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Investigation of the Hydrophobic Qualities of Oil in Relation to Sand Porosity

Quantitative Methods in Rocks and Minerals

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Abstract

Even though all marine oil spills differ in nature and outcome, the qualities of oil and sand are consistent; oil is hydrophobic, while sand, which is porous and generally comprised mostly of silica, is hydrophilic. Through experimentation, clear links are shown to be present between sand porosity and the hydrophobic qualities of oil; sand which was dry and completely unsaturated allowed SAE-30 motor oil to penetrate far further in comparison to sand which was fully saturated with a saltwater solution, which allowed for no percolation at all. However, a larger group of samples and more effective sample preparation methods are required in order to establish a definitive assessment of oil flow through sands that are not fully saturated.

Background

Oil spills have widespread and severe consequences, affecting not only the environment and wildlife but also industry and the economy. These damages are also long term; oil that reaches intertidal areas has been shown to persist within sand for lengthy periods of time – even years (Mulhare et al., 1997). While the exact nature and impact of each oil spill disaster is difficult to predict by looking at past situations given the numerous variables involved, from the volume and type of oil to regional topographical qualities to weather and climate patterns (Fine et al., 1997). However, given the scenario of an oceanic oil spill which eventually reaches sandy beach shores, basic qualities of both sand and oil can be applied and used in experimentation.

Sand grains are generally classified as being between 1/16 to 2mm in diameter and are larger than silt and clay particles. Due to the relatively large size of its grains, sands are fairly porous substances. Porosity is the measurement of the void spaces between particles, usually expressed in terms of volume as either a fraction or percentage. Sands usually have a porosity of between 20 and 40%, meaning that there are ample spaces in between sand grains for fluids to flow.

The most common component of sand found by the coast is usually quartz, otherwise known as silica or silicon dioxide (SiO_2). Quartz sand is hydrophilic by nature, meaning that it is able to undertake hydrogen bonding with water molecules (Tschapek et al., 1982.). By contrast, oils are non-polar and consist of hydrocarbons that lack the ability to hydrogen bond. Thus, oil is hydrophobic and does not mix with water.

Crude oil is a mixture of many different hydrocarbons and organic compounds. Fortunately, the most volatile components of crude oil evaporate quickly after spillage, and some other components are broken down through photolysis, a process during which UV radiation in sunlight oxidizes some of the hydrocarbons present in the oil (Kingston, 2002), and other natural means. However, the vast majority of the parts of crude oil are hydrophobic and consequently undissolvable in water; it is for this reason that oil spills which occur at sea are able to cross the ocean to the shores of beaches.

Research Question

Given the hydrophilic qualities of quartz sand and the hydrophobic qualities of oil, does altering the level of saturation of a volume of sand impact the ability of oil to penetrate the sand?

Methods

A. Sample Preparation

An experiment was conducted to investigate whether adding differing quantities of water to sand would affect the ability of oil to percolate through the sand. To simulate the differing levels of saturation at various points of the beach shore, three samples were made; sample A represented completely dry and unsaturated beach sand, sample B half-saturated sand, and sample C fully-saturated sand. Three 1000mL test tubes with identical diameters and heights were used for the samples to maximize the accuracy of the results.

To represent beach sand, commercial play sand was used (the properties of which can be seen in Table A). Each test tube was filled to the 500mL mark with sand; the tubes were shaken while being filled to allow the sand to settle and reduce extraneous pockets of air.

Properties of Commercial Play Sand	
Sort	Poorly Sorted
Grain Size	0.25 - 1.0 mm (medium-coarse)
Sphericity	0.5 - 0.7
Roundness	0.1 - 0.5 (angular)
Qualitative observations	Primarily clear, unstained quartz sand

Table A. Quantitative and qualitative qualities of the commercial play sand used during experimentation.

