SPE-SPE-188222-MS-MS

Processing and Recycling Drill Cuttings at Source - Technology and Services Adhering to Zero Discharge Legislation

Authors: Robbie Pond, Pierre-Marie Hinden, TWMA and Sveinung Tysse, ZADCO

This paper was prepared for presentation at the Abu Dhabi International Petroleum Exhibition & Conference held in Abu Dhabi, UAE, 13-16 November 2017.

Abstract

This SPE paper describes ZADCO's reasoning for opting to utilise the TCC RotoMill® as the proprietary technology at the core of ESNAAD-TWMA's integrated drilling waste management services on the four UZ750k artificial islands in Abu Dhabi. It outlines the basis for this conclusion after examining the drilling programme, well profiles and volume of material that would be generated across the long-term drilling campaign. It also outlines how they could optimize their drilling programmes whilst complying with and exceeding regulations outlined by ADNOC through the use of this technology.

The paper explains the TCC RotoMill® technology, its fundamental operating parameters and capabilities which are illustrated in the final presentation of data from this case study and the field results from this project. The background and evolution of the TCC RotoMill® is detailed from its origins of being created in conjunction with an International Oil Major ahead of regulatory change in the UK (OSPAR convention). The paper will illustrate the evolution of the technology to modern day units offering throughput of up to 10Mt per hour of NAF drill cuttings in onshore / offshore locations and latterly, being adopted as a mobile technology servicing the land rig market.

Lastly, the paper outlines the application of this technology on the UZ750k four artificial islands as an integral part of the larger scope of drilling waste management which collects, transfers and contains all of the drilling returns prior to treatment and/or disposal. The solution was developed whereby drill cuttings are contained and treated at source, enabling ZADCO to meet and exceed legislative parameters. This eliminated the requirement for ZADCO to transport a significant amount of drilling returns offsite, thereby significantly reducing logistics costs and likelihood of environmental or safety incidents.

The success of the project is summarized in the case study data and key facts which outlines the value added benefits of collecting, transferring, storing and processing 1,443,029 bbl. (volumes to date) of drilling returns with no material having to be transferred offsite and sailed via a supply vessel onshore saving approx. 532,896 km of shipping.

By returning base oil to the Company, TWMA has saved ZADCO approximately $12.7m in recovered base oil across the four islands (which is extracted from the drill cuttings using the TCC RotoMill® and transferred back to ZADCO.)

Introduction

ZADCO Operating Company is part of the ADNOC Group comprising of three major shareholders, ADNOC (60%), Exxon (28%), JODCO (12%). ZADCO operate in the offshore Upper Zakum field located approximately 84km NW of Abu Dhabi in the Arabian Gulf. The field represents the third largest offshore oil reserves found globally to date with sustainable reserves with projected production for approximately 100 years.

The decision was made, given the operational parameters, scale and longevity of the campaign, to build artificial islands in the field whereby drilling rigs, production facilities, support services and accommodation would be situated. The drilling campaign includes Extended Reach Drilling (ERD) progammes and Maximum Reservoir Contact (MRC) wells. To date, ZADCO has built an initial four artificial islands – South, North, Central and West - whereby each island houses two land based drilling rigs. Each island will have production facilities which tie into a central repository on Central Island. ZADCO's existing drilling programme targets more than 400 ERD wells in total (approx. +30 wells per year).

Table 1: Well Profile

Section	Typical Depths	Fluid Type
30" Conductor	250ft	Water Based Mud (WBM)
16" Top Hole	6,000ft.	Water Based Mud (WBM)
12.25" Intermediary	12,000ft.	Non-Aqueous Based Drilling Fluid (NAF)
8.5" Reservoir section	20,000ft. - 35,000ft.	Non-Aqueous Based Drilling Fluid (NAF)

As part of the initial planning phase, a full review of drilling waste management options were considered to evaluate the best method of collecting, transporting and storing all drilling returns. In addition, maximizing the recovery of the valuable base oil contained in the NAF drill cuttings and in turn minimizing the overall drilling returns required to be disposed of were also considered. As part of ZADCO's Environmental Impact Assessment (EIA) the view of ADNOC/SPC/ZADCO was that this project would achieve their drilling programme while discharging zero material to sea. Therefore

ZADCO consulted with the market to analyse a number of solutions that allowed them to meet and exceed environmental legislation and project requirements. Due to the logistics requirements, it was deemed un-economical and impractical to transport the drilling returns from the islands to land for treatment and/or disposal. Therefore, ZADCO examined available technology that could be used on-site to treat and/or dispose of the material, in particular the drilling returns containing hydrocarbon content.

