Treatment of Crude Oil-Contaminated Sand: Wetting, Adhesion and Cohesion

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Abstract**—Improvement of the sand treatment techniques requires detail information of the contaminated sand properties. Most of previous studies went detail on geotechnical properties of crude oil-contaminated sand or soil but not much on their other physical properties [4]. This research work characterized the physical properties of sand, crude oil and crude oil-contaminated sand namely density, viscosity, pH value, wetting, adhesion and cohesion study. The crude oil-contaminated sand and model sand sample were taken from Sabah field and Terengganu beach, Malaysia respectively while crude oil sample was from FPSO Cendor, Malaysia. Sand bulk and grain densities were measured using cylinder and analytical balance. For crude oil, its density and viscosity were measured using a graduated cylinder and automated viscometer AMVn respectively. pH value determination of crude oil was performed using Mettler Toledo pH meter . For wetting, adhesion and cohesion study, goniometer has been used for contact angle measure measurement. As a result, the bulk density of real and model sand sample were 1.3442 g/ml and 1.5342 g/ml respectively. The grain density of real sand sample using first and second method were 2.5713 g/ml and 1.4042 g/ml while for model sand were 2.1660 g/ml and 1.5306 g/ml respectively. The crude oil density obtained was 0.7845 g/ml while its kinetic, dynamic viscosities and pH value were 3.1071 mPa.s, 3.9607 mm^2/s and 6.17 respectively. For wetting study, the contact angle between the crude oil and both sand sample surface were 0° which indicates the sand was strong oil-wet.**

Keywords— characterization, crude oil-contaminated sand, density, pH, sand production, viscosity, wetting

I. INTRODUCTION

Oil and gas companies faced sand production problem which considered as one of the oldest problems and it has already proven to be one of the toughest to solve [8]. The problems of sand production are abrasion of downhole casing, failure of casing or liners from removal of surrounding formation, subsurface safety valve and surface equipment, casing buckling, compaction and erosion and even loss of production due to sand bridging in flow lines [6]. The crude oil cleaned up techniques are physico-chemical, thermal and biological treatments [2]. The first two cleaned up techniques are not really efficient compared to the third technique but the cost for the biological treatment is very expensive. The treatment of crude oil-contaminated sand need to be improved such as it may be done in-situ at offshore, which can cut the cost of shipment of sand treatment and disposal. Improvement of contaminated sand treatment techniques requires detail information about the characteristics of the crude oil-contaminated sand as lack of data limits the sand handling technique. Thus, the research work was done to collect the detail physical properties of crude oil-contaminated sand.

II. METHODOLOGY

A. *Materials*

In this research work, two different sand samples were used. First sample was crude oil-contaminated sand, also named as real sample was obtained from Sabah field, Malaysia. Second sample known as model sand sample was taken from Terengganu beach, Malaysia which have not contaminated by the crude oil. To prepare the clean sand samples, both samples were washed using distilled water and detergent repeatedly to remove all the suspended substances. The clean sand sample was then dried in venticell for 24 hours at 80˚C to make sure that the samples contain no water or moisture that may affect the physical properties of the sand. The determinations of bulk and grain densities of the sand were using the cleaned sand samples.

B. *Methods*

i. Bulk density of sand

Sand bulk density was determined using graduated cylinder and analytical balance. 10ml graduated cylinder was weighted using analytical balance and mass was recorded. The graduated cylinder was filled with cleaned real sand sample up to 5ml. The cylinder and sand was weighted and recorded. Mass of sand was obtained by total mass of cylinder and sand subtracting the mass of cylinder. Then, the sand density was calculated. The steps were repeated for model sand sample. Every sample was experimented by three times to obtain the average value in order to reduce the human error.

ii. Grain density of sand

Sand grain density was determined using two methods which were water displacement and by graduated cylinder along with analytical balance. Two methods were used as for comparison. For water displacement method, 10ml of graduated cylinder was filled with 3ml water and weighted using analytical balance. Mass of cylinder and water was recorded. A few of sand grains of real sand sample were added into the cylinder and again it was weighted and the mass was recorded. The water reading level in the cylinder was observed and recorded. Mass of sand was obtained by mass of cylinder, water and sand subtracting the mass of cylinder and water. The grain density of the sand was calculated. The steps were repeated for model sand sample. Every sample was experimented by three times to obtain the average value.

