AN ABSTRACT OF THE THESIS

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Dr. Skip Rochefort

On April 20th, 2010 the Deepwater Horizon drilling rig in the Gulf of Mexico malfunctioned leading to a 4.9 million barrel oil spill. The released oil affected marine life, coastal ecosystems, and the economic framework of the Gulf of Mexico. The Gulf spill spurred research on absorbent materials and engineering outreach. Crude oil can be removed by adsorbent or absorbent materials or through bioremediation. Sheep wool and other absorbent materials were used for surface clean-up experiments and evaluated using absorbency ratio metrics. Educational modules were developed to bring engineering applications to K-12 outreach programs. Additionally, mushroom mycelia act as a filter for contaminants in ecosystems and can bioremediate hydrocarbon compounds. Oyster mushroom mycelium were cultivated and used to test bioremediation of crude oil in a controlled environment. Absorbency ratios ranged between 3.97 to 14.7 mL oil per gram material. Educational modules reached 800 students and 20 middle school teachers between June and September 2010. Many outreach programs continue to use the material that was developed. Bioremediation experiments did not yield conclusive results, but small mushroom growth was seen in Petri dish trials grown with deionized water. Future work includes analysis of crude oil concentration after mycelium degradation, effect of introduction of mushroom mycelium into gulf region, and sheep wool material analysis.

Key Words: absorbency ratio, adsorbent materials, educational modules, oyster mushrooms

The 2010 Deepwater Horizon Gulf Region Oil Spill: Educational Modules and Methods for Long-Term Remediation

by

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I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

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Deepwater Horizon Gulf Region Oil Spill Educational Module

Chapter 1: Background

On April 20th, 2010, the Deepwater Horizon mobile drilling unit, located in the Gulf of Mexico, malfunctioned leading to explosions and the eventual sinking of the rig. The Deepwater Horizon was closing off the exploratory Macondo well when explosions occurred. Eleven crew members lost their lives and dozens more were injured. Search and rescue efforts were abandoned after three days and the resulting oil spill, referred to as the Gulf spill, was found to be much larger than originally thought. From April 20th to August 8th, 2010, the well continued to leak oil, affecting much of the Gulf Coast, before being capped with thick drilling mud and cement. Almost 4.9 million barrels of oil leaked from the well, endangering coastal and marine life, coastal populations, and emergency responders (On Scene Coordinator Report, 2011). Multiple conventional technologies were used to clean up the Gulf spill including dispersants, skimming, retaining booms, absorbent booms, in-situ burning, and on-shore remediation efforts.

1.1 Conventional Clean-Up Methods

The majority of these clean-up methods were not harmful to the environment, but the detrimental effects of dispersants were not immediately realized. Corexit 9527A and 9500A, the dispersants used in the Gulf, are chemical solvents or surfactants. The oil is broken down into small particles making it easier in theory for naturally occurring marine microorganisms to digest. However, the chemical implications of the dispersant were not considered before proceeding with widespread application. Corexit was found to be toxic to microorganisms and fish eggs, seemingly the same organisms that would benefit from its use. A study was jointly published by Georgia Institute of Technology and Autonomous University of Aguascalientes in 2012, showing that Corexit increased the toxicity of the Macondo crude oil by 52 times (Snell, Rico-Martinez, & Shearer, 2012). This testing was completed after 1.84 million gallons had been applied aerially and at the well site on the ocean floor. **Figure 1** shows aerial dispersant application. The main constituents of Corexit include several carcinogenic chemicals, which were not fully examined before use (On Scene Coordinator Report, 2011). Skimming was used to reclaim as much oil as possible before widespread dispersant use began.

Figure 1: Aerial dispersant application over gulf region. Oil is seen floating on the ocean surface (Cousins, 2013).

Skimming removes oil from the ocean surface by use of a slow moving boat. A weir is set at the oil-water interface to skim off the oil. Oil floats because it is less dense than water which makes skimming effective (On Scene Coordinator Report, 2011).

Skimming attachments were the most effective at gathering oil and over 1000 private vessels were employed during the clean-up efforts.

Booms, long plastic buoys filled with shredded plastic or absorbent material, were also employed to corral and absorb the oil before it reached the shoreline. Preventative measures were taken to ensure that oil did not reach the coastlines, but anchoring the booms proved problematic due to stormy weather and rough sea conditions. Many entrances to freshwater systems were blocked with booms arranged in chevron shaped patterns to divert oil from reaching inland, but proved ineffective because most did not stay in place. Over 1.6 million feet of containment booms were placed along the shoreline and about 500,000 feet of absorbent booms were used (On Scene Coordinator Report, 2011). These booms were filled with different absorbents: hydrophobic and oleophilic materials to trap oil and repel water. Containment and absorbent booms were often used in combination to prevent and soak up oil creep. Marine conditions made implementation of booms problematic. Waves and wind pushed oil over and under booms and into protected areas. Optimizing oil clean-up was important to reduce the amount of damage to sensitive areas.

Dispersant use was limited by an Environmental Protection Agency directive on May 26th, 2010. Open air burning was then used above the well head to mitigate the oil as it surfaced. Open air oil burning releases contaminants into the air, which can be harmful to coastal populations, so this technique was only used on open water. Air quality was monitored by various agencies to ensure that smoke or residues did not harm any relief workers or Gulf residents (On Scene Coordinator Report, 2011).

Along the coastline, oil was cleaned from beaches by hand sifters, heavy equipment, and many volunteers which proved to be time and labor intensive. Oil that reached wetlands was dealt with in several ways. Natural attenuation, grooming, manual removal of oil, sifters, sediment relocation, tilling and mixing, sand treatment, cutting vegetation, low pressure flushing, sorbents, and vacuuming were all used to clean the sensitive wetland environments (On Scene Coordinator Report, 2011).

1.2 Alternative Clean-up Methods

Many researchers associated with universities and industry developed methods to remove oil from the ocean and beaches. The technologies included absorbent materials, chemical processes, and new machinery.

Liquids soak into absorbent materials, while droplets stick to the surface of adsorbent materials. Paper towels and sponges are examples of absorbent materials, while hair and wool are adsorbent materials. Liquids can be removed from adsorbent materials much more easily than from absorbent materials. The focus of this research is to compare the effectiveness of adsorbent and absorbent materials for use in surface oil spill clean-up.

