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Successful Batch Processing of Heavy Oil Sludge at Oman (2011 to 2014)

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Abstract

Sludge is an intrinsic by-product of the Oil & Gas Industry, it is considered a hazardous waste and there are few technologies within the industry to process it under an environmentally sound protocol.

Sludge to Oil Technology (STO) is a proprietary process utilized to break emulsions of hydrocarbons/water/solids. The process is based on a series of chemical reactions involving surfactants that interact with other reagents in releasing heat and neutralize the non-covalent forces that form the bonds between the substrate and the wetting agent. Final separation is achieved by using specific gravity differential between the different components of the de-emulsified mixture. The byproducts of the reactions are inorganic salts, water and carbon dioxide.

Two different centrifuges are used to achieve a fast and accurate separation. The byproducts of the reactions are inorganic salts, water and carbon dioxide.

This technology has been successfully implemented at the operator site by the contractor under a pilot project. Over the term of the contract, more than 100,000 bbl of raw sludge had been treated meeting the following KPI's: Oil < 1.0% BS&W, Water < 20 ppm OIW and Solids < 1.0% TPH.

The process has been applied in-situ where the emulsions are stored and has recovered more than 50,000 barrels of saleable crude oil. The recovered water has been sent for re-injection and the solids meet all the requirements of the Ministry of Environment and Climate Affairs (MECA) - Oman as a treated waste under international standards. At a time when crude oil prices have reached over $100.00 USD/bbl this technique can prove to be not only environmentally sound but also an addition value to the operator's production bottom line.

The STO process was applied directly in the field where the emulsions are stored and can bring great technical and economical advantages to the user.

At a time when crude oil prices have hiked this technique can prove to be very economical not only for oil recovery, but for also as preventative maintenance and to mitigate from potential environmental liabilities.

Fig. 1

Introduction

The topography and landscape of most of the asset area is characterised by flat plains interspersed with small drainage channels and occasional rocky outcrops. The elevation with reference to the mean sea level ranges from about 140 m. The geology of the asset comprises mainly carbonates and clastics.

The native vegetation is composed of desert plants and grasses, and trees, which are rarely seen. The fauna include a few species of largest mammals including the mountain gazelle and the Rheem gazelle, both of which qualify under the IUCN world Red List and the regional Red List threat categories. A few smaller mammals, mostly gerbils, 96 species of birds and jerboas are likely to be present in the vegetated areas. Many migratory species come to the region in particular pink flamingos and Egyptian eagles.

There is a field at the center of Oman that is a hub for multiple Exploration & Production activities including hazardous waste management. Oil Sludge has been historically stored at this location. This sludge is the product of tank cleaning operations, pigging and daily transport and storage of crude oil and produced water. There are 9 concrete pits at the location. The sludge pit represented an Environmental liability for the Operator[1].

The sludge is a combination of water, solids and crude oil that form a stable emulsion. The sludge composition is:

- Oil 35-60%
- Water 45-55%
- Solids 4-35%

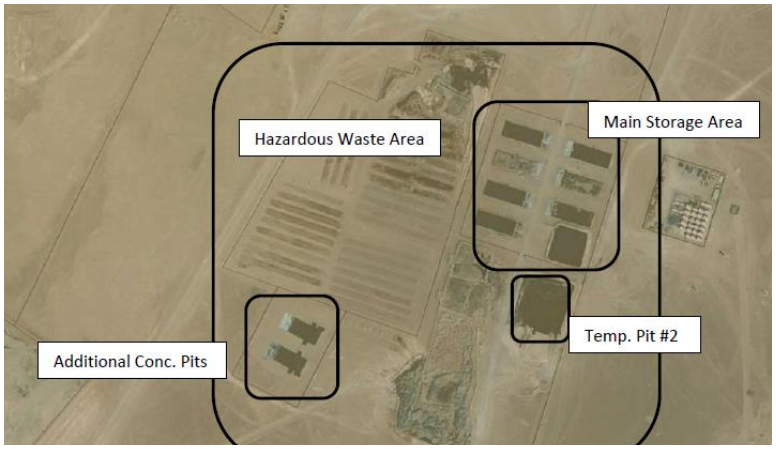


Fig. 2

The oil is heavy (16-19 API) with high concentrations of asphaltenes and paraffins.The presence of naphtenic acids or their metallic soaps is not documented but it can be the source of the high stability of the emulsions.