ZADCO evaluated and elected to use Cuttings Re-Injection (CRI) and drilled dedicated disposal wells for the sole use of receiving inert drilling returns which once full would be capped. Given the sheer number of wells being drilled in a concentrated geographical area, ZADCO had a concern that over the coming 25 years, a well drilled in close proximity to the disposal wells may have potential of interference and in worst case scenario drilling waste penetrating existing wells causing a potential hydrocarbon release to the sea. Therefore, ZADCO took the decision to treat the Non-Aqueous Drilling Fluid (NAF) Drill Cuttings prior to re-injection to eliminate their long-term environmental liability exposure.

ZADCO analyzed a number of different technologies in the market and opted for field proven thermal desorption technology. This technology uses heat generated from kinetic energy to separate the three constituent parts of the NAF drill cuttings and remove the hydrocarbon content. ZADCO engaged with TWMA and its partner ESNAAD to supply this technology as part of a fully integrated drilling waste management programme. This programme covered all elements of collection, transportation, segregation and treatment of the various materials produced on the first two islands (South & North) as a byproduct of drilling. The subsequent two islands (Central & West) were also tendered and ESNAAD-TWMA were again successful in award and deployed their thermal desorption technology, the TCC RotoMill® on all four islands. The TCC RotoMill® is designed to recover 99.9% of the hydrocarbon content of NAF drill cuttings resulting in the remaining recovered solids containing less than 1% (typically less than 0.1%) hydrocarbon content by weight, and the water is compliant with ADNOC disposal requirements of <300 ppm (typically < 20ppm).

The Thermal Processing Technology

TWMA utilised its TCC RotoMill® technology for the recovery of the base oil within the NAF drill cuttings allowing the recovered solids and water to be disposed of by CRI. This proprietary and world-leading thermal technology has a successful history worldwide for the treatment of NAF drill cuttings onshore and offshore. The TCC RotoMill® constitutes Best Available Technology (BAT) and Best Environmental Practice (BEP) for the treatment of NAF drill cuttings.

The TCC RotoMill® uses, as a basis, a cylindrical mill that grinds a bed of solids within the mill chamber causing kinetic energy creating heat through friction. Once the mill reaches a pre-determined temperature set to suit the evaporation properties of the particular base oil in use, the NAF drill cuttings are fed into the chamber causing the liquids (oil and water) to flash evaporate from the solids. The resulting gases then exit the mill and pass through a cyclone, where any fine solids particles are removed prior to gases travelling to the oil and steam condensers respectively, before the liquids are recovered as base oil and water from the condensers. Solids are collected from the mill and cyclone during the process and disposed of along with the recovered water via CRI.

The TCC RotoMill® is fed using a hydraulically operated positive displacement piston pump, into the mill process chamber. This transfer is controlled at all times by the TCC RotoMill® PLC control system to ensure that the optimum conditions are maintained throughout the process. The PLC monitors and regulates critical temperatures and pressures using data from temperature thermocouples and pressure transducers ensuring an even process flow. Another feature of the control system is the ability to store historic trends from the process, for evaluation at any time.

The throughput of the TCC RotoMill® is proportional to the amount of energy that is imparted into the bed of solids within the mill chamber. The more energy applied to the solids, the greater volume of liquid content is evaporated. This in turn increases the throughput of the NAF drill cuttings. Throughput is also governed by the physical properties of the NAF drill cuttings such as the oil/water/solids ratio, rock formation type and temperature of the feed material.

Below (Figure 1) shows an overall TCC RotoMill® process flow diagram.

Figure 1. TCC RotoMill® Process Flow Diagram

The TCC RotoMill® produces three distinct outputs:

Oil
The recovered oil is reused in the drilling fluid system by ZADCO (Table 2), as it retains the physical properties found in the drilling mud due to the pre-determined temperature within the mill chamber.

Water
The recovered water is discharged at less than 300ppm and is typically <20ppm hydrocarbon content. This is well within the ADNOC regulatory requirements. The water is mixed with the solids and re-injected into the disposal wells.

Solids
The recovered solids have a hydrocarbon content of less than 1% and typically less than 0.1%. These solids are classed as inert and are disposed of using CRI.