Chapter 2: Model Development

Stephanie Silliman, an Oregon State University summer intern from Carnegie Mellon University, was sponsored by the Subsurface Biosphere Initiative to work under the guidance of Dr. Skip Rochefort. This project investigated oil spill clean-up methods and was a collaboration between Stephanie Silliman, Dr. Rochefort, and the author. The oil had been flowing from the Macondo well for over a month by June 2010 when absorbent materials became the focus of the author’s research. Sheep wool was available in Dr. Rochefort's lab from a previous project, and was used for oil spill clean-up experimentation when the Gulf spill progressed without news of a suitable solution.

2.1 Absorbent and Adsorbent Materials

Materials were collected for testing and sheep wool was compared to other materials including an oil absorbing polymer (Envirobond 403), recycled cellulose, human hair trimmings, non-woven woolen pads, and booms filled with sheep wool. Each material will be described to illustrate its qualifying characteristics.

Sheep wool is an adsorbent material, meaning that liquids cling to the surfaces of individual fibers. This is caused by an oleophilic outer layer and hydrophilic inner layer in each fiber. Lanolin, the natural oils produced by sheep, cling to the surface of each fiber and help repel water (Hydro-Carbon: Filtration & Separation, 2013). Each fiber has tiny barbs along the surface, similar to human hair, that trap oil as depicted in **Figure 2 (a)** and **(b)**. **Figure 2 (a)** shows how oil droplets stick to the hair surface and **Figure 2 (b)** presents an SEM image of a hair strand.

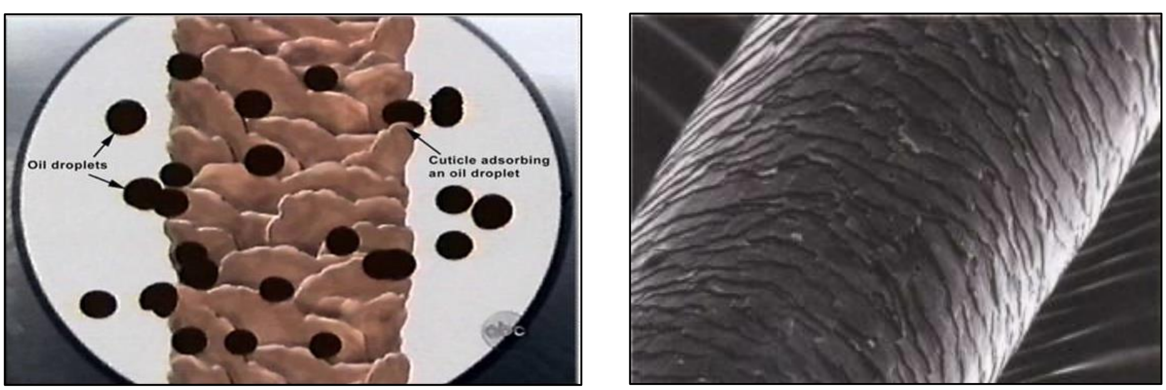

Figure 2 (a) and (b): (a) Hair and wool have rough surfaces that provide surface area for oil to stick to (Matter of Trust, 2010). This is an adsorbent quality. (b) An SEM image of a strand of hair shows the rough surface (Gamble, 2013).

Sheep are raised as meat animals in Oregon's Willamette Valley, and therefore, the wool is not cultivated for resale. Wool from meat animals generally has a coarser fiber than sheep bred for wool production and has a small length to diameter (L/D) ratio which makes it undesirable for woolen products. Farmers generally burn the wool or send it to the landfill (Field, 2014). This makes wool from meat animals a sustainable material for oil spill clean-up because it is abundant and is currently a waste product.

Oil absorbing polymer was purchased from Steve Spangler Science, an online provider of science demonstration kits. The block copolymer, formally called Envirobond 403, bonds with many hydrocarbons including those in gasoline, diesel, and crude oil. As the hydrocarbons are absorbed, the hydrophobic and oleophilic gel increases in volume (Spangler, 2013). Cross-linking is an irreversible chemical reaction depicted in **Figure 3** that occurs in the oil absorbing polymer. The polymer chains entangle and then bond, creating a network that does not come apart. Cross-linking prevents recovery of oil from the polymer. Though the theory behind oil absorbing polymer is interesting, disposal is a major concern, since the waste product is still a petroleum product that does not permit recovery of oil. **Figure 4 (a)** shows the cross-linked polymer after oil absorption.

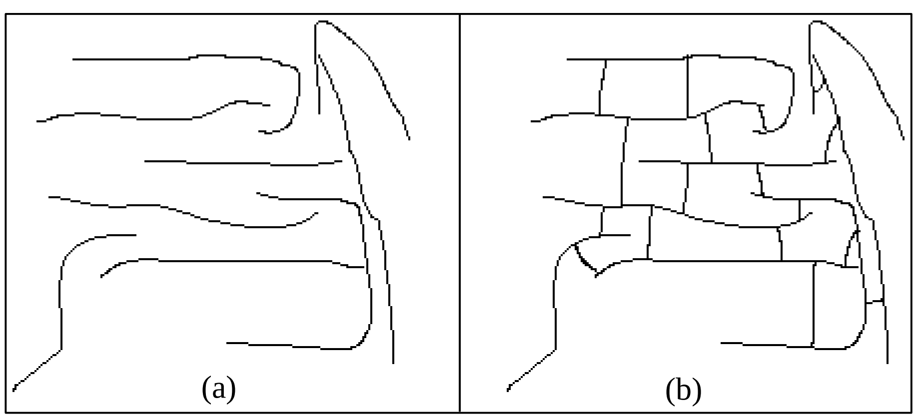

Figure 3 (a) and (b): (a) Long polymer molecules in an entangled state prior to cross-linking (b) The cross-linked polymer (Mississippi, 2005).

Recycled cellulose is a common industrial oil-spill clean-up product used around machinery. Cellulose pellets were purchased from New Pig, an industrial absorbent material supplier. The product, PIG® Oil-Only Lite-Dri® Loose Absorbent, is hydrophobic and floats for easy clean-up on open water (New Pig, 2013). The material does not permit oil recovery due to the highly compressed form of the material.

Hair trimmings were donated by Dr. Skip Rochefort (**Figure 4 (b)**) and used in tests because hair has the same adsorbent qualities as sheep wool. The hair samples were challenging to work with due to short strand length.

(a) (b)

Figure 4 (a) and (b): (a) Oil absorbing polymer after absorbing Marvel Mystery Oil from the beaker of water (Spangler, 2013). (b) Dr. Rochefort's hair was used to test the absorbency ratio of human hair against other materials.