Sludge has been stored in pits as the need arisen form volumes produced and pit capacity, new pits were constructed as capacity was reached. Many species of animals, particulary small mammals, reptiles and birds were trapped in these pits to die inside the sludge. A pilot project was awarded to implement the technology on this site in March 2011. Upon a successful pilot, operations continued until today. The three fractions extracted from the process have passed the required KPI's and the crude oil has been incorporated to the production line of the operator as the water and solids have been disposed of according to local regulations.

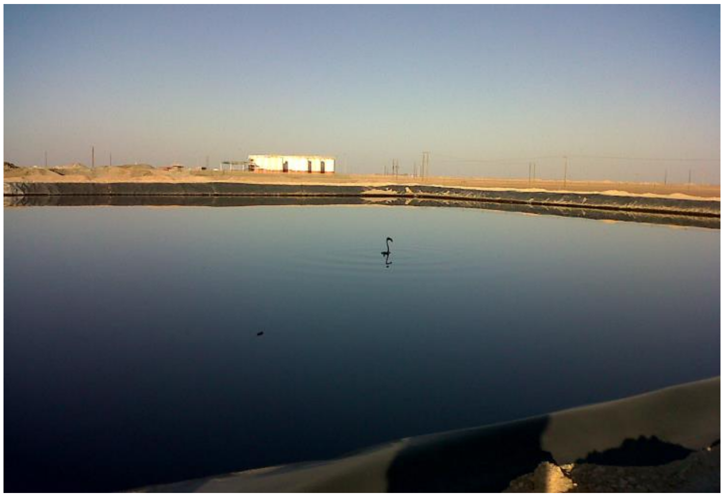


Fig. 3

Statement of Theory and Definitions

STO is a proprietary process utilized for emulsion resolution. The process is based on a series of physical processes and chemical reactions involving amphiphilic surfactants (aionic and ionic) which interact as structural analogs disrupting the three layer surface of the emulsion micelles; the presence of other reactants which release heat and independently neutralize the Van der Waals ionic and induction of non-covalent forces including the dipole-dipole hydrogen bonds, the instantaneous dipole induction forces known as London forces and the long range induction forces known as Hamaker forces. These interactions form the bonds between thesubstrate and the wetting agents making the emulsion stable.

Fig. 4

The exothermic reaction that evolves during the process does not change the chemical structure of the aliphatic hydrocarbons and is mainly a reaction among the specific reactants added. The byproducts of the reactions are inorganic salts, water and carbon dioxide that form tiny bubbles which promote oil flotation and solids separation. Solvation of the inorganic salts by the released water is also promoted while viscosity is reduced by means of the temperature increase resulting from the reaction. The reaction is not pH dependent and does not change the initial pH of the emulsion throughout the process. Once the emulsion is unstable, it is now possible to separate its constituents by specific gravity differential into minerals, water and hydrocarbons.

Figure 4 shows a feasibility batch test performed in the lab at 1g separation.

A mechanical process for separating the emulsion constituents is needed following the reaction; in this case, using a centrifuge is essential to achieve a fast and accurate separation.

Description and Application of Equipment and Processes

The process was implemented using a Sequencing Batch protocol. A predetermined amount of sludge (50 bbl) would be transferred into one of two of the sequential reactors. A process overview is shown in figure 5. The equipment was placed between two of the Sludge pits and on top a HDPE liner to avoid any possible contamination caused by spillages.

