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Torleiv Bilstad, Bjørnung Jensen, Martin Toft
& Evgenia Protasova

**Petroleum production in symbiosis with
fisheries? The norwegian experience**

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Petroleum production in symbiosis with fisheries? The norwegian experience

TORLEIV BILSTAD¹, BJØRNING JENSEN²,
MARTIN TOFT² and EVGENIA PROTASOVA¹

¹ Environmental Engineering, University of Stavanger, 4036, Norway

² Halliburton, Baroid Surface Solutions, Eldfiskveien 1, 4056 Norway

torleiv.bilstad@uis.no bjornung.jensen@halliburton.com
martin.toft@halliburton.com evgenia.protasova@uis.no

Abstract

Fisheries and offshore Oil and Gas (O&G) industries have a long history of co-existence. Both industries leave an impact on the marine environment, and are subject to regulations in order to ensure sustainable use of resources. Offshore O&G exploration, drilling and production activities may impact fisheries through seismic activities, discharge of hazardous waste and presence of physical structures.

Historically, cuttings from drilling sub-surface wells have been deposited directly from the platform to the seabed. However, environmental laws and regulations for the Norwegian offshore sector prohibit such practice when the oil on cutting exceeds 1% by weight. Re-injection of cuttings as a slurry into subsurface formations is still practiced. Due to migration, leaks, re-entering of slurry onto the seabed, and collapsing formations this disposal method is on a decline. Transport of oily cuttings to shore for final treatment is the preferred Norwegian practice. However, cutting treatment on platforms is also continuously evaluated. For logistics and cost reasons, as well as health, safety and environmental (HSE) and working environment reasons, emphasis is put on offshore waste minimization, reuse and recycle.

Keywords: drilling cuttings, oil based mud, produced water, best available technologies (BAT)

Résumé

Les pêches et les industries Pétrolières et Gazières (P&G) offshore ont une longue histoire de coexistence. Les deux industries laissent un impact sur le milieu marin et sont soumises à des règlements afin de garantir une utilisation durable des ressources. Les activités d'exploration offshore,

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forage et production de P&G peuvent affecter les pêches à travers des activités sismiques, le déversement de déchets dangereux et la présence de structures physiques.

Historiquement, les déblais provenant de puits de forage sous la surface ont été déposés directement à partir de la plateforme au fond marin. Cependant, les lois et règlements environnementaux pour le secteur offshore norvégien interdisent une telle pratique lorsque l'huile de la coupe dépasse 1% en poids. La réinjection de déblais sous forme de boue dans des formations souterraines est encore pratiquée. À cause de la migration, les fuites, la boue rentrant sur le fond marin et l'effondrement des formations, cette méthode d'élimination est sur le déclin. Le transport des déblais huileux à terre pour le traitement final c'est la pratique que privilégient les norvégiens. Toutefois, le traitement des déblais sur les plateformes est également évalué en permanence. Pour des raisons de logistique et de coût, ainsi que pour des raisons de santé, de sécurité et d'environnement (HSE) et de milieu de travail, l'accent est mis sur la réduction des déchets en mer, la réutilisation et le recyclage.

Mots clés : déblais de forage, huile à base de boue, eau produite, meilleures techniques disponibles (MTD)

Introduction

On the Norwegian Continental Shelf co-existence of offshore O&G with fisheries and aqua culture is supported by strict regulations and zero discharge from O&G activities.

Types and amount of fluids utilized when drilling a well determine to which extent the drilled cuttings are legally considered hazardous waste. The main categories of drilling fluids are oil based (OBM), water based (WBM) and synthetic based mud (SBM). The purpose of adding fluids to the drilling operations is to cool and lubricate the drill bit, to stabilize the well bore, to control subsurface pressure, to control formation pressure, to control well stability, to control corrosion, and to carry cuttings to the surface.

Drill cuttings

Drill cutting particle size varies between 10 μm and 20 mm depending on the drill bit, well bore length and geological formations. Depending on the quality of OBM, the geological formations and whether drilling is in hydrocarbon reservoirs, cuttings are coated with different hydrocarbons including PAHs, PCBs, and heavy metals. Re-injection of cuttings as a slurry into subsurface formations has over the last few years been

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challenged due to several cases of loss of formation integrity, leading to migration of oil and water, leaks, cuttings re-entering the sea bed and collapsing formations. Such mishaps have developed into increased focus on proper design and maintenance of injection wells. The method of re-injection is, however, still widely used (Figure 1).

