The University of Mississippi Undergraduate Research Journal

Volume 3 Article 5

5-1-2019

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Abstract

Crude oil spills are one of the most destructive disasters that can occur, and they are extremely difficult to recover from. Many studies focus on what can be done to clean these crude oil spills, but more research should be focused on means of prevention. Currently, very little is known about how the moisture content levels and the packing efficiency of soil can affect an oil spill. These two factors alone can offer a variety of information to environmental agencies, manufacturers, and refineries. Through utilization of a chemical engineering lab, a recording mechanism, and ImagePro software, data was collected and analyzed. This study simulated, on a small scale, the conditions of an oil spill. The study focused on the differences in the oil spill spreads for petri dishes containing various moisture content levels and packing levels. Each dish contained the same percentages of soil, clay, and sand. The first major finding was that areas with high levels of moisture are more likely to have separable spills and are not likely to experience spills in which the oil penetrates the soil extensively. The second finding was that areas with densely packed soil are less likely to be susceptible to deep penetrating oil spreads. The last finding was that drier areas will experience rapid rates of spreading. The conclusion was made that water or compactness caused an interruption in travel time or space for the oil and led to a decline in the areas of the spreads for dishes with those variables.

Introduction

In the past, much research has focused on the characteristics of the environments in which oil spills are most harmful. The Emergencies Science Division (ESD), also known as the Environmental Emergencies Technology Division of Environment (EETD), Canada, has been dedicated to performing oil and chemical research for decades (United States Environmental Protection Agency & Emergency Response Division & United States Environmental Protection Agency, 1999). A great deal of research also focuses on the methods of soil remediation used to clean up oil spills. Afshar (Afshar, Mirmontazeri, & Yeung, 2014) expands on the idea of using naphthenic acids as a surfactant and remediation agent. These examples concentrate on the intricate details for studying and cleaning the spill after the oil spill has already occurred, and demonstrate the diversity of soil remediation research.

Soil remediation is a common research area where this particular study is likely to have great impact. Most immediate-response remediation efforts following an oil spill are highly mechanical and labor-intensive, leaving behind substantial quantities oil (Jung, Jang, & Ahn, 2016), eventually leading to the need for long-term soil remediation efforts. Although adsorbents can be used to 'mop' up excess oil (Teli, Valia, & Mifta, 2016) some longer-term remediation techniques include bioremediation technology (Guimarães, Arends, Vander Ha, Vande Wiele, Boon, & Verstraete, 2010) solvent extraction, using surfactants and bioemulsifiers (Ayeldeen, Negm, & El Sawwaf, 2016) and subcritical water extraction. Bioremediation is a process used to treat contaminated media, including water, soil and subsurface material, by altering environmental conditions to stimulate growth of microorganisms and degrade the target pollutants. Solvent extraction is a method used to separate compounds based on their solubilities. Surfactants and bioemulsifiers are used to encapsulate the oil droplets. Similar to solvent extraction, supercritical fluid extraction is the process of separating one component from another using supercritical fluids as the extracting solvent. However, these methods are merely ways to clean up crude oil spills once damage has already began to occur.

Soil is a diverse and complex composition consisting of minerals, organic matter, water, air, and living organisms. The delicate habitats within soil can be permanently damaged from crude oil contamination. These oil spills could stem from industrial spills, waste treatment, oil extraction and production, or inferior goods storage. After only seven days, the toxicity of an oil spill causes a 90% death rate of earthworms at 2% oil contamination, and 100% bacterial inhibition at 1% petroleum content (Lim, Lau, & Poh, 2016). These figures help illustrate the devastating effects to the soil habitat which can have long-lasting effects on the entire ecosystem. These effects include deteriorating wildlife and extensive oil penetration through layers of the Earth. This study will compare how oil spreads in loosely packed soil samples versus tightly packed soil samples that contain the same percentages of soil, clay, and sand, relative to each other. The data will then be used to interpret and prepare more preventive measures to help lessen the effects of potentially detrimental oil spills before they occur.