Second method was using graduated cylinder and analytical balance. Real sand sample was weighted approximately to 5g using analytical balance and the mass was recorded. The weighted sand was directly put into 10ml of graduated cylinder and sand volume was recorded. Grain sand density was calculated. The steps were repeated for model sand sample. Every sample again was experimented by three times to obtain the average value.

iii. Density of crude oil

The method was simply using graduated cylinder and analytical balance. Firstly, the mass of 25ml empty cylinder was recorded. Then, the cylinder was filled with 20ml crude oil. Then, the mass of crude oil was determined and its density was calculated. The experiment was repeated for three times to obtain the average value of crude density.

iv. Viscosity of crude oil

Crude oil viscosity was obtained using an automated viscometer AMVn. Power supply and box automated viscometer AMVn were switched on. Crude oil sample was filled in 1.8mm diameter capillary tube with 1.5mm diameter metal ball. Then, the capillary was entered into the capillary block of the viscometer. Software was opened and all the information required was fulfilled such as sample name was crude oil, density was 0.7845g/cm3, temperature was 26˚C and measuring system AMVn was standard 70×4. Next, 'start' button was clicked and let the viscometer run the viscosity measurement of the crude oil. Once the test was completed, the result was save in excel and copied out.

v. pH of crude oil

Crude oil pH value was determined using a Mettler Toledo pH meter. Firstly, the pH meter was tested using the distilled water as a sample to determine the efficiency of pH meter and the value obtained must be approximately to 7.00. Then, the crude oil sample will be tested. Three reading were obtained and the average value was calculated.

vi. Wetting, adhesion and cohesion

Wettability was corresponding to the contact angle between the crude oil and sand surface. A flat and smooth sand surface was firstly prepared in order to use as a contact surface. Clean sand grains for both real and model sand samples were glued in two different pieces of glass slides and were left for dried. The sand grains must be ensure to cover all the glass slides surface as it will affect the fluid contact with the surface.

Contact angle was obtained using a goniometer. Firstly, image Analysis Workstation and VCA 3000TM platform were turned on. VCA 3000TM was clicked for window icon in windows desktop. A live video image of the needle appeared in the upper-left hand corner of screen. The stage was lowered by rotating vertical Knob CCW. For larger specimens, the syringe head CCW was tighten to prevent scratching the specimen surface. The syringe head CW was slowly rotated and back to the up-right position and the syringe head was locked in place. The stage was raised upward by rotating Vertical Knob CW until the specimen was just below the needle. The drop was focused in field of view to get a sharp image by moving the stage along the guide rails. The AutoFAST button was clicked to freeze the image and for calculation. Two numbers were displayed; those were left and right contact angles. The main switch was switched off after the result was recorded.

III. RESULTS AND DISCUSSION

i. Bulk density of sand

Three reading were obtained for each sand sample and the average density was calculated to reduce the error. The density of the real sand sample were 1.3532 g/ml, 1.3254 g/ml and 1.3540 g/ml while for model sand sample were 1.5474 g/ml, 1.5144 g/ml and 1.5468 g/ml. Thus, average densities for real and model sand sample were 1.3442 g/ml and 1.5362 g/ml respectively.

The reading indicates that the density of real sand sample was less dense than the model sand sample by 0.1920 g/ml of average density difference.

Table 1: Bulk density of real sand sample

Mass of 10ml cylinder (g)	**Mass of 10ml cylinder and 5ml sand (g)**	**Mass of 5ml sand (g)**	**Sand density (g/ml)**
25.3070	32.0729	6.7659	1.3532
25.3121	31.9393	6.6272	1.3254
25.3081	32.0718	6.7700	1.3540
Average sand density (g/ml)			1.3442

Table 2: Bulk density of model sand sample

Mass of 10ml cylinder (g)	**Mass of 10ml cylinder and 5ml sand (g)**	**Mass of 5ml sand (g)**	**Sand density (g/ml)**
25.3075	33.0444	7.7369	1.5474
25.3077	32.8795	7.5718	1.5144
25.3073	33.0377	7.7340	1.5468
Average sand density (g/ml)			1.5362

ii. Grain density of sand

Two methods have been applied for the grain density determination of both sand samples namely water displacement and by graduated cylinder. The application of two different methods was for comparison purpose. For the water displacement method, the densities of real sand sample were 2.3250 g/ml, 2.3740 g/ml and 3.0150 g/ml while model sand sample were 2.2840 g/ml, 2.1900 g/ml and 2.0240 g/ml. The average density of real and model sand sample were 2.5713 g/m and 2.1660 g/ml respectively. On the other hand, for the second method that using graduated cylinder, the densities of real sand sample were 1.3897 g/ml, 1.3910 g/ml and 1.4289 g/ml while model sand sample were 1.5126 g/ml, 1.5636 g/ml and 1.5155 g/ml. The average density of real and model sand sample using graduated cylinder method were 1.4032 g/m and 1.5306 g/ml respectively.