Non-woven woolen pads were obtained from Northwest Woolen Mills in Woonsocket, RI. Premium woolen blankets are the company's primary market, but relief blankets for disasters are also sold. The sorbent pads were marketed as an oil clean-up technology shortly after the Gulf spill began. Each pad was three square feet, needle punched to create a felt-like texture, and advertised to absorb eight gallons of oil per square. The wool used to make the pads is of different quality than that obtained from

Willamette Valley sheep. **Figure 5** shows the pads which contain 100% recycled wool scraps (NW Woolen Mills, 2013) (Butler, 2013). The pads were cut into one inch squares for testing. Later tests used larger samples to measure oil absorbency capacity with different oil removal techniques.

Figure 5: Non-woven wool pads from NW Woolen Mills.

Booms were also modeled using sheep wool and women's nylon stockings for outreach program presentations and experiments. Three inch sections of nylon stockings were cut and filled with sheep wool to create an adsorbent boom. Boom construction and use was formulated to simulate absorbent booms used on the Gulf spill.

2.2 Experimental Oils

Two types of oil were used for testing: Marvel Mystery Oil, a fuel additive, and a crude oil sample from a deep sea Gulf of Mexico well. Marvel Mystery Oil (henceforth referred to as red oil, because of the color) was part of the kit from Steve Spangler Science and claimed to have similar properties to crude oil (Spangler, 2013). An MSDS of the red oil yielded information about the density and composition of the product. The density of the red oil was 0.87 g/mL which is very close to the measured average density of the crude oil used for experimentation.

Figure 6: Crude Oil and Marvel Mystery Oil

The crude oil was tested to determine the density before beginning both sections of this project. This density was used to determine the API gravity, the oil industry standard for characterizing crude oils. At the start of adsorbent material testing, the density was determined to be 0.85 g/mL and rose to 0.91 g/mL before mushroom experimentation began. These densities translate to 35° and 24.6° on the API gravity scale, respectively and were calculated using **Equation 1**, where *SG* is specific gravity.

$$\text{API gravity} = \frac{141.5}{\text{SG}} - 131.5 \qquad (1)$$

This qualifies the oil as a light crude oil to begin with, and a medium weight crude oil after some of the volatile components evaporated. The bottle of crude oil used for testing was open for short periods of time during experimentation. Volatile fractions of the oil may have escaped to leave heavier fractions remaining in the bottle. Oils are also classified as sweet for low sulfur content or sour for high sulfur content. The oil obtained was sweet, light crude oil which is typical for a Gulf of Mexico well.

2.3 Testing

Absorbency ratio tests were first completed by creating miniature “oil spills” in Petri dishes. Each dish was filled with DI water and 5 mL of oil was added to the surface using a syringe. Tests were completed with red oil and crude oil. One to three grams of sheep wool were placed on the oil and agitated with a stir rod to simulate ocean conditions. Once the wool was saturated with oil, it was squeezed into another Petri dish and a syringe was used to measure the amount recovered from the “oil spill”. From here, absorbency ratios were calculated with **Equation 2** and recorded as shown in Appendix A. Though Steve Spangler Science claimed Marvel Mystery Oil had similar properties to crude oil, the red oil was easier to remove from the wool. The red oil released fewer vapors and was less messy. After testing sheep wool, the other materials were tested in the same manner and compared to the wool.

$$\text{Absorbency Ratio} = \frac{\text{mL oil}}{\text{g wool}} \qquad (2)$$

Oil recovery and wool re-use were also investigated. Oil can be recovered from the wool, and the material can be reused for further oil clean-up. The recovery ratio was calculated with **Equation 3**.

$$\text{Recovery Ratio} = \frac{\text{mL oil recovered}}{\text{mL oil absorbed}} \qquad (3)$$

After the first round of oil adsorption, a known amount of oil was added to the “oil spill” and the used wool was placed back on the simulated spill to test re-use. The wool was stirred until saturation was reached and the oil was squeezed out and measured with a syringe to calculate the second use absorbency ratio using **Equation 2**. The re-used wool attracted oil more effectively than virgin wool due to previous hydrocarbon saturation. Less water was found in the recovered solution as well.

After initial testing for absorbency, recovery, and re-use, a bench scale procedure was created for outreach events and background information was compiled to aid students in understanding the importance of clean-up efforts (Appendix B). Multiple materials including two types of sheep wool, non-woven woolen pads, oil absorbing polymer, and recycled cellulose were used to show students the comparison between absorbent, adsorbent, hydrophobic, and hydrophilic materials. Importance of oil recovery was stressed in presentations and demonstrations. Booms were also tested and compared to un-processed materials. The nylon boom casing reduced the effectiveness of the sheep wool and absorbed more water than oil. Red oil was used to prevent exposure to crude oil for all outreach labs. Safety precautions were followed to avoid excessive skin contact and fume inhalation. The comparison between sheep wool and oil-absorbing polymer formed the basis for a lab experiment developed for K-12 outreach programs at OSU. This procedure was formulated for various outreach camps and catered to the age group and interest level of participants. Qualitative labs were also developed to assess which material was most effective at removing oil from the water surface. Quantitative labs were reserved for older students that had more time available to complete the lab exercises (Appendix F).

Alternative oil removal methods were also considered. Bench-scale stainless steel rollers were obtained and used to remove oil from three by four inch sections of non-woven woolen padding. The first method developed included a roller pressing against a metal mesh screen so that the oil could be drained through the screen. Design problems led to unsuccessful oil removal, therefore two rollers were set up in a wringer fashion without a mechanical crank. This was more effective because constant pressure could be applied to the sample by operators to remove the oil. Much of the recovered oil clung to the rollers because of the viscous nature of oil. Rollers were wiped down to remove as much of the recovered oil as possible after each use. Though a bench scale non-mechanical system proved difficult, adding a mechanical element and an oleophobic coating would likely increase the recovery yield. The bench scale procedure is outlined in Appendix C.

Chapter 3: Experimental Results

Crude oil density was measured with 5 mL volumetric flasks and a balance before absorbency testing and also before mushroom experimentation. Results are presented in **Figure 7** and **Figure 8**, and the average density is depicted with a dotted line. The red line depicts the average density of the red oil used for experimentation gathered from the MSDS. The standard deviation is presented as error bars on the data set. The average density was used in all calculations of absorbency and recovery ratios.