Interfacial phenomena between liquid droplets (oil), solid media (soil), and air porosity within the solid media, comes under the broad topic of wetting fundamentals. Within soil and oil combinations, high levels of roughness and porosity of the soil will limit the spreading of crude oils over the area.

Viscosity and density of the oil, wicking within the pores of the soil, and surrounding environmental conditions, such as temperature, will also affect how oil spreads in an area (Mohamed, Abdullah, & Younan, 2015).

Two popular mathematical models, the Hydrocarbon Spill Screen Model (HSSM) and non-aqueous phase liquids (NAPL) simulator, are used to simulate the transport of organic contaminants from the soil surface to the top of the groundwater level beneath the soil. This region is called the vadose zone, and even after a crude oil spill, organic contaminants would be detectable in this zone. At the base of the vadose zone and interface with groundwater, an oil lens is formed (Bear, & Cheng, 2010). The HSSM model is one-dimensional in nature, and tracks the spreading of (light) LNAPL in a vertical direction from its original spillage point on the land surface to the groundwater table. Xu (Xu, Chai, Wu, & Qin, 2015) studied an oil spill using the HSSM model. Their results indicated that oil spills had larger areas in shorter amounts of time, within the vadose zone. Also, more oil reached the water table because the rates of saturation were more extensive. Soil with larger amounts of water, or higher moisture content levels, had smaller oil saturation rates. Less oil reached the water table in soil with higher levels of moisture.

The NAPL simulator is more complex than the HSSM, and describes the transport of NAPLs near the surface of granular soils (Guarnaccia, Pinder, & Fishman, 1997). Unlike the one- dimensional HSSM model, it is three dimensional. It takes water, NAPLs and gas phases into account. Similar to the HSSM model, the soil domain is centered around the vadose zone. It also consists of a capillary fringe zone and the water-table zone. When using the NAPL model, the assumption is made that the phase wetting of soil occurs three phases. Water, NAPL and gas are constant. Therefore, the IFT between oil and soil are accounted for by a constant term in this model. Since this is a complex, detailed model, this is a reasonable approximation.

Experimental Section

The samples used in this experiment were created by calculating the standard composition of soil, clay, and sand. The composition used is based on the most common makeup in soil on average. The calculated percentages were used to proportion the amount, in grams, of each component. The masses of soil, clay, and sand were each measured by an electronic scale. The amounts of water needed for the dishes were calculated according to the target moisture content percentage (0%, 5%, or 10%), and evaluation was required to determine how these levels affected crude oil spill spread

$$MC = \frac{M_W - M_D}{M_W} \times 100$$

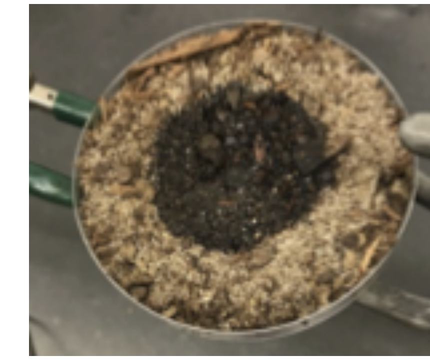
where MC is the moisture content (%) of the material; Mw is the wet mass of the sample; and MD is the mass of the sample after drying, effectively the dry mass of the sample.

The calculated amount of water was then added to each petri dish for each trial via 3 mL syringe. At least ten minutes was allotted for the water to fully absorb into the mixture. The three components were mixed thoroughly in a 500 mL beaker, and the mixed contents were deposited into a small petri dish. The same method was repeated for each trial. The only variation was the extra requirement of pushing the contents compactly inside the petri dish for the tightly packed trials, as opposed to the loosely packed trials. For both the loosely and densely packed samples, the top of the sample was leveled off to ensure that they both occupied the same volume inside the dish. The packed dish was therefore not piled up higher but pressed down tighter in the same size dish.

After each petri dish was prepared, it was elevated by two high clamps attached to two ring stands. 10 mL of motor oil was measured out for each dish. The motor oil was transferred from a small beaker via 3 mL syringe to a 10 mL graduated cylinder. The 10 mL of oil was then poured into the center of the petri dish. In order to examine the spread later, a camera recorded the process for ten minutes from the bottom view of the petri dish.