Technological Development

In the mid 1990s the UK government introduced regulatory reforms that came into force in 2001 relating to offshore discharges creating the OSPAR agreement (DECC, 2016). OSPAR is the mechanism by which 15 Governments & the EU cooperate to protect the marine environment of the North-East Atlantic. These reforms were brought into effect to counter the existing practice of dumping all drilling returns into the sea or legs of the platforms. It was estimated that there was as much as 80,000Mt per annum of NAF drilling returns disposed of in this way since North Sea drilling began. This legacy disposal is now considered a massive financial burden on the Operators who bear the cost of removing the drill cuttings piles or paying significant penalties if that is not possible during the decommissioning phase in the project lifecycle.

TWMA working in partnership with a Major International Oil Operator commenced a joint development programme onshore to develop, evaluate and commercialize equipment to treat NAF drill cuttings and comply with the targets outlined in the OSPAR convention. The Department of Trade and Industry (now department for Business, Energy and Industrial Strategy) in 2001 reported to OSPAR and accepted that TWMA's TCC RotoMill® is internationally recognised as Best Available Technology (BAT) and Best Environmental Practice (BEP). (DECC, 2014).

TWMA selected an existing principal, the Thermal Cuttings Cleaner (TCC) and commenced development of the technology which formed a key part of a fully integrated offshore processing system which includes collection, transfer storage and processing. Once the concept had been field proven and commercialized onshore the next stage of development was to engineer a system capable of being situated directly on an offshore installation. The key elements addressed during this part of the development programme, were to meet and exceed <1% hydrocarbon on drill cuttings, modularization of the plant, weight and footprint, meet zoning requirements and achieve processing throughput in line with drill cuttings generation rates. Individual module weights were designed to comply with crane lift capabilities and footprints engineered to fit within available space on offshore installations. The zoning specifications were designed to comply with Zone 2 requirements. Safety

features included using enclosed containers with a CO2 purge system, integrating the equipment into the rigs emergency shutdown with a PLC control system to regulate all operating parameters. During continual development throughput efficiencies were achieved allowing the TCC RotoMill® to be used on increased ROP's and section diameters.

Most importantly there would be no emissions from the process to the atmosphere and the recovered oil would be suitable for reuse in the active drilling fluids. During initial onshore trials, GCMS testing of this recovered base oil showed that the process had not altered the properties of the base oil or its performance in the drilling fluid. The level of retained hydrocarbons in the recovered water was typically <20 ppm and the suspended solids between 5 and 15 mg/litre. The inert recovered solids had a retained hydrocarbon content of less than 0.1%.

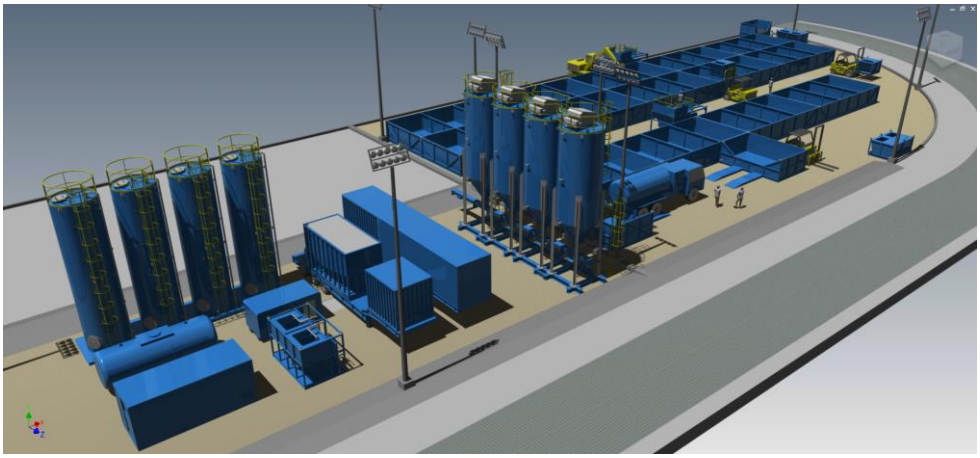
From operation of the first unit which provided 132Kw power into the mill chamber and achieved a throughput of up to 0.75Mt per hour, continual development has led to present day whereby TWMA design, manufacture, own and operate a fleet of units delivering power up to 1400Kw achieving field proven throughput of 10Mt per hour of drill cuttings. These units have been deployed in contrasting geographical locations including remote operating sites on land and sea with varying temperatures from minus 51 degrees Centigrade (-59.8 degrees fahrenheit) in North Dakota to 55 degrees Centrigade (131 degrees farenheit) plus in Abu Dhabi with humidity of 100%.