Table 3: Grain density of real sand sample by water displacement

Mass of 10ml cylinder and 3ml water (g)	**Mass of 10ml cylinder, 3ml water and sand (g)**	**Increase of water level (ml)**	**Mass of sand (g)**	**Sand density (g/ml)**
19.6137	19.8462	0.1	0.2325	2.3250
19.6186	19.8560	0.1	0.2374	2.3740
19.6027	19.9042	0.1	0.3015	3.0150
Average sand density (g//ml)				2.5713

Table 4: Grain density of model sand sample by water displacement

Mass of 10ml cylinder and 3ml water (g)	**Mass of 10ml cylinder, 3ml water and sand (g)**	**Increase of water level (ml)**	**Mass of sand (g)**	**Sand density (g/ml)**
19.6772	19.9056	0.1	0.2284	2.2840
19.6242	19.8432	0.1	0.2190	2.1900
19.6406	19.8230	0.1	0.2024	2.0240
Average sand density (g//ml)				2.1660

Table 5: Grain density of real sand sample by graduated cylinder

Mass of sand grains (g)	**Volume of sand (ml)**	**Sand density (g/ml)**
5.0029	3.6	1.3897

5.0075	3.6	1.3910
5.0012	3.5	1.4289
Average sand density (g//ml)		1.4032

Table 6: Grain density of model sand sample by graduated cylinder

Mass of sand grains (g)	Volume of sand (ml)	Sand density (g/ml)
4.9915	3.3	1.5126
5.0036	3.2	1.5636
5.0013	3.3	1.5155
Average sand density (g//ml)		1.5306

Comparing those two methods, the real sand sample was denser than the model sand sample by 0.4053 g/ml of average density difference using the water displacement method while for the second method; the real sand sample was less dense than the model sand sample by 0.1274 g/ml of average density difference. On the other hand, the grain density of both real and model sand sample was denser when using water displacement method compared to the second method. The average grain density difference of the real sand sample was 1.1681 g/ml and for the model sample was 0.6354 g/ml when using two different methods.

Basically, the experiment that used water displacement method gives the higher density for the real sand sample compared to the model sand sample. Theoretically, the reservoir sandstone has higher porosity than other types of sand samples in order for it to store the hydrocarbon fluid. So, in this research work, the pore space of the real sand sample was filled with the water while for the model sand sample, it was less porous than the real sand sample and contained less water. This degree of porosity affected the density of the both sand samples when using water displacement method.

iii. Density of crude oil

Crude oil density was measured manually using a graduated cylinder. The experiment was repeated three times and the average density was calculated. The crude oil densities were 0.7911 g/ml, 0.7774 g/ml, 0.7849 g/ml and the average crude oil density was 0.7845 g/ml.

Table 7: Density of crude oil

Mass of 25ml cylinder (g)	Mass of 25ml cylinder and 20ml crude oil (g)	Mass of 20ml crude oil (g)	Crude oil density (g/ml)
51.6833	67.5046	15.8213	0.7911
51.6804	67.2287	15.5483	0.7774
51.7221	67.4204	15.6983	0.7849
Average crude oil density (g/ml)			0.7845

From the density value, API gravity of crude oil was calculated. API gravity obtained was 48.87˚ API which the crude classified as light crude oil. If API gravity is greater than 31.1, less than 22.3 and between 22.3 and 31.1, the crude oil classified as light, heavy and medium respectively [5].

iv. Viscosity of crude oil

Viscosity of crude oil was directly measured using an automated viscometer AMVn. Using this equipment, a single running sample must gain four viscosities reading with three repetitions and an average viscosity but using this crude oil sample, the first repetition viscosity reading cannot be obtained as the metal ball in the capillary tube stucked when it was rotating about 180˚. This is much related to the range of viscosities and the composition of the crude oil itself.