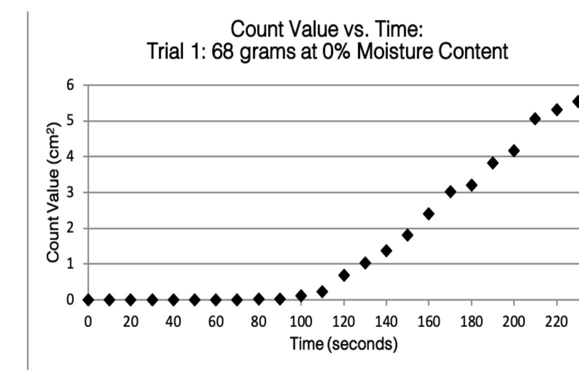
The videos of the trials were uploaded to a computer. The video was screenshotted in increments of ten seconds to better examine the rate of spread for each trial. The screenshots were cropped, saved, and opened into Image Pro. Using Image Pro, each picture was individually calibrated. Manually, the area within the screenshot that was a part of the oil spread was selected with a dropper tool. Then, the count function was used to determine the magnitude of the spread, in cm2. The values, in relation to their corresponding time values, in seconds, were recorded in Microsoft Excel. The values were then used to construct graphs depicting the oil spread for each petri dish (time versus area of spread cm2).

Next, the data compiled from Image Pro was used to calculate the area difference between each ten second increment. The area difference was then divided by the amount of time that elapsed resulting in the rate of change in area value. With these values, additional graphs were created depicting the area rates of the oil spread at specific times during the given trials.



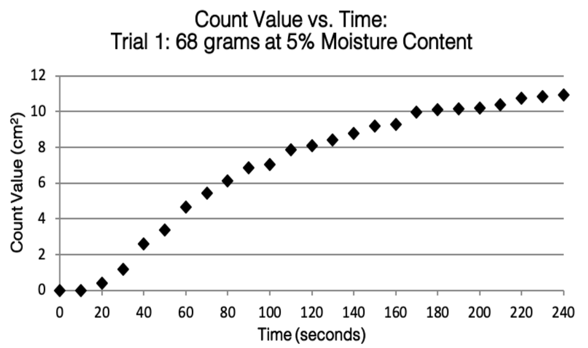
a. For 0% moisture content (68 grams dish trials):

For the trials that had zero percent moisture content, no water was added to the petri dishes. When oil was poured onto the dishes in this category, the oil spread reached the bottom of the petri dishes the quickest. The count values of the oil spreads, representing the area of the spread, obtained from Image Pro, also reached higher values for these dishes.



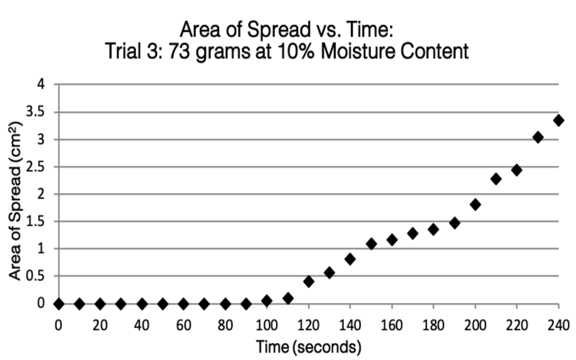
b. For 5% moisture content (68 grams dish trials):

For the trials that had five percent moisture content, a calculated amount of water was added to the petri dishes via 3 mL syringe. The water was then mixed thoroughly into the sample. When oil was poured onto the dishes in this category, the oil spread reached the bottom of the petri dishes slower than it did in the dishes with zero percent moisture content but quicker than it did in the dishes with ten percent moisture content. Similarly, the area values of the oil spreads reached lower values than the dishes with zero percent moisture content, but higher values than the dishes with ten percent moisture content.