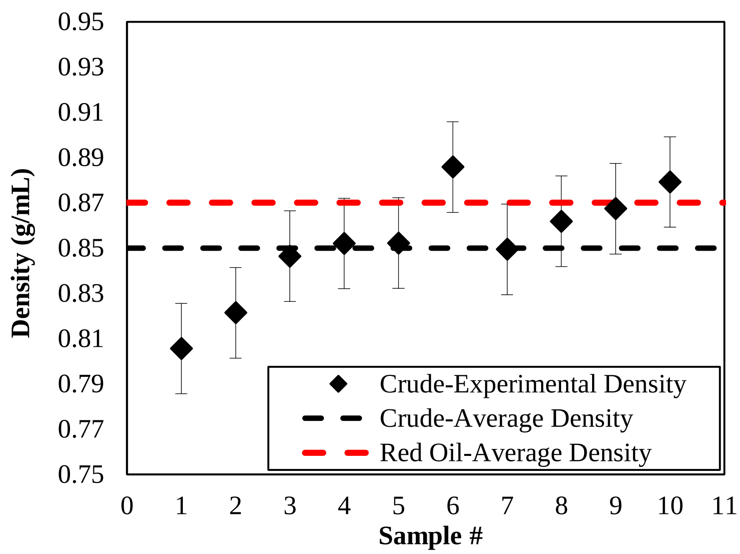

Figure 7: Density of crude oil and red oil before absorbency testing.

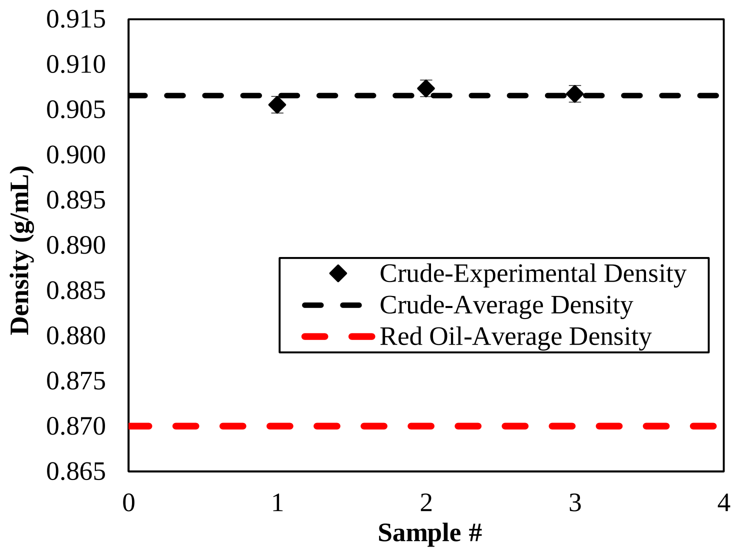

Figure 8: Density of crude oil and red oil before mushroom experiments.

Testing conducted with loose sheep wool yielded data presented in **Figure 9** and **Figure 10**. All absorbency ratios are presented in terms of milliliter oil per gram wool and recovery ratios are in gram oil per gram solution recovered. The absorbency ratio of loose wool was high compared to other materials examined, but decreased with number of uses as shown in **Figure 9**. First use of loose wool yielded an absorbency ratio of 11.4 mL/g with second use decreasing to 8.9 mL/g. This may be due to oil coating the wool fibers and reducing the surface area available for trapping oil droplets. The recovery ratio for loose wool determines how much oil is present in the water/oil solution adsorbed by the wool. A recovery ratio of 0.5 g oil/g solution represents a 50-50 mixture of oil and water. Both the first and second use of the wool yielded approximately the same recovery ratio as shown in **Figure 9**, indicating that even though the absorbency ratio for second use is lower, the same ratio of oil and water is being adsorbed. Both **Figure 9** and **Figure 10** include the standard deviation of data shown as error bars.

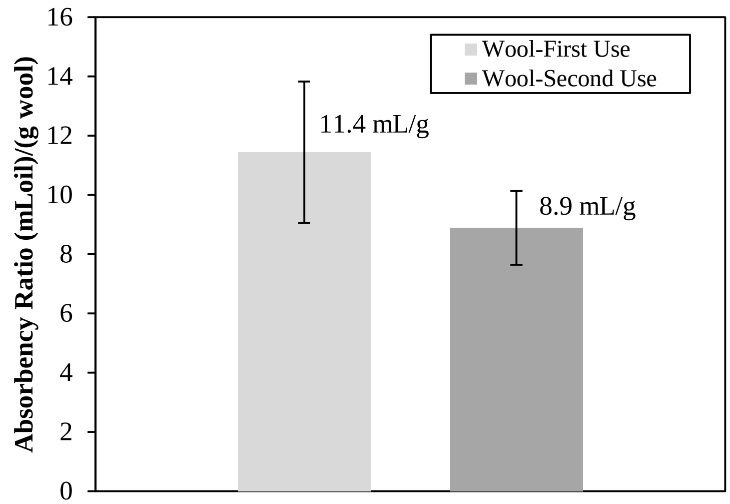

Figure 9: Absorbency ratio in milliliter oil per gram wool for loose wool during first and second use. The absorbency of loose wool decreases with continued use.

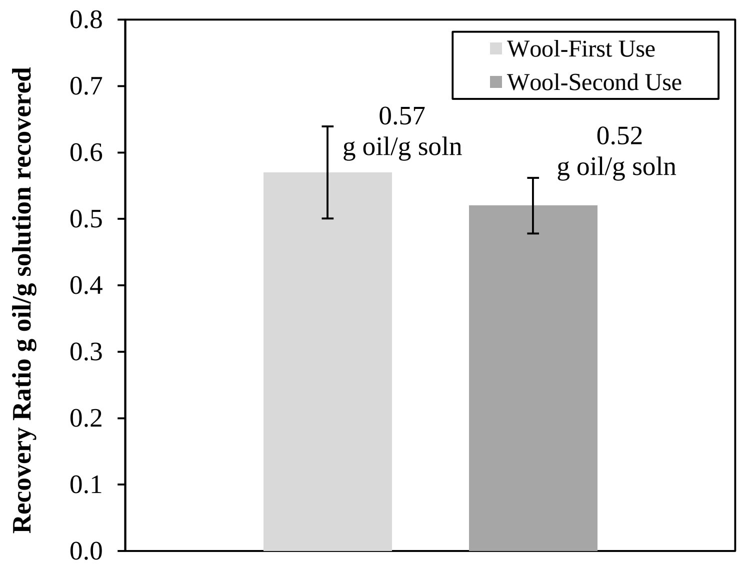

Figure 10: Recovery ratio of loose wool in gram oil recovered per gram solution recovered. The recovery ratio stays relatively constant between first and second use.

