuracy, precision, detection limit, quantitation limit, linearity, range and robustness. It is therefore recommended that validation of the complete OiW method (specifically the determination of lower limits of detection / quantitation) is carried out with respect to setting and meeting the Harald KPI.
- The OiW procedure should include the analysis of Quality Control (OSPAR method section 6.8.3) samples and blanks (OSPAR method section 9.1) to provide assurance of accuracy of results and the absence of contamination in the complete method. The use of planned and *Ad Hoc* quality checks are in line with Good Laboratory Practice, and can be developed using purchased or in-house known concentration quality control samples.
- The method for establishing a correlation between the OSPAR and Wilks Infracal analysed samples is currently under review by the Chemistry & Environment Department. A detailed formal procedure should be developed to cover the production of standards, analysis and the statistical treatment of the received results. Determining the most appropriate method and formalising it will ensure transparency in data calculation and reporting.
- Although checks are performed on the OiW analyser before use (checking the zero reading) and samples are repeated. Additional performance checks should be carried out routinely using a secondary reference material to check the OiW analyser performance in terms of drifting, faults and to ensure the calibration is valid.
- The training programme and associated matrix for the Harald Production Technicians should be updated to reflect the requirement for OiW sampling and analysis. Existing and new Production Technicians should complete the newly developed OiW training. Alternatively, competency levels should be measured against the programme requirements. This should also include On-the-Job-training.

Introduction

The review comprised a series of interviews offshore and onshore, as well as reviews of relevant documentation. Maersk Oil Denmark provided Lloyd's Register EMEA with a number of documents prior to the commencement of interviews. These documents included: procedures, organisational charts, copies of the newspaper articles and Maersk Oil Denmark's responses to those articles. There were also several other documents that were reviewed onsite. The following Maersk specific documents were provided for review. The OSPAR and DECC guidance documents referred to in the report are also included for completeness.

No.	Document number	Title/description	Date/revision
1	OPM 2B, Part 3	Produceret Vand Specifikationer. Oil in Water (OiW) sampling, analysis, and reporting with Wils InfraCal (English translation).	2010-09-13 Rev 9
2	OPM 2B, Part 3	Produceret Vand Specifikationer. Olie-i-vand (OiW) Prøvetagning, analyse og rapportering med Wilk Infracal.	2011-02-01
3	OSP 026	Operations Safety Procedure. Packing and transport of samples.	Edition 6. 01 Nov 2009
4	Fælles program M10-03	Prøvetagning af Oile til OiW korrelationer mellem Wilks Infracal og OSPAR referencemetoden. Chemistry and environment.	30/07/2010
5		English translation of Politiken articles.	
6		Maersk Oil Denmark's stated response to above articles.	
7		Maersk Oil Denmark submits report to Danish Environmental Protection Agency.	03.01.2011
8	HSEQ program	Danish operation 2011. Danish and English versions.	
9	Maersk	Framework for effective management of HSE.	
10	OiW reports	Maersk Olie I produktionsvand. Månedsrapport for April 2010.	
11	DUC	DUC in the North Sea. Schematic of DUC platforms.	06/2008
12	Memo P010-288 SFH/aro	Memo IOW verification 2010 follow-up.	01.11.2010
13	DEN-HSEQ-MSM-001 Rev 1	Environmental Management System. Danish Operation.	Rev 1.0 24.11.10
14	DS/EN ISO 14001:2004	Initial audit report. Environmental Management System Certification.	10.12.2010
15	Flexim	Ultrasonic Clamp on flow measurements in Denmark for Offshore company Maersk Oil and Gas.	15.12.2010
16	KBR	Specifications for flow meter for Halfdan phase IV.	04/03/2009
17		Danish Operation organisational chart.	
18	Job Descriptions	Laboratory Technician, Production Supervisor, Control Room Assistant, Production Technician.	
19		Daily logs (dates as listed).	
20		Daily Production Check Lists.	
21		Daily Operational Highlights Report (various dates).	
22		Planned maintenance schedules for Tyra West produced water process trains (CBI and IPF).	