Figure 1. Oil Based Drilled Cuttings Injection in Norwegian Sector
(Norsk Olje og Gass, 2013)

WBM normally consists of environmental friendly chemicals, classified as green and yellow with regard to environmental toxicity, which allows for direct discharge to sea. However, in environmental sensitive areas such as the Barents Sea, also WBM discharges are in many areas prohibited or subject to governmental approval and possible discharge permit. The Barents Sea is a “0-discharge area” and a permit is always required, also for sub-surface injection. Figure 2 shows the trend of using WBM in Norway.

Figure 2. Water Based Drilled Cuttings Disposed Offshore Norway
(Norsk Olje og Gass, 2013)

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Treatment of OBM drilled cuttings is initiated offshore by a shale shaker consisting of vibrating screens. Further solids control could include gravitational sand settling, a specialized desander and deciliter as well as centrifuges, all successively removing smaller solids from the mud. The shale shaker is the universal common separation technique for separating fluids from cuttings. Each well typically produces 300-1800 tons from the shaker, with 5-15 % by volume oil.

Depending on local regulations and oil content on cuttings, available disposal options include discharge to sea, underground injection, and further offshore and onshore treatment. In Norway permits are required for all discharges as well as sub-surface injection. Figure 3 summarizes years of accumulated drilled cuttings mass production from the Norwegian offshore petroleum sector. Treatment of offshore generated drilled cuttings is a challenge compared with cuttings generated onshore. After shaker separation of mud and cuttings, the transport routes for the two components include internal transport on the rig itself, from the rig to vessel, further transport by vessel to onshore receiving facilities, and on to treatment facilities and possible reuse or final disposal. This is a cost issue of great concern; logistics and transportation of offshore drilled cuttings.

Figure 3. Oil Based Drilled Cuttings, mud and oil emulsions transported to shore from Norwegian Offshore Sector (Norsk Olje og Gass, 2013)

After the oily cuttings have been through a Thermomechanical Cuttings Cleaner (TCC) unit shown in Figure 4, the recovered drill fluid is compared to virgin drill fluid in Figure 5.

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Figure 4. The Principal of the Thermomechanical Cuttings Process Mill (Halliburton, 2007)

Figure 5. Comparing virgin drill fluid with TCC treated fluid recovered for reuse (MI Swaco, 2013)

The process mill is the heart of the TCC separation process and converts kinetic energy to thermal energy by creating friction in the cuttings. Solids are recovered through an auger system, discharged through a cell valve as dry powder and on to rehydration, with recovery of water prior to disposal. Oil and water flash off as vapors, and are condensed and separated in a condenser skid. The water and crushed cuttings are cleaned to levels below Norwegian requirements for sea discharge, 30 mg/L oil in water and 1 % oil by weight on cuttings.

Produced water

Produced water is defined as a byproduct from oil and gas exploration and production. Water brought to the surface co-produced with oil and gas may include water originally in the reservoir, water injected into hydrocarbon formations, metals and varying amount of chemicals added during drilling, production and treatment processes (Aquatec, 2013). Due to presence of numerous hazardous components, produced water should be treated prior to discharge. Additionally, treated produced water should be tested for toxicity to marine ecosystems. Salinity of produced water varies from 100 mg/L to 400 000 mg/L (saturated brine), compared to 35 000 mg/L salinity in normal seawater (PWS, 2010).

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Key parameters of produced water are according to Statoil (2014):

- Oil concentration of 100 - 500 ppm for oil field and 10-200 ppm for gas field
- Salinity of 1 - 40 ‰
- Oil droplet sizes of 2 - 20 microns
- Viscosity of 0.2 - 2 cP
- Density of 990 - 1050 kg/m³
- Pressure of 10 to 80 bar
- Temperature of 30 to 150 °C.

According to Walsh (2014) components in PW is summarized as:

- Dispersed oil
- Dissolved oil (HC, BTX, phenols, PAH, etc)
- Dissolved organic acids (SCFA, naphthenic acids)
- Dissolved formation minerals (NaCl, CaCO₃, FeCO₃, FeS_x, BaSO₄, etc)
- Dissolved metals (Fe, Zn, Mn, Cr, etc)
- Process & Production chemicals (Cl, MeOH, glycols, LDHI)
- Produced formation solids (clay, sand, carbonate)
- Precipitated mineral solids (CaCO₃, FeCO₃, FeS_x, BaSO₄, etc)

- Dissolved and precipitated corrosion products (metal oxides)
- Dissolved gasses (O_2 , H_2S , CO_2)
- Combinations of the above; i.e., Schmoos
- Various bacteria and by-products (SRB, GHB)

There is a distinct difference between produced water from oil and gas production as presented in Table 1.