TWMA also developed a mobile, truck mounted drill cuttings processing unit, the TCC RotoTruck which was engineered for the land market whereby it serves multiple rig pad operations by driving onto site, processing and moving location with less than 12 hours rig up/down time. (Appendix A – TCC RotoMill® Operating Information)

Description and application of equipment and processes

TWMA installed one TCC RotoMill® per island (four in total) to treat the NAF drill cuttings produced by the two land rigs per island as part of a fully integrated drilling waste management service package (Figure 2). The service package was designed and specified for this project to collect and transport the drilling returns from rig site to an on-island tank farm whereby the drilling material streams are segregated and treated accordingly prior to compliant material being transferred to the cuttings re-injection phase. By installing one TCC RotoMill® per island all drilling returns are contained and processed on the site therefore eliminating the logistical and operating costs, efforts and risks related to transferring the drilling returns offsite.

Figure 2: Island Site Layout



Presentation of data and results

Since installation TWMA has successfully collected, transported and stored over 1.4m bbl. of drilling returns using TWMA's EfficientC cuttings handling system across the four islands using equipment and processes designed and engineered by TWMA .

Table 2: Volume of drilling returns transported and collected using EfficientC

	2014	2015	2016	2017 (to 30th June)	Total
South Island	128,186	90,928	125,095	95,317	
North Island	77,134	20,764	110,118	104,055	
Central Island	0	38,558	171,961	117,015	
West Island	0	22,045	186,973	148,835	
Total Drilling Returns Handled (bbl.)	**207,334**	**174,310**	**596,163**	**465,222**	**1,443,029**

*Source TWMA operational reports

In the same period TWMA has processed 95,278.07Mt of NAF drill cuttings using the TCC RotoMill®, recovering the base oil and allowing the recovered solids and water to be re-injected.

The remaining hydrocarbon on solids during that time has been on average approximately 0.15% by weight (Appendix B) which is significantly lower than the regulatory 1% requirement that ZADCO had stipulated. On average the hydrocarbon content of the recovered water is 20ppm (Appendix C) which again is well within the 300ppm ADNOC stipulated discharge limits.

By collecting, transporting, processing and disposing of all drilling returns on island TWMA has diverted significant volumes from onshore disposal routes. The total volume of inert re-injected material since project inception has been 3.070m bbl. (including seawater overflush).

The success of the selected methodology in collecting, transferring, storing, treating and disposing of the drilling returns at source eliminated the below.

- 1,443,029 bbl. placed into skips to be transported ashore = 71,261 skips based skip holding on average. 20.5bbls (Appendix D)
- 71,261 skip loads would require c. 1,096 boat round trip based on an average of 65 skips per boat/barge
    - 1,096 round trips would equate to 184,181 kms (114,445 miles) travelled via sea to and from the islands
- Other logistical requirements such as forklifts movements, crane lifts and truck journeys would have been required on both the island and onshore with added safety risk management required, incurred cost and potential for delays to impact drilling
- Once onshore, the drilling returns would have been sent to a certified landfill / treatment site which again would have added to mileage travelled and cost of disposal

During the campaign, the TCC RotoMill® has recovered 94,701 bbl. of base oil with an estimated recovery value of $12,677,450 (Appendix E) reducing the fluids spend for ZADCO by the same amount.

Conclusions

The drilling returns on the ZADCO UZ750k project have been successfully collected, transported stored and processed, further validating the application of the TCC RotoMill® technology as an integral part of a fully integrated drilling waste management programme and the benefits of treatment at source. The $12.7m value in recovered base oil shows tangible cost saving on fluids spend through effective recovery. Environmentally, the project has achieved the aim of meeting and exceeding the environmental regulations set out by ADNOC and ZADCO. There has been no mainstream drilling returns sent to land for disposal or landfill and ZADCO has been able to optimize its drilling programme by avoiding potential rig non-productive-time NPT caused as a knock on effect to logistical challenges to remove the drilling returns from the islands, such as bad weather delays.

The combination of treating NAF drill cuttings with the TCC RotoMill® and re-injecting the recovered solids and water is a world-first and will remain a blue print for future projects in the GCC and across the globe.

Acknowledgements

The authors wish to thank ZADCO for their support and permission to publish and present this paper.