A saltwater solution was made at 35ppt (parts per thousand) to match the average salinity of seawater by adding 17.5g of coarse sea salt to 482.5g of water and stirring well. Prior to the experiment, the porosity of the sand was found to be 0.32 (32mL of fluid for every 100mL of sand), and consequently 80mL of the saltwater solution was added to sample B to represent half-saturation, while sample C was fully saturated with 160mL. To distribute the saltwater as evenly as possible through the sand, samples B and C were again shaken well. Samples B and C were covered to prevent water evaporation, and all three samples were left over an approximately 65-hour period to settle.

B. Experimentation

In this experiment, commercial SAE-30 motor oil was used. Following the 65-hour settling period, 100mL of the motor oil was added to each sample. After adding the oil, the depth of oil penetration was taken by measuring with a ruler in millimeters the vertical length between the line of sand in the test tube and the point of oil penetration as visible through the test tube (Fig. A). Four points evenly distributed along the circumference of each test tube were consistently used for each sample to measure the depth of percolation (Fig. A); a mean of the four points was also calculated for each logging of data. Following the measurement, a corresponding picture of each sample was taken. Data was recorded every 30 minutes for every sample over a total period of 420 minutes.

Fig. A. The distance between the top of the sand and the furthest point of visible oil penetration was measured using a ruler. The vertical distances were measured from predetermined areas on the test tube, as marked by black string.

Results

Following 420 minutes of recording data, it was found that the SAE-30 motor oil percolated though the sand in both Samples A and B while failing to do so in Sample C (Fig. B and Table B). This was as expected; given that Sample C was fully saturated in accordance with the porosity of the sand, all of the void spaces between the sand particles would have been filled by the salt water solution, leaving no room for the oil molecules to flow through. In addition, because the motor oil was hydrophobic, the oil could not mix with the water in the sand. Thus, throughout the experiment, the 100mL of oil added to Sample C remained separate and above the sand and saltwater mixture (Appendix C).

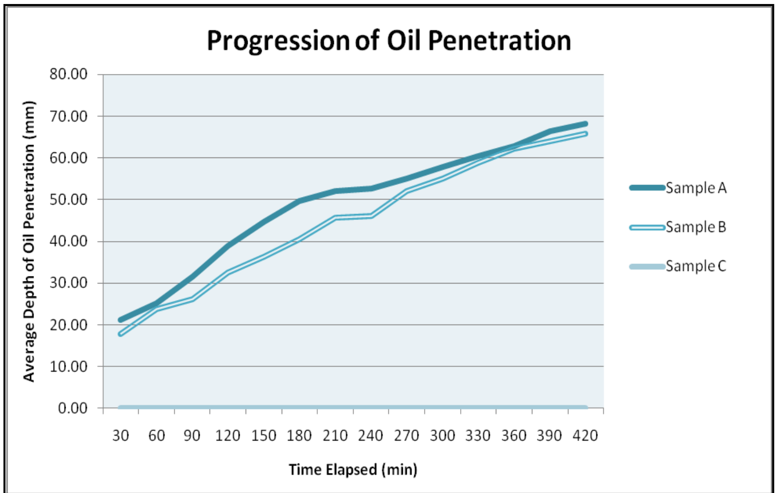


Fig. B. Progression of oil penetration over the period of experimentation in each sample. Data featured in the graph can be found in Table B.

	Depth of SAE-30 Motor Oil Penetration (mm)														
Time (min)	A1	A2	A3	A4	A Avg	B1	B2	B3	B4	B Avg	C1	C2	C3	C4	C Avg
30	23	24	19	19	21.25	18	17	18	18	17.75	0	0	0	0	0
60	30	28	21	22	25.25	25	23	24	23	23.75	0	0	0	0	0
90	39	35	30	22	31.5	28	24	25	28	26.25	0	0	0	0	0
120	45	41	40	30	39	34	30	33	33	32.5	0	0	0	0	0
180	55	50	48	46	49.75	40	40	40	42	40.5	0	0	0	0	0
210	57	53	50	48	52	45	46	46	46	45.75	0	0	0	0	0
240	57	54	50	50	52.75	45	46	46	47	46	0	0	0	0	0
270	57	56	53	54	55	52	52	52	52	52	0	0	0	0	0
300	60	58	57	56	57.75	55	55	56	54	55	0	0	0	0	0
330	64	62	58	58	60.5	59	60	58	58	58.75	0	0	0	0	0
360	65	65	62	59	62.75	62	63	63	61	62.25	0	0	0	0	0
390	69	67	67	63	66.5	64	64	65	63	64	0	0	0	0	0
420	70	70	69	64	68.25	66	67	66	64	65.75	0	0	0	0	0