No.	Document number	Title/description	Date/revision
23		Competency matrices, and identified Production Operations Guidelines (POGs) and procedures (both OSPs and OPMs).	
24		The Tyra production unit discharge permit, as issued by the Department of Environmental Protection 20 September 2009.	
25		The Gorm production unit discharge permit, as issued by the Department of Environmental Protection 20 September 2009.	
26		The Dan production unit discharge permit, as issued by the Department of Environmental Protection 20 September 2009	
27		The Halfdan production unit discharge permit, as issued by the Department of Environmental Protection 20 September 2009.	
28		The Tyra production unit discharge permit, as issued by the Department of Environmental Protection 31 January 2011.	
29		The Gorm production unit discharge permit, as issued by the Department of Environmental Protection 31 January 2011.	
30	SGS	Analytical sample analysis reports for OiW OSPAR correlation samples.	28.09.2010
31	Maersk	Excel spreadsheet Calibration curves from Wilks, OSPAR correlations.	No date
32	OSPAR Recommendation (OSPAR 01/18/1, Annex 5) Amended by OSPAR Recommendation 2006/4 (OSPAR 06/23/1, Annex)	OSPAR Recommendation 2001/1 for the Management of Produced Water from Offshore Installations (Consolidated text).	2001/1 adopted by OSPAR 2001 and amended by 2006/4
33		Guidance notes for The sampling and analysis of produced water and other hydrocarbon discharges. DECC. Including Section 9 OSPAR reference method (ISO9377-2 as modified by OSPAR).	Version 2.1 Aug 2010