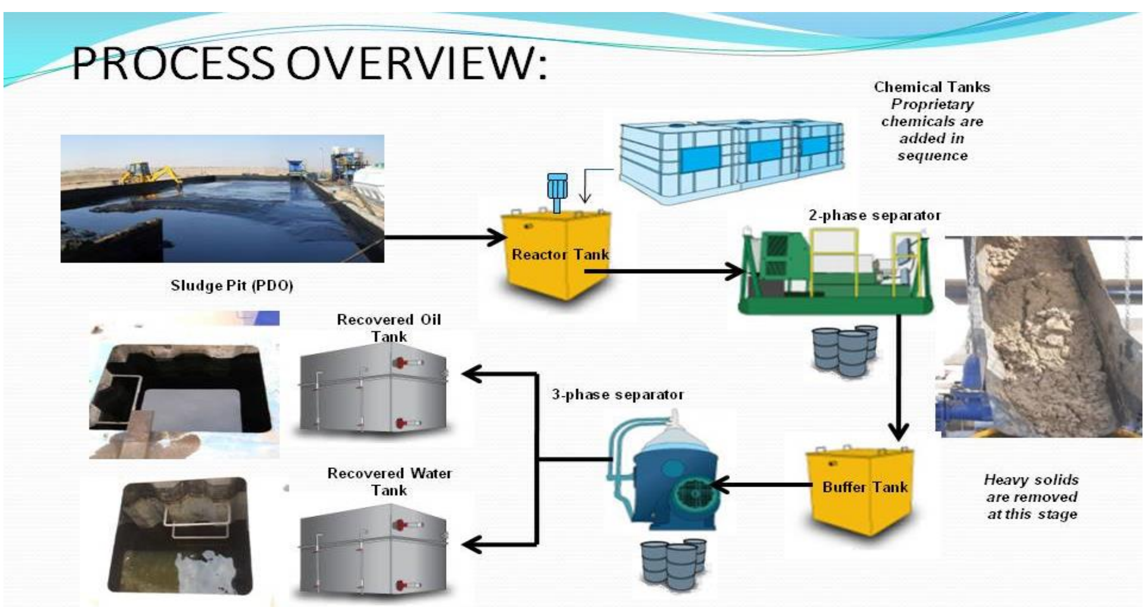


Fig. 5

The process can be described as follows: Refer to the equipment list on details of each equipment mentioned.
Batch Loading. Using the sludge pump (Tesla pump) SP-01 either reactor tank is filled up to a predetermined capacity.

Chemical Processing. The agitator is turned on and the process begins with homogenization of the sludge. Chemicals are added using a prescribed volume and they flow from the top of the reactors by gravity into the reactor. Reaction times and are monitored and after the last of 3 chemicals is added the agitator is turned down by reducing the RPM using the correspondent VFD in the control panel.

Fig. 6

Decanter Centrifuge. After the reaction time is passed, the reactor is emptied using a progressive cavity pump PCP-01 to send the sludge through a decanter centrifuge DC-01. This centrifuge will separate the heavy solids from the main stream. The solids are collected in drums for further processing. The centrade of the decanter centrifuge is sent to an oil water separator to allow the free water to separate from the water/oil emulsion.

Disc Stack Centrifuge. The emulsified mixture of oil and water is expected to break by the chemical action and is kept in the Oil buffer tank. Additional chemicals might be added here to promote better separation during the second stage centrifugation. The mix is now diverted into a disc stack centrifuge DSC-01 using PCP-02. This flow passes through one of the two heat exchangers to increase the flow temperature to 75C before entering the centrifuge. This allows for viscosity reduction and better separation. The DSC-01 is capable of producing 7,000 G's of force and is capable of breaking many emulsions and micro emulsions. The DSC-01 has three discharge ports: Water / Oil / Solids. They go into three different tanks in the same skid.