The differences in produced water quality and composition from oil and gas fields play an important role in design of produced water treatment process. One of these important parameters is water/HC ratio; from 0.05 in gas fields up to 0.9 in oil fields. These values directly affect the choice of treatment processes.

The composition and characteristics of produced water are strongly dependent on the origin of the water, oil quality and upstream processing. Produced water contains dissolved gasses, dissolved minerals, dissolved organics including hydrocarbons, suspended oil or oil droplets, sand and drilled cuttings as well as various production chemicals. The amount and composition of produced water can vary a great deal from one field to the other and during the lifetime of a field (Statoil,

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2014). Table 2 presents produced water compositions from different fields on the Norwegian Continental Shelf.

Produced water discharge

Discharge of produced water is regulated by law. Treatment based on regulations needs to be implemented for both sub-surface reinjection and water directly disposed of to the marine environment. Figure 6 shows produced water from offshore Norway. Discharges of produced water on the Norwegian Continental Shelf reached a peak in 2010 with a volume of 190 million m³. Production of produced water from the Norwegian Continental Shelf is predicted to decrease significantly from 2016. Minimizing produced water close to the production source is a priority. Practical use of produced water is reinjection into producing wells for pressure maintenance and enhanced oil recovery (EOR). This requires proper treatment before injection. Another disposal strategy is disposal of untreated produced water into aquifers.

Data in Table 3 compare injected produced water in the US. Texas is the leading state in terms of both injections for disposal and for enhanced oil recovery purposes.

Figure 6. Water Production and Discharge from Norwegian Continental Shelf (Statoil, 2012)

Presence of hydrocarbons in slop water is an additional separation challenge. Slop is run off from platform deck and consists of 80 % water with added components and mixtures of oil-based drilling fluid, water-based drilling fluid, wellbore clean-up detergents, completion fluids, cement spacers, rig wash, brines with different salts and solids from cuttings. Slop is usually shipped onshore for treatment from the Norwegian Continental Shelf. In order to reduce onshore shipping, an alternative strategy may be to inject slop into subsurface formations or offshore slop pretreatment.

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By 2020, the onshore oil and gas industry will generate over 500 million barrels of produced water a day – driven by an increase in the production of unconventional oil and gas and an increasing number of mature oilfields where water to oil ratios are growing significantly.

There will be huge opportunities for water companies offering solutions that enable exploration and production companies to overcome the challenges associated with managing this produced water and to turn it into a valuable asset rather than a waste stream.

Laws and regulations

The marine ecosystem is a very sensitive and complex environment. Sustainability is often depending on human activity. In case of environmental disasters, healing of marine ecosystems may take tens of years, if at all healing. Such disasters often result in biological and ecological degradation and species extinction as well as significant economic losses for people in coastal regions. Internationally, governments have strict regulations and requirements for discharge of hazardous components. Table 4 shows limits for oil content in water discharged to sea.

The OSPAR Commission and the Norwegian authorities set requirements for the use of environmentally friendly chemical additives (PLONOR, “yellow” and “green” chemicals), but exact discharge limits have only been set for the content of oil, less than 30 mg/L (NPD, 2012).

PLONOR stands for Pose Little or No Risk. «Yellow» chemicals are chemicals in use that do include in “red or black” restricted categories. “Green” chemicals are chemicals in the PLONOR list of the OSPAR; permitted without specific conditions.

Figure 7 presents development of regulations for oil content in discharged produced water with the main goal of “zero discharge” in 2020. Intense development and usage of best available technologies (BAT) make positive impact of achieving standards set by the authorities for safety and treatment of produced water.

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Figure 7. Development of Produced Water Regulations (Statoil, 2014)

Best available technology

Minimizing produced water close to the production source is a priority in development of BAT. Produced water management strategy usually includes four main steps referring to Figure 8 (Statoil, 2014):

- water shut-off (reduce production of water in mature fields by isolating water producing zones);
- reinjection;
- shallow disposal (deposition);
- produced water treatment or top side treatment.

Figure 8. Produced Water Management Strategy (Statoil, 2014)

Reinjection is usually more costly than top side water treatment. However, reinjection could also be used for pressure maintenance and enhanced oil recovery. Top side treatment

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and reinjecting both require proper treatment of produced water. Reinjection and shallow disposal options will depend on production well properties and specific discharge permissions in order to design produced water treatment for minimum discharge requirements (Statoil, 2014).