Table B. Compilation of all of the measurements taken during experimentation. A1-A4 denote the four points which were consistently measured on Sample A, and vice versa for B1-B4 and C1-C4. Averages of the four data points for each sample were calculated (highlighted) and were the points featured in the produced graph (Fig. B).
Sample A: 500 mL sand; Sample B: 500 mL sand, 80 mL saltwater solution; Sample C: 500ml sand, 160 mL saltwater solution.

However, some of the results of the experiment were also surprising. It was initially expected that, given that sample B was half-saturated with water, there would be fewer gaps between the sand particles and thus the ability of the motor oil to percolate through would be reduced, resulting in the oil penetrating a lesser distance in sample B in comparison to sample A. While the oil still penetrated further through sample A, samples A and B had results that were closer than was anticipated.

Other observations of interest include the non-uniformity of the oil penetration and the presence of stratification, both of which can best be seen in Sample A (Table B and Appendix A). While the oil failed to penetrate through the sand entirely in Sample C and the depth of penetration amongst the points used in Sample B was fairly regular (Table B and Appendices B and C), the level of percolation between the four points selected for measurement in Sample A varied significantly during measurements; in some instances, there were variations of up to

17mm between two of the points during the measurement period (Table B). This was likely caused by the manner in which the sand settled during sample preparation, but expanding the number of samples used would elucidate the finding.

A qualitative observation of different layers of the SAE-30 motor oil within the sand in Sample A was also made (Appendix A, also visible in Fig. A). This stratification could be caused by either the distribution of sand grains into layers during settling, the separation of the different hydrocarbons composing the motor oil, or a combination. However, an analysis of the different oil layers could not be made.

Conclusions

The results clearly show the hydrophobic qualities of oil impacts its percolation through sand that has been saturated at different levels. Since quartz sand is hydrophilic and porous, adding water and forming a mixture reduces the ability of oil to penetrate it by occupying the void spaces between the sand grains. Thus, oil is completely unable to percolate through sand which is completely saturated by water (Sample C) while simultaneously being able to completely penetrate sand which is completely unsaturated (Sample A).