Oil Recover. The oil recovered in the Oil tank of the three-compartment tank is pumped using CP-03 and passed through a 50 micron bag filter to remove any potential large particle still in the oil. It would be stored in the Recovered Oil Tank and depending on its quality it could be brought back for polishing at the DSC.

Water Recover. The water coming from the oil water separator and the DSC-01 is pumped into the 457 bbl Recovered water tank where it is stored. The water here is also treated using flocculation compounds and coagulation polymers to remove any suspended solids and oil. Finally the water is filtered using a 5 micron cartridge filter and sent to the treated recovered water tank.

Solids. Using PCP-01 the solids from DSC-01 are passed one more time through the DC-01 to be extracted from the system. The collected solids in drums are then scheduled for further treatment using the recovered water and the same chemicals as in the main process but in a higher concentration. This solids can be treated once or twice using the same batch process as needed.

Boiler Circuit. Hot water is continuously run through the Heat exchangers to provide the heat to make the separation possible. The boiler circuit includes the boiler water tank ST-01, the centrifugal pump CP-02 and the boiler.

Fig. 7

The equipment list of the project is shown on Table 1 below.

Description	ID	Material of Construction	Comments
Reactor tank	RT-01	CS-EC	Skid mounted w/loading hopper
Reactor tank	RT-02	CS-EC	Skid mounted w/loading hopper
Sludge pump	SP-01	SS Direct drive Agitator	Tesla pump
Agitator gear driven	AG-01	SS Direct drive Agitator	Mud agitator w/ vfd
Agitator gear driven	AG-02	SS Direct drive Agitator	Mud agitator w/ vfd
Progressive cavity pump	PCP-01	Pump	Part of decant. Cent.
Decanter centrifuge	DC-1000	SS	Existing equipment
Buffer tank 1	BT-01	CS-EC	With high/low level float sensors
Progressive cavity pump	PCP-02	Pump	Part of decant. Cent.
Disk stack centrifuge	DSC-2000	SS	Alfa laval or similar
Water tank	WT-01	CS-EC	Three compartment tank
Oil tank	OT-01	CS-EC	Three compartment tank
Solids tank	ST-01	CS-EC	Three compartment tank
Centrifugal pump	EP-CP-110-1	Centrifugal Pumps	Open impeller
Centrifugal pump	EP-CP-120-2	Centrifugal Pumps	Open impeller
Centrifugal pump	EP-CP-120-3	Centrifugal Pumps	Open impeller
Centrifugal pump	EP-CP-110-4	Centrifugal Pumps	Open impeller
Centrifugal pump	EP-CP-120-5	Centrifugal Pumps	Open impeller
Level controllers	LC-XX	Heavy Dutty Float Switch	10 pcs. Total
Filter housing	BF-Al-010-#1	AL Housing, SS	Aluminum fiter bag housing 100psi
Filter housing	BF-Al-020-#2	AL Housing, SS	Aluminum fiter bag housing 100psi
Filter housing	BF-Al-020-#3	AL Housing, SS	Aluminum fiter bag housing 100psi
Air compressor	AC-01	AIR COMPRESSOR	Diesel power air compressor 50 hp
Pneumatic pump	PP-DP-100-2.0	2" Inlet/Outlet Max. 120PSI Max. CFM 125	Oil/water transfer pump
Pneumatic pump	PP-DP-120-2.0	2" Inlet/Outlet Max. 120PSI Max. CFM 125	Oil/water transfer pump
Crane	BCK-01		Lifting crane 10 ton
Boiler	WB-01	WATER HEATER	Operating tem 85c @ 850galhr
Recovered oil tank	ST-01	CS-EC	Depending on ick up cycles
Recovered water tank	ST-02	CS-EC	Water to be procured on site
Treated water tank	ST-03	CS-EC	Water to be procured on site
Agitator	AG-03	Direct drive Agitator	Direct drive agitator
Agitator	AG-04	Direct drive Agitator	Direct drive agitator
Agitator	AG-05	Direct drive Agitator	Direct drive agitator
Pneumatic pump	PP-DP-130-1.0	PTFE	1" diaphragm pneumatic pump
Pneumatic pump	PP-DP-140-1.0	PTFE	1" diaphragm pneumatic pump
Pneumatic pump	PP-DP-150-1.0	PTFE	1" diaphragm pneumatic pump
Day tank #01	DT-01	HDPE	1,000 lts chemical tank
Day tank #02	DT-02	HDPE	1,000 lts chemical tank
Day tank #03	DT-03	HDPE	1,000 lts chemical tank
Day tank #04	DT-04	HDPE	Static pressure tank for dsc-01
Pneumatic pump	PP-DP-160-1.0	CI / BUNA N	2" diaphragm pneumatic pump
Pneumatic pump	PP-DP-160-1.0	CI / BUNA N	2" diaphragm pneumatic pump
Solids bin	SB-100	CS-EC	Solids recovery bin
Generator set	GS-01	N/A	Generator 460vac/3ph/60hz 200kwhr
Laboratory office	LAB-01	N/A	Lab and office work center
20' storage container	SC-01	N/A	Storage and shop area
Control panels			Manual actuation