Norwegian guidelines for produced water treatment systems include, but are not limited to, two treatment stages to fulfill the World Bank Standard discharge limits, and three treatment stages to fulfill stricter discharge requirements. This should also apply for treatment of water from 2nd stage separator/3rd stage separator/coalescer. In treatment systems with two treatment stages, the stages shall be based on different separation principles. A treatment stage is per definition a separate physical oil removal stage (Statoil, 2014).

Table 5 presents comparison of BAT for produced and slop water treatment, showing key parameters and conditions for successful implementation of each.

Conclusions

Sustainable management of the petroleum industry and its co-existence with the fishing sector may be achieved by developing and implementing BAT. Available technologies and strategies are sufficient for solving the drilling waste and pro-

duced water challenges. The choice of solution is depending on composition, location, distance to shore and laws and regulations. BAT provides acceptable results for O&G waste treatment with respect to marine environmental conditions and laws and regulations. Enforcing laws and regulations is the key to sustainable coexistence between fisheries and O&G industries.

References

- Aquatec. 2013. *Produced Water Treatment and Beneficial Use Information Center* [Online]. Available at: <http://aqwatec.mines.edu/produced_water/intro/pw/> [Accessed 23.03.14].
- EIA, US Energy Information Administration. 2014. *Global Petroleum and Other Liquids* [Online]. Available at: <http://www.eia.gov/forecasts/steo/report/global_oil.cfm> [Accessed 20.02.2014].
- Halliburton. 2007. *Baroid Surface Solutions. Thermal Desorption Technology*. [Online]. Available at: <http://www.halliburton.com/public/bar/contents/data_sheets/web/sales_data_sheets/sds-059.pdf> [Accessed 20.02.2014].
- MI Swaco. (2013). Base Oil GC/MS scan. Example from Bautino. Kazakhstan. Word-file.
- NPR, Norwegian Petroleum Directorate. 2012. *Discharge of Produced Water* [Online]. Available at: <<http://www.npd.no/en/Publications/Reports/Long-term-effects-of-discharges-to-sea-from-petro->

Petroleum production in symbiosis with fisheries? The norwegian experience

[leum-activities/The-Oceans-and-Coastal-Areas/2-Discharges-of-produced-water/](#)> [Accessed 23.03.2014].

Norske olje og gass. 2013. *Environmental Report. Oil and Gas Industry*. [Online]. Available at: <<https://www.norskoljeoggass.no/Global/2013%20Dokumenter/Publikasjoner/Environmental%20Report%202013.pdf>> [Accessed 20.03.2014]

PWS, Produced Water Society. 2010. *Produced Water Facts* [Online]. Available at: <http://producedwatersociety.com/index.php/produced_water_facts/> [Accessed 23.03.2014].

SPE, The Society of Petroleum Engineers. 2009. *Produced Water Management* [Online]. Available at: <<http://www.spe.org/dl/docs/2009/Veil.pdf>> [Accessed 01.04.2014].

Statoil. 2012. Presentation by Knut Åsnes at MinNovation Seminar at the University of Stavanger, Norway, April 26.

Statoil. 2013. *Water Production and Related Challenges* [Online]. Available at: <<http://www.ipt.ntnu.no/~jsg/undervisning/prosesser-ing/gjester/LysarkRamstad2013.pdf>> [Accessed 26.03.2014].

Statoil. 2014, Presentation by Anne Finborud at Separation Technology seminar at the University of Stavanger, Norway, February 27.

Veolia Water. 2013. *Application of MPPE for Treating Produced Water Toxins* [Online]. Available at: http://www.tuvnel.com/assets/content_images/2_3%20VWS%20MPP%20Systems.pdf [Accessed 01.04.14].

Walsh, J. 2014. European Desalination Society, Two Day Course on “Water Treatment for Upstream Oil and Gas”, May 10-11 Grand Resort Hotel, Limassol, Cypros.

Appendix

Table 1. Parameters of Oil Field vs. Gas Condensate Field
(Statoil, 2014)

Specification	Gas condensate field	Oil field
Gas/Liquid ratio (GLR)	High	Low to medium
Water/Oil ratio (WOR)	Low (< 0.05)	Low to high (0-0.9)
Quantity of water	Low ($< 50 \text{ m}^3/\text{h}$, condensed water only)	Medium to high (50-2000 m^3/h)
Salinity of water phase	No salt	Medium to high ($> 3 \%$)
Foam stability	Low	Low to high
Foaming problems	Seldom experienced	Often experienced, oil specific
Water in oil stability	Low	Medium to high
Emulsion problems	Seldom experienced	Often experienced, oil specific
Oil in water stability	High	Low to high
Produced water treatment	Very difficult	Easy to difficult, oil specific

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Table 2. Produced Water Compositions from Norwegian Continental Shelf (Statoil, 2013)