Non-woven woolen pads were cut into one inch squares and saturated with crude oil. Two by four inch samples were tested with the roller system and red oil for easier clean-up. **Figure 11** and **Figure 12** show the absorbency ratio and recovery ratio of non-woven wool pads with crude oil and red oil depicted in gray and red, respectively. Red colored data was collected using rollers in **Figure 11** and **Figure 12**. The standard deviation is presented as error bars on both figures.

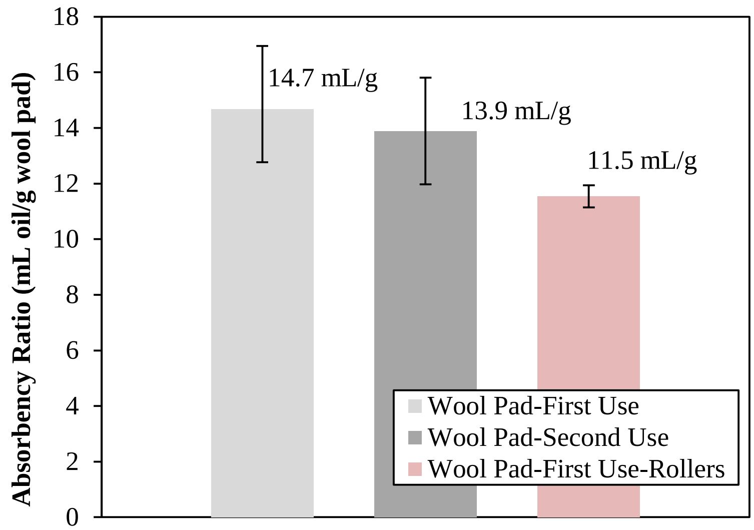

Figure 11: Absorbency Ratio of non-woven wool pad samples with crude oil and red oil. The red oil samples were tested with the roller system.

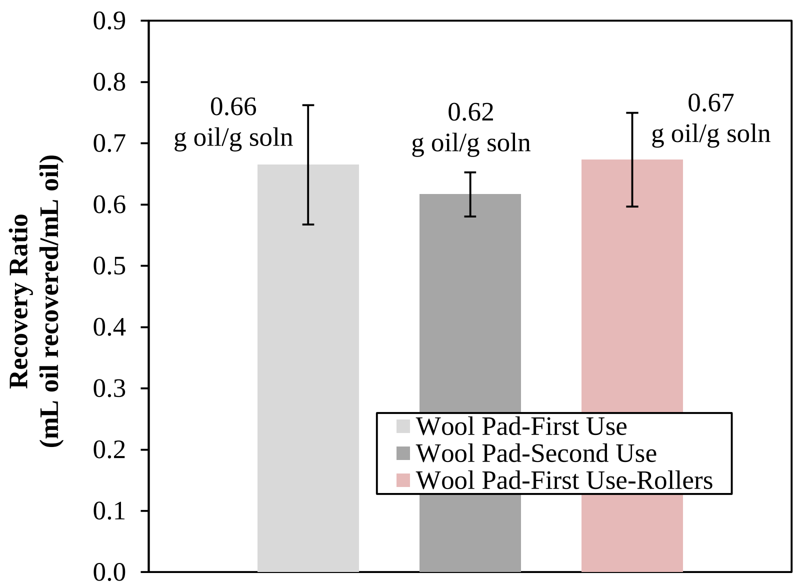

Figure 12: Recovery ratio of non-woven wool pad samples with crude oil and red oil. The red oil samples were tested with the roller system.

The absorbency ratio of other materials was tested with the red oil. Recycled cellulose and oil absorbing polymer do not permit oil recovery and are single-use clean-up methods. The absorbency ratio of these products is lower than that of the loose wool or non-woven wool pad as shown in **Figure 13**. The standard deviation of trials is presented as error bars. The absorbency ratios of all the materials are shown in **Figure 14** with black bars denoting crude oil tests and red bars denoting red oil tests.

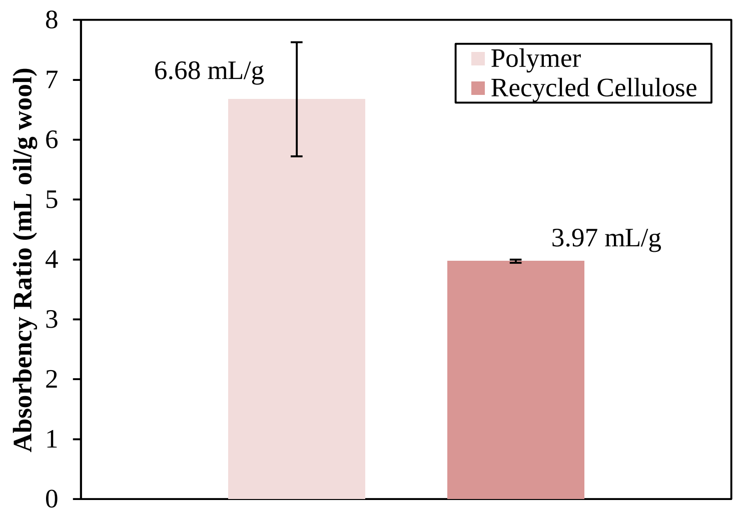

Figure 13: Absorbency Ratio of recycled cellulose and oil adsorbing polymer.

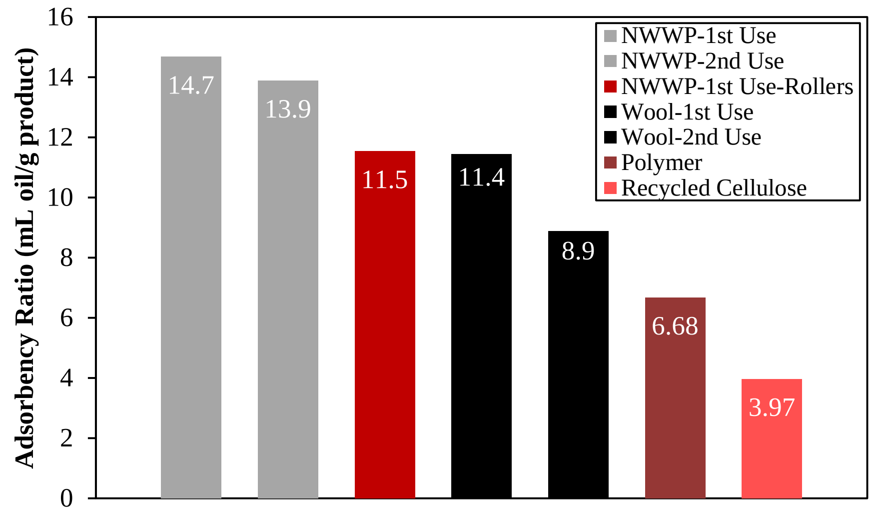

Figure 14: Comparison of all absorbency ratios (mL/g) for adsorbent and absorbent products. Non-woven wool pads are notated as NWWP.