Table 1

Presentation of Data and Results

Utilizing STO technology the sludge was be treated so the three constituents present in the sludge can be physically separated as Water, Oil and Solids (minerals). The three components should meet the following parameters:

- TPH of the solids recovered should be < 1.0%
- BS&W of the recovered oil should be < 0.5%
- The OIW of the recovered water should be < 20ppm.

Fig. 8

It has been proven that the big size heavy solids can be removed using the decanter centrifuge with a particle mean size average of around 100µ (see figure 8 and the particle size distribution chart in Figure 9). The solids removed in this step have a TPH content of 0.5% to 2.5%. In order to achieve the required KPI of <1.00% the solids are tested in the field using a retort kit and if not compliant they are subjected to the process as a "second pass" this generally leaves the solids with a TPH concentration of 0.10% to 0.80%. (Kmiec, I., Nahmad, D.G., Nasir, A. et al, 2008, SPE-115222)

The Disc Stack centrifuge is designed to separate thre phases as light solids, oil and water. The particle size distribution of the solids coming out of this centrifuge shouws a distinctively smaller average particle size with a mean near the 10µ. (See Figure 10)

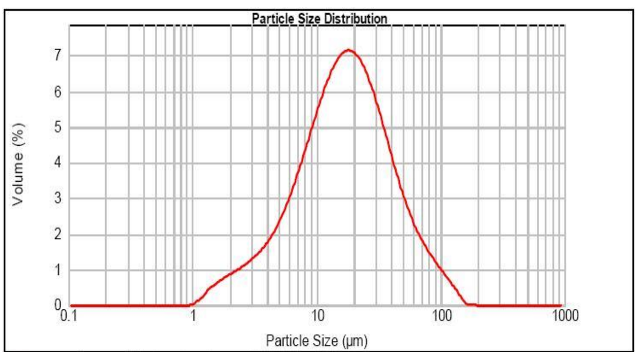


Fig. 9

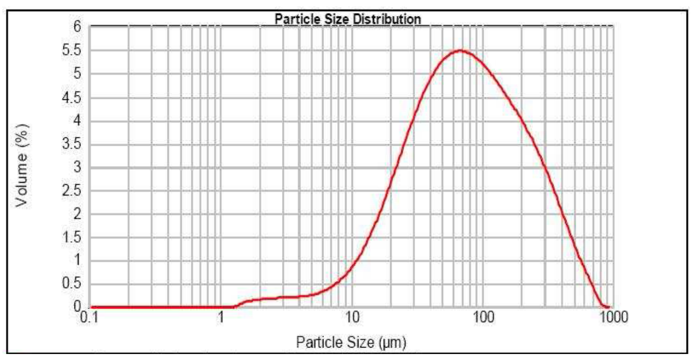


Fig. 10

By end of May 2014 we could say that we have -

- Succesfuly completed the trial run within two weeks after commissioning.
- Treated 102,988 bbl of sludge until the end of may 2014.
- Recovered 49,266 bbl of crude oil.
- Over 1,010 days without LTI and more than 31,301 man hours worked.
- Removal of the environmental liability and potential hazards.
- Substantial recovery of the main company product from a waste stream.
- Achievement of the main principles of waste minimization, recycle and treatment under a sustainable process

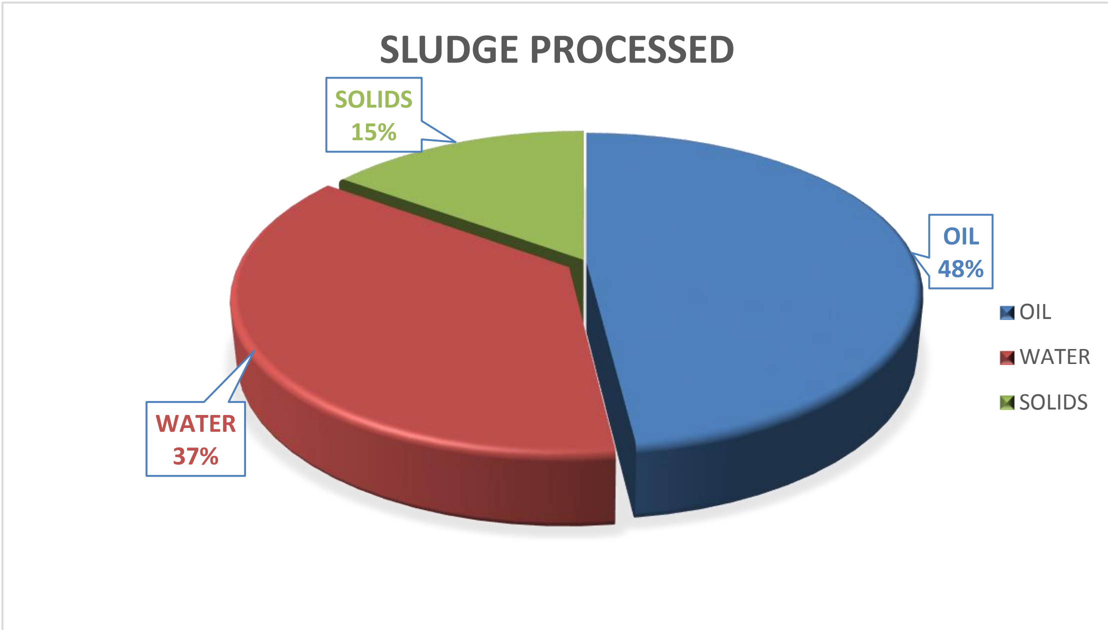
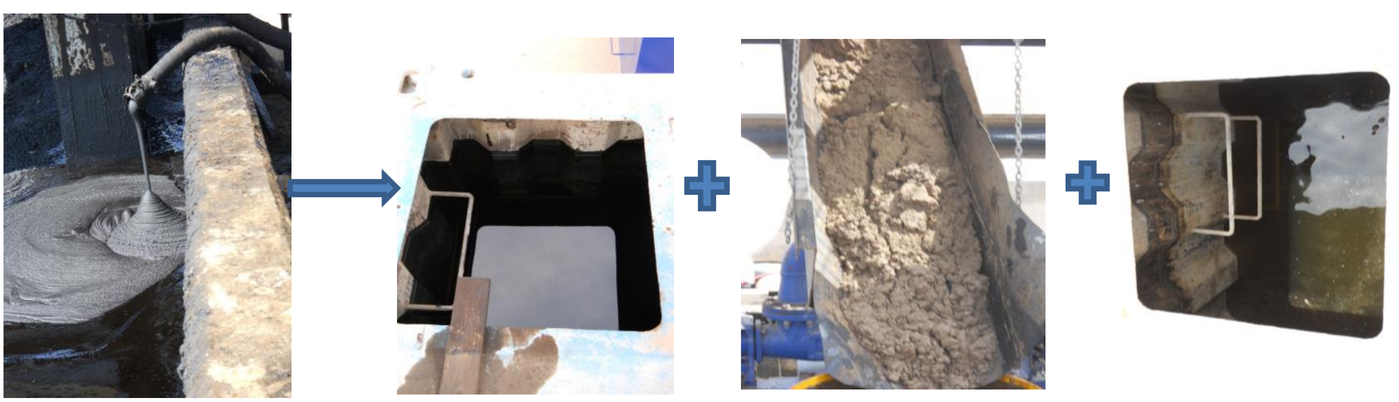