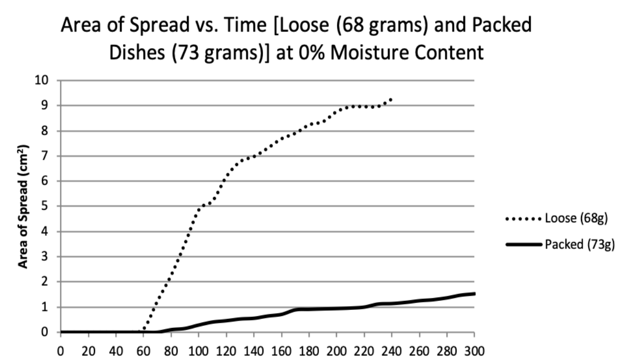
c. For 10% moisture content (68 grams dish trials):

For the trials that had ten percent moisture content, a calculated amount of water was added to the petri dishes via 3 mL syringe. The water was then mixed thoroughly into the sample. When oil was poured onto the dishes in this category, the oil spread reached the bottom of the petri dishes the slowest. Also, the area values for the oil spreads for dishes in this category had the smallest values.



d. For 0% moisture content (73 grams dish trials):

Trials of more densely packed samples were also conducted and analyzed. When compared with their respective loosely-packed counterpart categories, the spreads in these dishes were remarkably different. For example, two dishes are both at zero percent moisture content levels, and they have the same percentage compositions of each component. The sample that is more densely packed at 73 grams will exhibit a spread where the oil reaches the bottom more slowly and the final count value or area of the spread is smaller. In contrast, the dish with only 68 grams of content will spread to the bottom quicker, and the spread will be more extensive.



Discussion

a. For 0% moisture content (68 grams dish trials):

As stated in the results section, samples within the zero percent moisture content category exhibited spreads with higher areas than the samples in five and ten percent moisture content categories. The oil in these dishes also reached the bottom of the petri dishes fastest. The petri dishes in this category did not have any water inside of them. Hence, there was no opposing force or substance present to restrict the oil from freely and easily reaching the bottom of the dish. The oil within these samples had free range to quickly move through the crevices of the dry samples.

b. For 5% moisture content (68 grams dish trials):

The results showed that samples with five percent moisture content levels (approximately 3.5 mL water) exhibited spreads with higher areas than the samples with ten percent moisture content levels. However, this category exhibited spreads with smaller areas than the spreads for the zero percent moisture content dishes. The oil poured into these dishes reached the bottom of the petri dishes slower than the dishes with zero percent moisture content levels and faster than the dishes with ten percent moisture content levels. For the dishes in this category, there was some degree of resistance faced by the oil trying to reach the bottom of the dish. This is why the oil reached the bottom more slowly as compared to the zero percent moisture content level dishes. The induction period for the dishes in this category was greater than those with zero moisture content due to oil reacting hydrophobically. This is also why, in the end, the overall area of the spread was smaller than the zero percent moisture content level dishes.

c. For 10% moisture content (68 grams dish trials):

The results showed that the samples with ten percent moisture content levels (approximately 7 mL water) exhibited the smallest spreads, when compared with samples in the categories with either zero or five percent moisture content levels. Similarly, the oil poured into these dishes reached the bottom of the petri dishes the slowest when compared with both the dishes with zero and five percent moisture content levels. The oil within the dishes with ten percent moisture content levels experienced the most resistance or repulsion due to the larger quantity of water present. These larger water quantities made it difficult for the oil to travel through the sample. The induction period for this category of dishes was the greatest because of an increased reaction of hydrophobia from the oil contacting the moisture in the dish. Since water and oil had difficulty in interacting or mixing, more of the oil would tend to sit on top or in pockets throughout the sample.

d. Densely packed versus loosely packed:

As previously stated, dishes with higher packing levels (73 grams), will have spreads that reach the bottom of the petri dishes more slowly than the dishes with looser packing (68 grams), even if the two dishes have the same moisture content levels. In the more densely packed dishes, contents inside the petri dish are more compacted and pressed together, resulting in smaller pores and hence more resistant avenues for oil transport. This is responsible for the slower rate of oil transfer to the bottom of the petri dish.