References

DECC, 2014, Methodology for the Sampling and Analysis of Produced Water and Other Hydrocarbon Discharges, 14.09.17

DECC, 2016, Decisions, Recommendations and Other Agreements Applicable within the Framework of the OSPAR Convention - Update 2016, 14.09.17

Appendices

Appendix A – TCC RotoMill® Operating Information

Types of Base Oil Recovered Using the TCC RotoMill®

- DF-1
- ESCAID 110
- ESCAID 120
- XP-07
- AMODRILL 1500
- DIESEL
- EDC – 95
- EDC - 99

Formation Types of NAF Drill Cuttings Processed Using the TCC RotoMill®

- Claystone
- Shales
- Sandstones
- Lignite
- Siltstone
- Limestone
- Mudstone
- Salt
- Chalk
- Carbonate
- Dolomite
- Coal

S.G. range of NAF Drill Cuttings Processed Using the TCC RotoMill®

1.3 – 2.25

Hole Size Section of NAF Drill Cuttings Processed Using the TCC RotoMill®

6” – 17.5” hole section

Source: TWMA

Appendix B – Hydrocarbon Content on Recovered Solids, 3rd party verified infracal test results

WIMPEY LABORATORIES L.L.C مختبرات ويمبي ذ.م.م

LABORATORY TEST REPORT

TWMA
Middle East Limited
Abu Dhabi, U.A.E

Report No. WAOC17-0454.24
Sample No. WAOC17-0454.24
Report Date: 22/03/2017

Introduction: Further to the request received from **M/s TWMA Middle East** to test a sample of Powder for the following parameter and the following result obtained as detailed.

Sample description	**: Powder**
Sample ID	**: RD28-0039**
Client	**: ZADCO**
Rig	**: 68-130**
Well	**: UZ 544 – UZ 541**
Hole Section	**: 12 1/4 – 8 1/2**
Sampled by	**: YEHUALASHET**
Sampling Date & Time	: **1/22/2017, 4:30**
Tested by	**: AS**

RESULT OF CHEMICAL ANALYSIS

Test	Method*	Unit	Result
TPH	IR (Infracal)	%	0.18

Signed for and on behalf of Wimpey Laboratories

P.O.Box: 115088 Tel.: 02-5503324 Fax: 02-5503387 Abu Dhabi U.A.E. WIMPEY LABORATORIES L.L.C

SREEJITH M
Laboratory Manager

Test results relate only to the samples tested.
This report shall not be reproduced except in full, without the written approval of the laboratory.
*Not Accredited

- End of text-

Source: TWMA

Appendix C – Hydrocarbon Content in Water, 3rd party verified infracal test results

WIMPEY LABORATORIES L.L.C مختبرات ويمبي ذ.م.م

LABORATORY TEST REPORT

TWMA
Middle East Limited
Abu Dhabi, U.A.E

Report No. WAOC17-0452.25
Sample No. WAOC17-0452.25
Report Date: 22/03/2017

Introduction: Further to the request received from **M/s TWMA Middle East** to test a sample of Water for the following parameter and the following result obtained as detailed.

Sample description	**: Recovered Water**
Sample ID	**: RD28-0028**
Client	**: ZADCO**
Rig	**: 68-130**
Well	**: UZ 544 – UZ 541**
Hole Section	**: 12 1/4 - 8 1/2**
Sampled by	**: YEHUALASHET**
Sampling Date & Time	: **01/21/2017, 9:30**
Tested by	**: AS**

RESULT OF CHEMICAL ANALYSIS

Test	Method*	Unit	Result
TPH	IR (Infracal)	ppm	22

Signed for and on behalf of Wimpey Laboratories

P.O.Box: 115088
Tel.: 02-5503324
Fax: 02-5503387
Abu Dhabi
U.A.E.
WIMPEY LABORATORIES L.L.C

SREEJITH M I
Laboratory Manager
Test results relate only to the samples tested.
This report shall not be reproduced except in full, without the written approval of the laboratory.
*Not Accredited

- End of text-

Source: TWMA

Appendix D – Savings in Transportation

Skip Volumes	
Skip Capacity (m3)	3.6
Estimated Cuttings S.G.	2.00
Calculated Mass per skip (MT)	7.2
bbls per skip (based on volume & 1bbl = 0.16m³)	22.50
bbls with skip at 90% capacity	20.25
Total volume of recovered oil in bbls	1,443,029
Total Number of skips	71,261
Number of vessels (65 skips per vessel)	1,096
Distance km per Vessel Round Trip (84km each way)	168.00
Total Distance in km	**184,181.48**

Source: TWMA

Appendix E – Recovered Base Oil volumes and dollar value

Year	Volume (bbl)	$ per barrel	Recovered ($)
2013/14	10,348	180	1,862,640
2015	11,171	160	1,787,360
2016	48,621	120	5,834,520
2017	24,561	130	3,192,930
TOTAL			12,677,450

Source: TWMA