Non-woven wool pads were determined to be the most effective clean-up method due to high absorbency ratio, mid-range recovery ratio, and material properties. The non-woven wool pads were able to retain their shape due to needle punched construction and were easy to work with in the roller tests which simulated potential large-scale oil removal methods.

Chapter 4: Delivery of Educational Modules

Dr. Skip Rochefort is the Executive Director of Oregon State University Precollege Programs and the Director of the Center for Outreach in Science and Engineering for Youth (COSEY). With his guidance, the oil spill outreach lab activity was launched during summer 2010 to teach students and teachers about alternative clean-up techniques. A short presentation was given to show the extensive damage to the gulf coast and to illustrate the reason for the project before each outreach lab. Each outreach program is outlined below.

4.1 Outreach Programs

COSEY is a collaborative academic outreach center that serves the K-12 community in the recruitment and retention of students to science and engineering. An emphasis is placed on underrepresented groups. It is jointly supported by the College of Engineering, College of Science, and OSU Precollege Programs. COSEY staff travel to regional elementary and middle schools to get students excited about science and engineering concepts by taking supplies for small scale lab experiments and demonstrations (COSEY, 2013). The oil spill lab was taught at COSEY camps serving over 200 students during summer of 2010 and continues to be used by teachers and outreach staff. The lab kits are available to be checked out from the COSEY office for local teachers to utilize in their classrooms.

The Summer Experience in Science and Engineering for Youth (SESEY) program is targeted at high school girls and minorities who are traditionally under-represented in science and engineering. Students attend a live-in, week-long camp on the OSU campus. They are assigned group lab projects where they work with college student research assistants and graduate students to collect data for and complete a scientific research poster for the end of the week poster fair (Rochefort, 2013). Four SESEY students experimented with the oil spill clean-up materials and created a research poster, shown in **Figure 15** for display at the poster fair. Part of the students' week-long project was using their imaginations to come up with other materials that may absorb or adsorb oil. Paraffin wax, straw, and household sponges were three of their ideas. Four students participated in this lab, and about 150 people learned of their work through the poster session.

Figure 15: The author with the poster created by high school students during the Summer Experience in Science and Engineering for Youth.

Science & Math Investigative Learning Experiences (SMILE) is a precollege program at Oregon State University, which supports outside-of-school, Science, Technology, Engineering and Mathematics (STEM) programs and teacher professional development. The mission of SMILE and their partners is to inspire and prepare minority, low-income, historically underrepresented, and other educationally underserved students, in mostly rural areas, to graduate from high school, enroll and succeed in higher education, and pursue STEM careers (SMILE, 2013). The oil spill lab was demonstrated to a class of high school teachers from the state of Oregon with the intention that they could do the lab or demonstration in their classrooms. A few of the absorbent materials were shared with them so they could replicate the techniques. Twenty-one teachers were present for the oil spill lab.

STEM Academy is a non-profit, extracurricular, precollege education program hosted by Oregon State University. The program, chartered at OSU since 1986, enlists community professionals to share their facilities, equipment, and expertise through hands-on classes, workshops, and mentorships to extend and augment the science curricula of the school systems (STEM Academy, 2013). Middle School Engineering Camp (E-camp) uses many of the COSEY lab kits during their week of activities. The oil spill lab was taught to 20 middle school students and continues to be used each summer. The lab is listed in Appendix D.

The ExxonMobil Bernard Harris Summer Science Camp is a two-week residential camp hosted at colleges and universities across the nation. Each camp provides promising middle school grade level students the opportunity to enhance their proficiency in STEM education while living on a college campus – all at no cost to the child or family (The Harris Foundation, 2013). Oregon State hosted this camp during the summer of 2010 and 30 middle school students participated in the oil spill lab.

In summer of 2010 OSU hosted an International Baccalaureate (IB) World Student Conference. The theme of the conference came from the IB mission statement, "creating a better and more peaceful world," and focused on six global topics: the fight against poverty, peace-keeping, education for all, global infectious diseases, the digital divide, and natural disaster prevention and mitigation (International Baccalaureate Organization, 2010). The oil spill lab was introduced to more than 300 IB students over the week-long conference and is listed in Appendix E.

The final adaptation of the oil spill lab was for OSU's School of Chemical, Biological and Environmental Engineering (CBEE) freshman introduction class, CBEE 101. This lab was adjusted to be quantitative and included a data processing element. Students completed the lab during class time and then organized and presented the class' data in graphical format as an assignment. The lab continues to be used for CBEE 101 and reaches about 200 students each year. It is listed in Appendix F.

4.1 Conference Presentations

To present the work accomplished during the summer of 2010, a research poster was presented at the Subsurface Biosphere Initiative Symposium at Oregon State University to fulfill the requirements of the sponsoring program. Stephanie Silliman returned to Carnegie Mellon University to resume classes and was unable to present the poster at the symposium and thus the author was sent to present in her place. The poster was then submitted to the American Institute of Chemical Engineers (AIChE) Student Conference in Salt Lake City, Utah in October 2010. The poster was entered in the Education Division and won first place. In the spring of 2011, the AIChE regional conference was held at OSU. The poster was entered in the competition and garnered second place overall.

Section II.

Long-Term Remediation Techniques for the Gulf Region Wetlands and Marshes

Chapter 1: Background

Microorganisms were the initial focus of interest for a bioremediation aspect of the project. After much research about microorganism species and characteristics, the complexity of this approach was revealed. Several species of microorganisms are known to degrade hydrocarbons including *Alcanivorax spp*. and *Nocardioides CF8*. *Nocardioides CF8* was obtained from a microbiology lab on the Oregon State University campus and cultured on lysogeny broth (or Luria-Bertani, LB) plates. Once consistent growth was observed, crude oil was added to LB plates to see if the microorganisms would clear spots on the agar.