Conclusion

The goal was to examine factors other than the ecosystem or major environmental characteristics that may influence the rate and degree of oil-spill spreads on soil mixtures. Another goal was also to conduct experiments that provided information on how to prevent detrimental oil spills before they happen instead of focusing on what can be done once it has already happened. The research results and analyses created some key findings.

First, areas in environments with high levels of moisture content in the soil are more likely to have separable spills. This simply means that in an area with high levels of moisture, the oil would be more like to isolate itself from the rest of the surrounding components because the water would cause it to rise or stay close to the upper levels of the ground. This could help with filtering oil from an area where an oil spill has occurred because the moisture rich ground would not be conducive to allowing the oil to mix homogeneously throughout the makeup of the ground.

The second finding is that areas with densely packed soil compositions are less likely to be susceptible to deep penetrating oil spreads. Since there is less leeway for the oil to travel in an area with very compact soil, it is less likely that the oil spread will be as detrimental as it would be in an area with loosely packed soil. When soil is densely packed, the pores or areas of air within the soil are smaller, and it is harder for oil to get through, especially to deep levels. Therefore, if oil is spilled in an area where the ground is comprised of soil with very high packing levels, it would be more feasible to clean it up before the effects become extensively harmful or uncontrollable.

The third key finding is that drier areas will experience more rapid rates of spreading. When an area is at or near the level of zero percent moisture content, this is when an oil spill is likely to be the most detrimental. In a dry area, oil will spread extremely quickly because there is no opposition or repulsion resulting from water not wanting to mix with it. Dry areas are where oil will reach down into deeper layers or levels of the ground, which makes it difficult to clean up. Also, dry areas will experience deeper penetration of oil more quickly than other areas. This makes is harder to remedy the problem before it becomes uncontrollable. Furthermore, dry areas have higher oil spread areas. This means that the effects are more damaging in dry areas when oil spills, compared with other areas.

Applications, Recommendations, and Further Work

The implications of this study are applicable to real world situations. Consider this scenario. If a manufacturer or oil refinery is seeking a location to build a factory or plant, it is important that the soil's moisture content levels and packing levels or the prospective areas are taken into consideration. An area with extremely dry, loosely packed soil would not be a suitable place for a refinery. Analyzing factors such as these and making logical decisions will help the environment and society at large.

A limitation of this experiment was that the mixing of the samples was done by hand each time. For this reason, it is hard to verify that all the samples were mixed to complete homogeneity for each trial. For further research on this topic, it is recommended that the researcher finds a more efficient way to ensure the samples are mixed to be as homogeneous as possible.

Further work entails completing similar trials with oils of varying viscosities. Also, the interactions between the samples and oil can be further studied using a contact angle machine. By calculating the surface and interfacial energies between the oil and the soil, further information regarding the oil spill can be interpreted. Implications of these findings could help solve real world problems and help shape the way people make decisions. Knowing how different moisture content levels affect the impact an oil spill may make on a specific area provides useful information. Knowing the moisture content levels and packing levels of the soil in an area will help experts make sure they are more aware of how much time they have to act before an oil spill's effects become too extensive to properly and efficiently stop.

Supplemental Information

Petri dishes were supplied by Fisherbrand, Co. Loosely packed samples were created using 24 grams of sand, 34.2 grams of clay, and 9.7 grams of soil. Densely packed samples were created using 25.8 grams of sand (supplied by Walmart, Incorporated), 36.7 grams of clay (supplied by the University of Mississippi Field Station), and 10.4 grams of soil (supplied by Scotts Company). Each of these quantities results in the same weight percentages, whether loosely or densely packed. The mass compositions for sand, clay, and soil in each dish were 35.3%, 50.3%, and 14.3%, respectively.

SuperTech™'s SAE 5W-20 motor oil was provided by Walmart Stores, Incorporated. Syringes were supplied by Becson, Dickinson and Company. Recording was conducted on Apple, Incorporated's iPhone 7 Plus. Analyses of pictures were conducted on Image-Pro Premier 9.2, 64-bit. Soil and clay were dried in 8 x 8 inch pyrex dishes, and sand was dried in a 5 x 9 inch pyrex dish using a Precision oven, prior to measuring the appropriate quantities making up the above compositions.

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