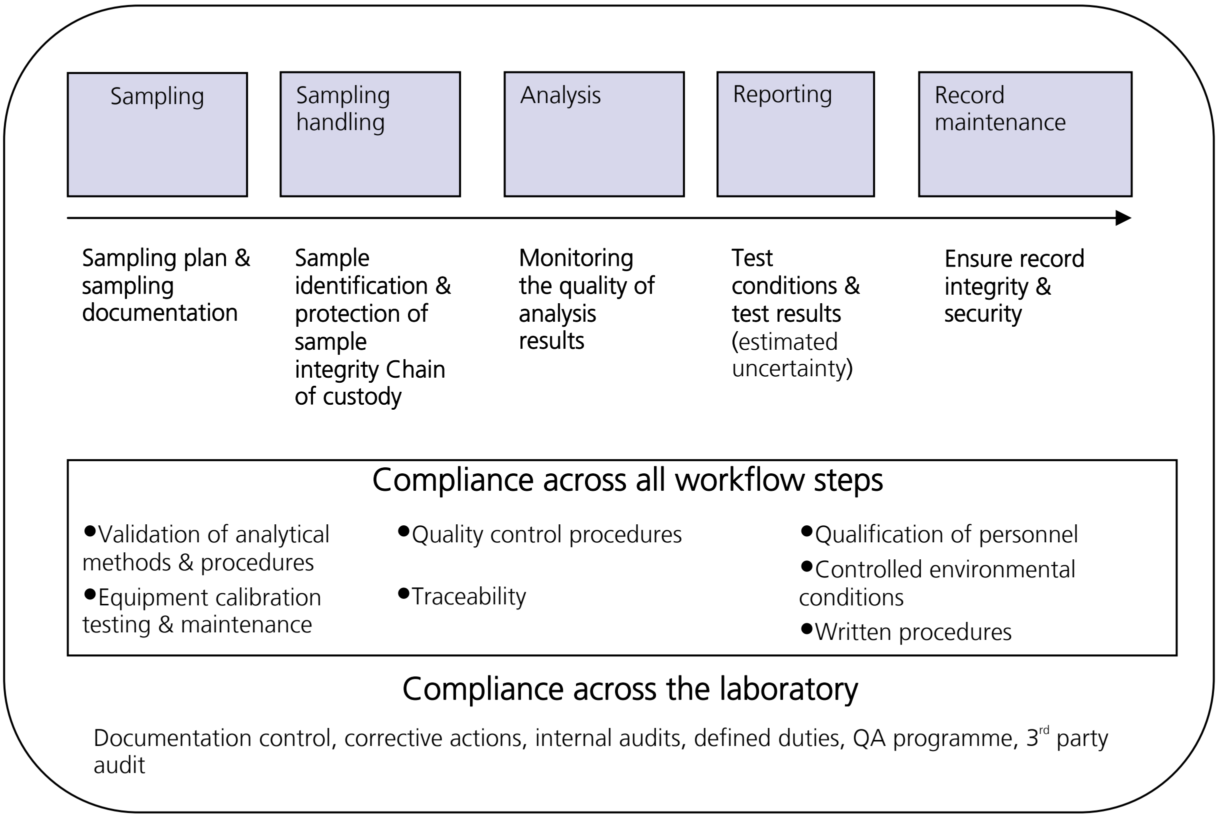
Principles of Good Laboratory Practices

The new OiW discharge permit requirements for the Maersk platforms, as issued on 31 January 2010, requires the laboratory procedures and practices be verified against the principles of Good Laboratory Practice (GLP) (in addition to permit requirements) for OiW measurement.

Principles of GLP (i.e. OECD) are more usually applied to studies to evaluate the properties of a test item (e.g. the effects of a pesticide). However, the principles of quality assurance in order to establish confidence in the data can still be applied, including:

- Organisation and personnel responsibilities.
- Written Standard Operating Procedures (SOPs).
- Statistical procedures for data evaluation.
- Instrumental validation.
- Reagent/materials certification.
- Analyst competence and qualification.
- Laboratory facilities environment.
- Specimen/sample tracking.
- Reporting of results.
- Documentation and maintenance of records.

The diagram below outlines the workflow (sampling to analysis to reporting) undertaken for the OiW procedure, together with the relevant requirements for GLP. The diagram is modified from the requirements of ISO 17025 for testing laboratories to incorporate the GLP requirements. Please note that ISO 17025 is the standard for laboratory technical competence demonstrating impartiality and performance capability.



Good Laboratory Practices for Maersk Offshore Laboratories

Sampling

- Sampling should be performed according to a sampling plan, and all sample details should be documented from origin.

Sample handling

- Samples should be uniquely identified and the sample integrity should be protected during transport and storage, including chain of custody, stability and storage conditions effects.
- There should be a traceable connection from the original samples through to the analytical data reported.
- Equipment used for sampling should be appropriate and well maintained (clean).

Analysis

- All routine tasks should be performed according to written procedures (analytical methods including actions in the event of problems, raw data, records, reporting, data handling).
- Analytical instruments should be calibrated, tested, and well maintained. Identification of faulty instruments. Material such as calibration standards should be qualified and traceable to System International (SI) units or to certified reference materials. Reagents and solutions should be labelled, stored appropriately and include expiration dates.
- People should be resourced appropriately and be qualified for their assigned tasks through education, experience, or training. Acceptable proof of training and competence should be established and documented.
- All analytical methods and procedures should be validated. This includes methods and procedures for sampling, testing and data evaluation.
- Environmental conditions such as temperature, humidity, and electromagnetic interference should be monitored and controlled.
- The quality of test results should be monitored, using ongoing planned and *ad hoc* quality checks.

Reporting and Records

- Test reports should include test results as well as an estimation of the overall measurement uncertainty (ISO17025 only).
- Records should be properly maintained to ensure data integrity and availability.
- Records should include anything verifying the original analytical results, due to repercussions of decisions based on the results.
- Facilities for secure storage, raw data, and reports to be retained for a specified time (with nominated archivist).

General

- Compliance with GLP and internal procedures (and discharge permit conditions) should be assessed during regular internal audits.
- External verification (by third party provider approved by Miljøstyrelsen) with GLP and permit requirements at least twice a year (if no major non-compliances this should decrease to annually).
- Known existing problems should be corrected and an action plan should be developed to avoid recurrence of the same or similar problems.