Ion (mg/L)	Ormen lange*	Oseberg	Njord	Gyda	Utsira aquifer**	Seawater
Na ⁺	4428	12500	19000	65340	10100	11150
K ⁺	90	335	747	5640	262	420
Ca ²⁺	220	978	4050	30185	494	435
Mg ²⁺	31	135	392	2325	714	1410
Ba ²⁺	19	134	765	485	6.7	0.1
Sr ²⁺	12	157	891	1085	12.1	6.6
Fe	0.6	0.1	23	-	5.7	0
Cl ⁻	6804	21900	41400	167400	18500	20310
SO ₄ ²⁻	7.9	5	15	-	2	2800
HCP ₃ ⁻	1008	633	230	76	1110	150
Organic acids	640	120	360	-	-	-
Salinity (TDS)	12650	36800	67513	272536	30100	36675

* Ormen lange – gas field, Oseberg – oil and gas; Njord – oil and gas; Gyda – oil field.

** Utsira Aquifer is saline aquifer CO₂ storage in Norwegian part of North Sea from Sleipner E and W.

Table 3. Produced Water Injection in the USA* (SPE, 2009)

Place	Injection for EOR	Injection for Disposal	Total injected volume
California	232.12 million m ³ /year	54.05 million m ³ /year	286.17 million m ³ /year
New Mexico	55.65 million m ³ /year	30.21 million m ³ /year	85.86 million m ³ /year
Texas	842.63 million m ³ /year	190.78 million m ³ /year	1033.41 million m ³ /year
Total	1130.4 million m ³ /year	275.04 million m ³ /year	million m ³ /year

*Data is converted from barrels to m³ with 1 barrel = 0.1589873 m³.

Table 4. International Environmental Discharge Limits of Oil in Water (Statoil, 2014)

Location	Maximum Oil Concentration (mg/L)
North Sea	30
USA Offshore Effluent Guidelines (EPA)	29 average (42 maximum)
NE Atlantic & Arctic Oceans	40
Mediterranean Sea	10 - 15
Caspian Sea	20 (under review)
Red Sea	15
Nigeria	15 onshore; 30 offshore
Indian Ocean (BH)	48
Western Australia	30 (50 maximum)

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Table 5. Comparison of BAT (Statoil, 2014)

Technology	Treatment	Driving force	Capacity	Applicability	Removal efficiency	Field of application
Hydrocyclone	Primary/secondary	Enhanced gravity; centrifugal force	2-10 m ³ /h	Mainly oil fields; high/low water flow, high/low OiW.	80-95 % of oil.	Heidrun
CFU*	Primary/secondary		540 m ³ /h	Mainly oil fields. High/low water flow; high/low OiW.	30-90 % oil removal; depends on inlet OiW.	Heidrun
CTour	Tertiary (enhancing)	Coalescence / extraction	125-300 m ³ /h	Oil fields. Removes dissolved components and a certain amount of corrosion inhibitor. High/low water flow; condensate must be available.	95 % removal of dispersed oil.	Statfjord A, B
Degasser	Primary/secondary	Dissolved flotation/ gravity	200 m ³ /h	All fields. High/low water flow; low OiW, low salinity water should be carefully evaluated.	30-80 % oil removal, depends on inlet OiW, droplet size and operating performance.	Statfjord B
MPPE**	Tertiary (enhancing)	Coalescence / extraction	43-90 m ³ /h ***	All fields. Removes dissolved components; low water flow; low OiW; low solids and scale potential.	50 - 90 % dispersed oil removal; 90 - 99 % of BTEX, PAH, NPD.	Tested at Troll A,B,C Asgard A.
Coalescer	Tertiary (enhancing)	Coalescence / extraction	35-180 m ³ /h	All fields. High/low water flow; high/low OiW; low solids and scale potential.	Up to 99 % oil removal.	Tested at Sleipner
Centrifuge	Primary/secondary	Enhanced gravity	40-100 m ³ /h	Gas/condensate fields. Open drain; low flow; high/low OiW.	Above 95 % oil removal, depends on flow rate and droplet size.	Ekofisk 2, Gyda, Heidrun, Snorre B
Filters/membranes	Tertiary (enhancing)	Coalescence / extraction		Gas/condensate fields. Low water flow; low OiW; low solids and scale potential;	—	

* CFU – Compact Flotation Unit.

** MPPE – Macro Porous Polymer Extraction.

*** Data is taken from Veolia Water Solutions and Technologies.

Available at: http://www.tuvnel.com/assets/content_images/2_3%20VWS%20MPP%20Systems.pdf.