After little success, attention was focused on mycelium, the supportive plant structure that produces mushroom fruit. Mycelium grows quickly and has simpler testing procedures than microbes. Though mushrooms are commonly thought of as a fungus, mycelium is actually the fungus that produces mushrooms. Mycelium has been shown to degrade short-chain hydrocarbons like diesel fuel in tests performed in the Puget Sound area (Stamets, 2005). Crude oil is a mixture of heavy and light hydrocarbons, therefore introducing the vegetative structure of mushrooms to crude oil would test their ability to break down heavier, or longer-chain, components. The oyster mushroom, *Pleurotus ostreatus*, is classified as a white rot fungus, leaving a white residue on degraded substrates. Mushrooms can also be classified as brown rot fungus, but this is less common. Oyster mushrooms primarily grow on woody substrates including wood chips, logs, stumps and snags, but can also be cultivated on cereal straws.

White rot fungi have been especially successful in bioremediation projects due to enzymes secreted by the mycelium. Lignin peroxidase, manganese peroxidase, and laccases are efficient at breaking down woody substrates. Wood contains cellulose, hemicellulose, and lignin: compounds that are composed of intricate carbon and hydrogen bonds. The enzymes released by the mushroom mycelium break carbon and hydrogen bonds which effectively break down the woody substrate. Manganese peroxidase mineralizes wood and is a main contributor to the decomposition process (Stamets, 2005). These enzymes are the key to crude oil decomposition.

Petroleum products are also made of long-chain hydrocarbon molecules, mirroring the composition of woody (cellulosic) substrates. Because of this, mycelium can effectively break down the carbon and hydrogen bonds found in petroleum products to create smaller reaction products that can be processed in an ecosystem. Oyster mushrooms have been proven to degrade benzopyrenes, dimethyl methyl phosphonates, dioxins, polycyclic aromatic hydrocarbons, polychlorinated biphenyls and trinitrotoluene many of which are found in petroleum products (Stamets, 2005).

Chapter 2: Myco-remediation Methods

In order to understand the cultivation of sawdust mycelium cultures, *Growing Gourmet and Medicinal Mushrooms* and *The Mushroom Cultivator* both written by Paul Stamets were obtained. These books, along with articles and interviews about Paul Stamets, provided the knowledge to successfully cultivate oyster mushrooms in a lab environment. Stamets is a renowned mycologist from the Puget Sound region in Washington. He has written many books about the medicinal and bioremediation uses of mushrooms including *Mycelium Running*. These three texts proved very useful for the instruction of mushroom cultivation and mycological information. His previous work with Battelle Labs provided a starting point for the research performed for this project.

2.1 Oyster Mushroom Mycelium Growing Cycle

First, mushroom mycelium was obtained. Fungi Perfecti, owned and operated by Stamets, was the online retailer utilized. Sawdust spawn was ordered because oyster mushrooms are easy to grow and have already been proven to degrade hydrocarbons. Oyster mushrooms are commonly recommended for home-growing kits for first time mushroom cultivators. Sawdust spawn arrived as a bag of mycelium growing on a sawdust substrate. The bag of sawdust spawn was able to inoculate about 20 gallons of substrate. Mushrooms can be grown at home, but several requirements are necessary. This experimentation took place in a lab environment. First, a clean, sterile substrate appropriate for the mushroom variety was necessary. Oyster mushrooms grow well on cereal straw or wood substrates including alder, cottonwood, and maple. Wheat straw was chosen due to its availability and ease of use. Growing containers were obtained next. Large, shallow, under-bed storage containers were used. These tubs measure 34 ¾” x 16 ½” x 6” and were easy to access for frequent care. A spray bottle was also necessary to provide frequent hydration.

Ideal mushroom straw substrate is between one and four inches in length. To achieve this, the wheat straw was chopped. The substrate that was obtained was not sterile and had to be decontaminated to eliminate competing bacteria and fungi. The typical pasteurization method uses a hot water bath or a live steam process. Resources prevented this method so a 0.7% bleach solution was used to soak the chopped straw for 4 to 5 hours, which is within the recommended 4 to 12 hours (Stamets, 2000). After removing the straw from the bleach solution and removing as much of the excess water from the material as possible, the straw was placed in the sterile growing tubs. The mushroom spawn was spread generously on top and gently mixed in with gloved hands.

Mycelium requires a humid environment, typically 80 to 100% in order to flourish and produce mushrooms. The first part of the cycle is the spawn run. The necessary conditions to let oyster mushroom mycelium establish on the growing substrate include total darkness, minimum air exchange, 78 to 84°F, and 90 to 100% humidity. The spawn run takes 10 to 14 days. After the spawn run, the mycelium begins to form pinheads (mushroom buds). The conditions for pinhead initiation are slightly different and are stimulated in nature by changes in weather or seasons. The humidity should be kept around 95%, but the temperature should be lowered between 55 and 60°F. Air exchange is also important to keep carbon dioxide levels low. The mushroom mycelium should be provided with light for about 12 hours per day. This step takes 7 to 14 days. When the pinheads have established themselves, the cropping, or mushroom production, portion of the cycle begins. The humidity should be lowered to 82 to 92% and the temperature raised between 60 and 64°F. Light should be provided for 12 hours per day and carbon dioxide levels should be kept low. The mycelium can stay in this period of the cycle for 5 to 7 weeks. Each flush of mushrooms can be gathered about every 10 days (Stamets & Chilton, 1983). Each mushroom variety has its own growing conditions which can be found from numerous reference sources. Several techniques were used to replicate the conditions suitable for oyster mushrooms.

At first, plastic sheeting was stretched over the tops of the mushroom tubs and small slits were cut in the top to allow limited air exchange. This helped keep the humidity inside the mushroom tubs high. **Figure 16 (a)** shows the plastic sheeting over the tubs before slits were cut. A spray bottle was used to spray de-ionized (DI) water into the slits in the plastic sheeting twice daily. After the spawn run period, a mini greenhouse frame (**Figure 16 (b)**) was built to cover the tubs and keep the humidity high. This frame allowed for hourly air exchange which kept the carbon dioxide levels at a reasonable level. The DI water spray was increased to 4 times daily to stimulate pinhead formation. The mushrooms were grown without an environmental chamber, so a change in seasons was not practical to stimulate pinhead formation.