Recommendations

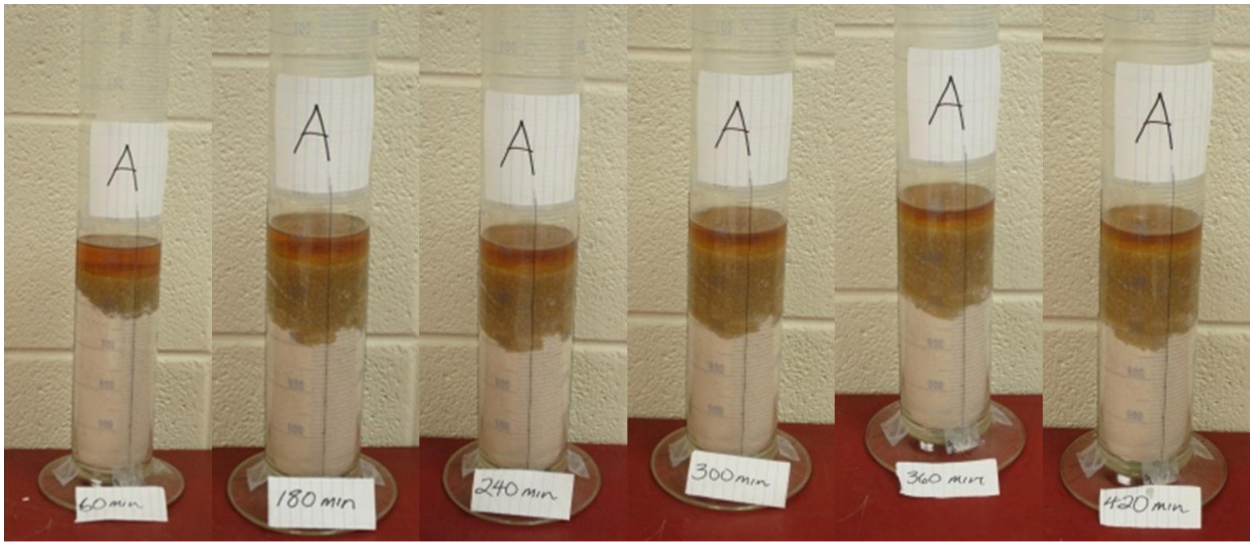
The following recommendations are offered for replicating the experiment. First, the similarity of the results of samples A and B are best explained by the new void spaces created while shaking Sample B following the addition of saltwater during sample preparation. As a result, the sand and saltwater mixture of sample B occupied a slightly larger volume in the test tube in comparison to samples A and C prior to experimentation. The new void spaces potentially allowed the motor oil in Sample B to percolate through at a rate similar to Sample A despite the addition of the salt water solution, causing the similar results. Though an attempt was made to remedy this problem by leaving all samples to settle, tightly packing the sand into the test tube after mixing with the saltwater solution may be a better way to reduce the extraneous spaces.

Second, as the experiment was intended to simulate a beach environment during an oil spill scenario, better-suited materials could be used in lieu of those featured during this experiment. Namely, crude oil or oil tar could be used in place of the SAE-30 motor oil, which has been refined and processed; crude oil is also darker in color in comparison to the SAE-30, which would allow for more qualitative analysis. A sample of beach sand could also be used instead of the commercial play sand used in the experiment; though both beach sand and the play sand are comprised mostly of quartz, natural beach sand contains extra organic compounds and other materials that also impact the hydrophilic properties of the sand (Tschapek et al., 1982.).