Then the experiment again conducted for the second time and again only the first reading of both kinematic and dynamic viscosities were obtained. So, the first viscosity reading of the first and second experiment was recorded and the average was calculated.

Table 8: Viscosity of crude oil

Crude oil	Viscosity	
	Dynamic (mPa.s)	Kinematic (mm^2/s)
Experiment 1	3.0871	3.9352
Experiment 2	3.1271	3.9861
Average	3.1071	3.9607

The dynamic viscosities of crude oil for the first and second experiment were 3.0871 mPa.s and 3.1271 mPa.s respectively with the average of 3.1071 mPa.s. The kinematic viscosities of the crude oil for first and second experiment were 3.9352 mm^2/s and 3.9861 mm^2/s respectively with the average viscosity of 3.9607 mm^2/s.

i. pH of crude oil

Based on the Table 9, the first, second and third readings of crude oil pH were 6.17, 6.16 and 6.18 respectively. The average reading was calculated and the value obtained was 6.17.This shows that the crude oil classified as weak acidic. The acidity of crude oil was very depends on its composition or hydrocarbon itself.

Table 9: pH value of crude oil

Test	pH Value
1	6.17
2	6.16
3	6.18
Average	6.17

v. Wetting, adhesion and cohesion

Wetting experiment conducted for both real sand and model sand samples showed that the sand surface was strongly oil-wet. Based on Figure 1 and 2, the dropped crude oil disappeared as it diffused into the sand instantly. This indicates that the crude oil strongly coated the sand and the system was oil-wet. Since there was no droplet on the sand surface can be observed and no angle can be measured, hence the contact angle between the crude oil and sand surface was zero.

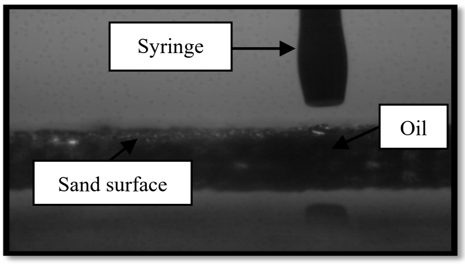

Figure 1: Crude oil dropped on the real sand surface

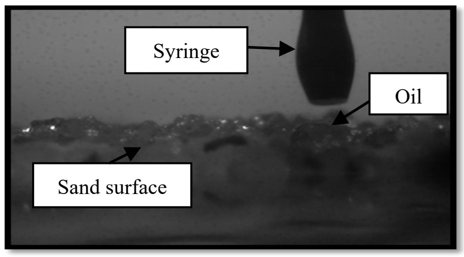

Figure 2: Crude oil dropped on the model sand surface

Theoretically, based on the equilibrium consideration that much relating to Young's equation, contact angle was depend on the surface tension between liquid and gas, solid and gas, and solid and liquid [3].

$$\gamma lg \cos \theta = \gamma sg - \gamma sl$$

γlg: Surface tension between liquid and gas
γsg: Surface tension between solid and gas
γsl: Suface tension between solid and liquid

As the contact angle was zero, which is less than 90˚, there was a large contact area between the crude oil and sand surface and this was strong adhesion present. This is because there was a great of their overall energy and high interactive force between the crude oil and sand. According to past studies, the interaction between the oil and sand were affected by the pH value whereas pH increases the interparticle repulsive force due to increase in oil viscosity [7]. On the other hand, based on the previous study, cohesion of fine sand significantly increased up to 1% of oil contamination and then decreased with increasing percentage of crude oil [1].

CONCLUSION

As a conclusion, both objectives have been achieved as the characterization of the crude oil-contaminated sand was performed and also the study on its wetting, adhesion and cohesion was done. All the value obtained were new data in research world as the characteristics of the crude oil-contaminated sand are varies depending on characteristics of the oil and gas field itself and crude oil will affect and change the physical and chemical properties of sand when it was contaminated [1]. As a result, the bulk densities of real and model sand sample were 1.3442 g/ml and 1.5342 g/ml respectively. The grain density of real sand sample using first and second method were 2.5713 g/ml and 1.4042 g/ml while for model sand were 2.1660 g/ml and 1.5306 g/ml respectively. The crude oil density obtained was 0.7845 g/ml while its kinetic, dynamic viscosities and pH value were 3.1071 mPa.s, 3.9607 mm2/s and 6.17 respectively. For wetting study, the contact angle between the crude oil and both sand sample surface were 0˚ which indicates the sand was strong oil-wet.

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