Fig. 11

Recovered Product	Amount Recovered
Solids	15,231 bbl
Oil	49,266 bbl
Water	38,431 bbl

Table 2



Raw sludge being pumped. Clean oil in storage tank. Clean solids out the centrifuge. Clean water in storage tank.

Fig. 12

Quality Assurance / Quality Control (QA/QC).-

Sampling is done daily using both “grab” and composite methods and sent to our field laboratory and to the Production Chemistry Laboratory on field on the same day and without any preservation procedure. The oil was taken from both top and bottom of the Recovered Oil Tanks. The water was taken directly from the sampling ports of the cartridge filter unit located between the Recovered Water Tank and the Treated Water Tank.

Figure 13 - Sampling.

Solids samples were taken at different intervals directly for the Decanter discharge chute. (See Figure 13).

Using our Laboratory facilities we were able to determine roughly the quality of the products using standard and modified techniques. The equipment and techniques used in the Laboratory are described in Table 3.

Measurement	Medium	Description	Method	Equivalent	Comments	Units
Total Petroleum Hydrocarbons (TPH)	Solids	Retort	Fann Inst®	N/A	Good for Measurements Down To 0.5%	W%
		Petroflag Dexil®	Dexil®	EPA SW-846	Excellent Method for THP In low Progress	ppm
Oil In Water (OIW)	Water	N/A	N/A	N/A	N/A	N/A
Bottom Sediment And Water (BS &W)	Oil	BS&W SD-96	Modified	ASTM-SD96	Good Approximation Using Our Equipment	VOL%
		BS&W D4007		ASTM-D4007		VOL%

Table 3

The Production Chemistry Laboratory in field used the following techniques to process the samples:

- Solids TPH EPA-8015B.
- Water OIW EPA-1664A.
- Oil BS&W ASTM-SD96

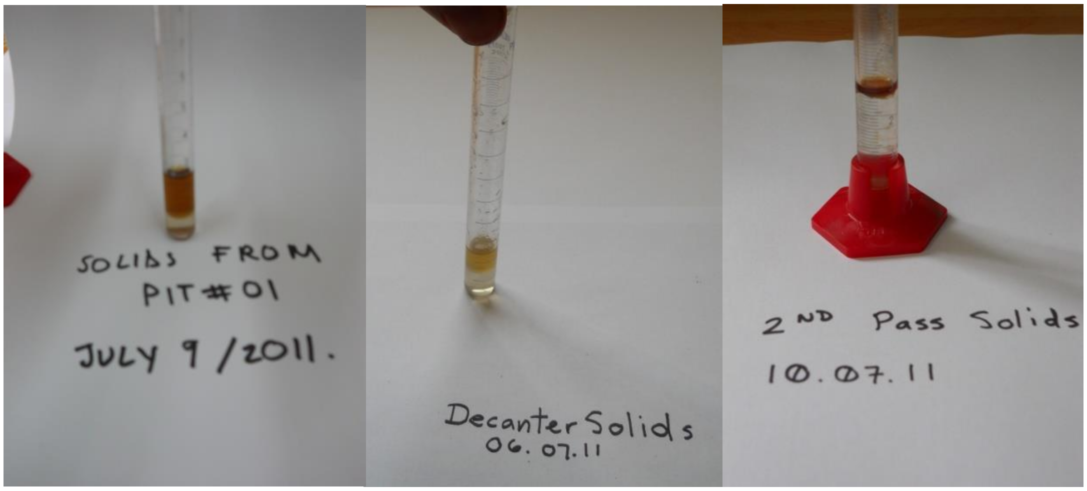


Figure 14

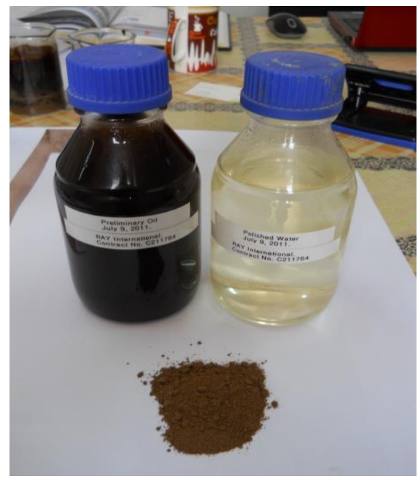


Figure 15

Figure 14 above. Shows how the retort is used to help the operator determine the quality of the solids produced and the average change after processing a sample. The Petroflag Dexil® system is used for more accurate results once the operator believes the solids should be within the expected threshold of quality. The water is evaluated in the field just by qualitative techniques using clear plastic containers to determine if there is any free oil left by staining and “clinging” to the plastic surfaces. A modified version of the ASTM-SD96 method using Hexane was used in our lab to roughly determine the quality of the recovered oil. Figure 15, shows samples labeled and ready to be taken to the lab for QA/QC.

Figure 16

Achievements.-

Up to June 30, 2012 the total volume of barrels processed and the byproducts recovered stand as follows:

Total Processed Sludge	bbl	37,258.00	100.00%
Recovered Oil	bbl	14,080.00	37.79%
Recovered Water	bbl	17,658.00	47.39%
Recovered Solids	bbl	5,520.00	14.82%

Table 4

Awards.-

During earth day, 2012 the project was awarded the "Green Inovation Award" in the Oman Green Awards 2012. This very special award was presented for the project by His Excellency Mohammed Bin Salim Bin Said al Toobi Minister of Environment and Climate Affairs.

The project was also awarded a "Special Commendation for Research and Development" in the same Oman Green Awards 2012.

In country value.-

The contractor has followed the national policy of In Country Value (ICV) and is very proud to have this project with a 91% Omani personnel, from top management positions to the operators and technicians in the field. This has constituted a challenge by itself due to the fact that the technology is new and the timeframe for implementation was very short which resulted on a very steep learning curve. However, all the challenges were surpassed and the technology is now being implemented on a daily basis with relative ease and in an efficient way.

Conclusions

The technology has been applied in the field now for over three years, the operator hadn't needed to construct any additional pits and the two temporary sand pits have not been used again for storage of sludge. The pits do not represent a trap for the local and migratory fauna.

The operator has enjoyed of additional reveneus coming from what was considered a waste, in most cases, the field unit has been producing more crude oil than a typical well in the oil field.

This has been the first commercial application of the technology in the Middle East, the crew is 100% Omani nationals that now understand and execute the process by themselves.

All the operators in Oman and in the world face the challenge of dealing with sludge as an operational daily activity, this technology can be an economical solution to extract the value of the hydrocarbons entrapped in the sludge and to minimize the environmental liability that these kind of waste represents.

Acknowledgments

We would like to acknowledge with special gratitude all the people involved in the implementation of this project specially:

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