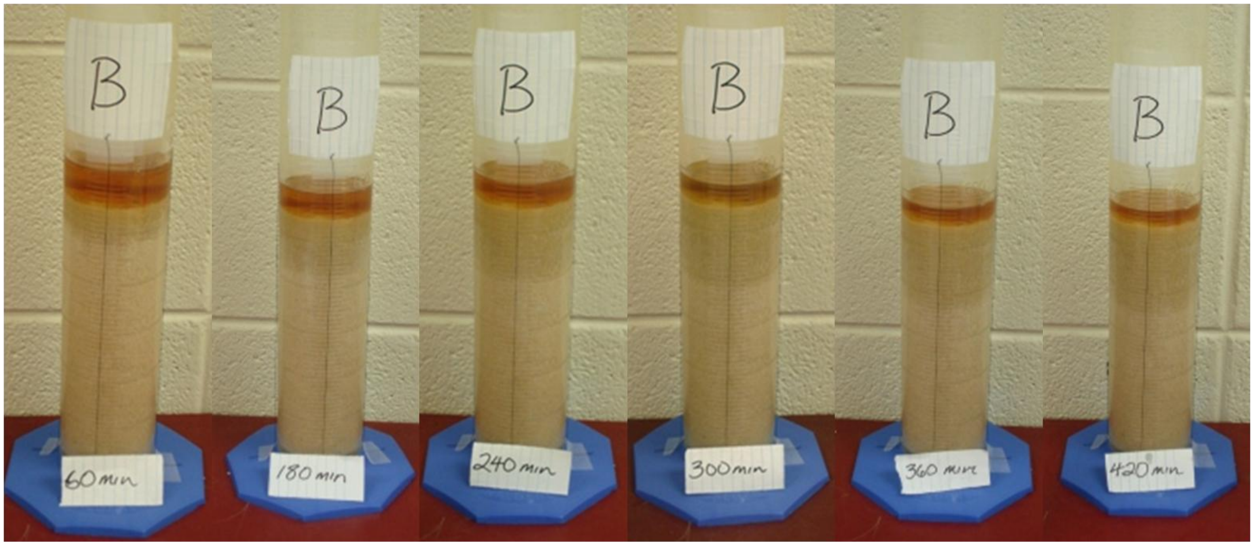
Extensions

An observation made during experimentation which would call for further research is the layering of oil as it percolated through the sand in sample A. As crude oil is a mixture of a variety of hydrocarbons and organic molecules, each of the components would have different sizes and flow rates. Thus, it is possible that different portions of oil would separate from each other as they percolated through a porous material such as sand. An experiment should be performed separating the hydrocarbons within oil using means such as chromatography. It would then be possible to analyze which components of crude oil would be the most difficult to remove from oil spill sites, as they would penetrate the soil or sand the furthest.

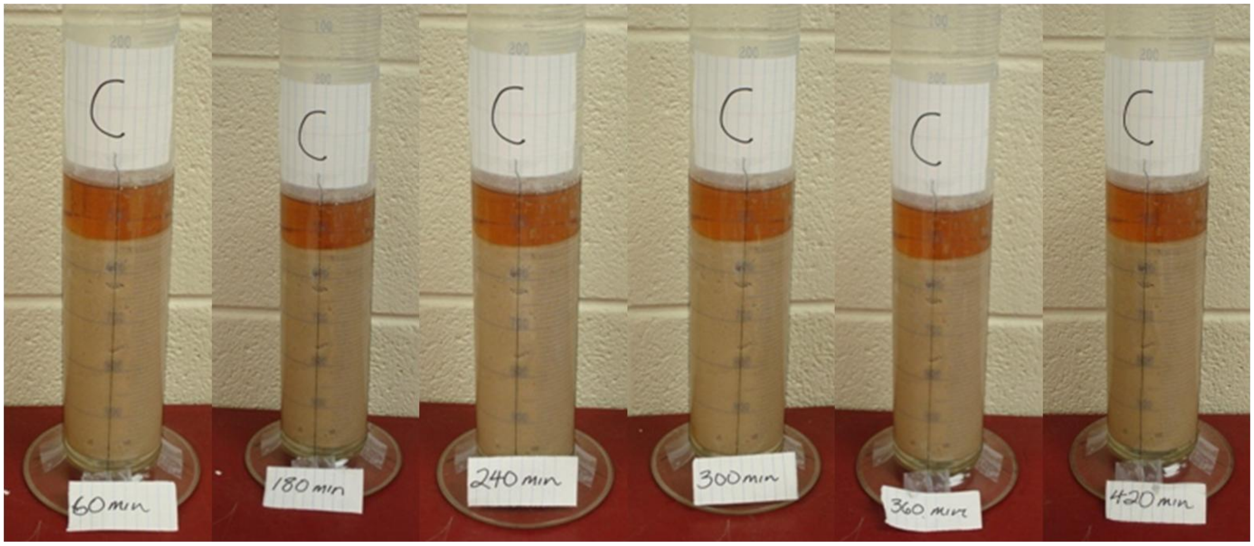
Appendices



Appendix A. Collection of photos depicting the percolation of oil through sample A at selected intervals of time (as marked). The length of black string in each photo indicates measurement point A1.



Appendix B. Collection of photos depicting the percolation of oil through sample B at selected intervals of time (as marked). The length of black string in each photo indicates measurement point B1.



Appendix C. Collection of photos depicting the percolation of oil through sample C at selected intervals of time (as marked). The length of black string in each photo indicates measurement point C1.

References

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Tschapek, M., Wasowksi, C., Falasca, S., 1982. Character and change in the hydrophilic properties of quartz sand. *Serrano 669.*