Figure 16 (a) and (b): (a) Plastic sheeting was placed over the inoculated tubs and taped down. (b) The greenhouse frame built for easy watering access.

The room where the mushrooms were grown was also modified to aid in keeping humidity high. Fresh air vents were covered and the door was kept shut with the lights off. This helped attain the growing conditions for mushroom fruiting. Due to the location of the growing area, a heating pad designed for planting beds was placed under the tubs to bring the substrate to the appropriate temperature for the different cycles.

2.2 Myco-remediation Methods

Once the mycelium established itself on the substrate and starting forming mushrooms, Petri dish sized crude oil tests were created. An ocean or wetlands like environment was created by filling each Petri dish halfway with DI water. Crude oil was added to the Petri dishes in light (0.25 mL), medium (0.375 mL) and heavy (0.5 mL) applications. Each Petri dish received 2 g of mycelium and substrate. The dishes were kept covered and in the same environment as the mushroom mycelium growing tubs.

For the larger scale crude oil tests, artificial seawater was made using the recipe titled *Preparation of artificial seawater* given in Appendix G (Kester, Duedall, Connors, & Pytkowicz, 1967). Conditions similar to those found in the gulf were approximated because mycelium bioremediation was designed to take place in the Gulf of Mexico. Gulf seawater has 35% salinity, so a recipe included in the aforementioned journal article was used (Appendix A). Each 9.5 quart tub contained 1 L of artificial seawater, either 0.1%, 0.5% or 1% crude oil and 190 g of mushroom mycelium and substrate. These tubs were placed in the same location as the initial mycelium tubs and watered and aired on the same schedule as described above. One set of tubs was started every 2 weeks until 3 sets were created in total. This allowed for differences in growth to be observed.

To measure conditions in the growing room, temperature and relative humidity Vernier Software & Technology, LLC probes were used. The temperature probes were used to measure the temperature in two locations in the mycelium growing bin. One was placed in the top inch of the substrate and the other was placed near the bottom of the tub. These measured the temperature difference which aided in determining if the heating pad was helping keep the substrate at the proper temperature. The relative humidity probe was first used inside the greenhouse tent, but malfunctioned due to collection of water vapor on the probe and was then moved outside the tent. This measured the relative humidity in the room where the mushrooms were grown. After covering the vents in the room, the relative humidity increased to an average of 58% but was still lower than the desired level. Adding the greenhouse tent increased the relative humidity of the air surrounding the tubs very close to the desired level.

2.3 Experimental Results

About six weeks after putting the Petri dishes together, the plate with the medium application of crude oil showed small mushroom growth as shown in **Figure 17 (a) and (b)**. Though this does not prove long-chain hydrocarbon degradation, mycelium that produces mushroom fruit indicates that enough nutrients are present for the organism to flourish. The three sets of oily tubs did not show as much promise. Though a regimented watering and airing schedule was followed, the tubs never produced any mushroom fruit. This does not necessarily prove that mycelium was unable to flourish, but could indicate that mycelium was affected by other influences such as salt water, different crude oil percentages, watering, or light changes. The initial mycelium cultivation tubs with no crude oil added produced many mushrooms, though many were misshapen due to high carbon dioxide levels, low light levels, and less than ideal humidity conditions. Creating an artificial growing environment proved difficult due to the changing conditions required for mushroom production and limited resources for optimal greenhouse set-up. Once the room was adjusted to one set of growing conditions, it seemed that the mycelium was ready to proceed to the next step in the growing cycle.

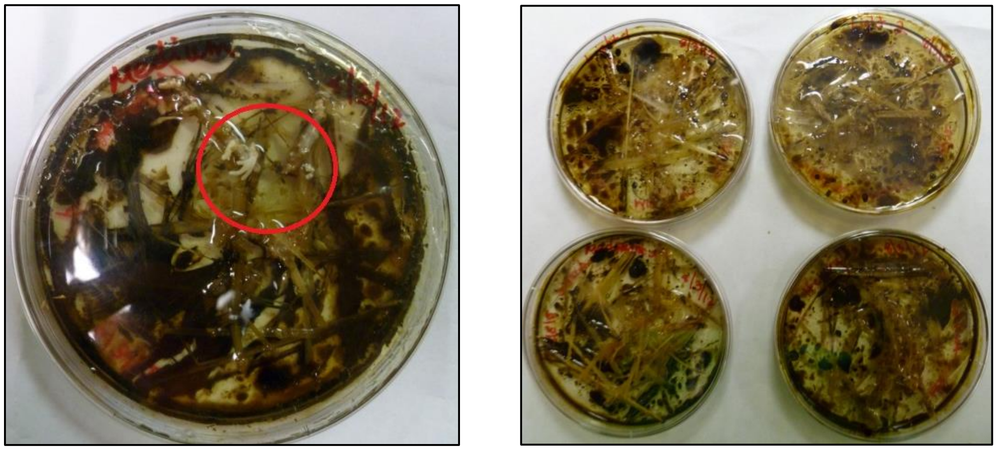

Figure 17 (a) and (b): (a) Medium oil application showing small mushroom growth after 8 weeks in red circle (b) Light, medium (2), and heavy oil application in petri dishes with mushroom mycelium.

Section III.
Conclusions

Adsorbent materials were determined to be the most effective at surface oil clean-up. The non-woven woolen pads had the highest absorbency ratio at 14.7 mL/g with loose wool at 11.5 mL/g. These materials proved to be the most applicable for an oil spill because the wool products can be re-used after oil is recovered from the product. The recycled cellulose and oil absorbing polymer are not sustainable choices because they do not release oil after absorption.

The mushroom part of this project yielded limited results. The Petri dishes with DI water grew small mushrooms, but the degradation of oil was not analyzed.

The educational models continue to be used at a variety of outreach events and are included as a lab for the CBEE 101 freshman intro class. These models introduce an environmental component of engineering that is applicable to the general population.

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APPENDICES

Appendix A: Petri Dish Procedure

ENGINEERING DESIGN: Deepwater Horizon Blowout Cleanup: Oil Absorbing Materials

Skip Rochefort and Audrey Oldenkamp
School of Chemical, Biological, and Environmental Engineering

Petri Dish Procedure

Materials

In order to complete this investigation you will need the following supplies for each group:

1-5 mL syringe
Crude Oil (approx. 5 mL/sample)
Petri dishes (4 for each sample, plus one extra for the simulated spill)
Tap Water
Gloves
Large Forceps
3 small trash bags (for all crude oil soaked waste)
3-1 g bunches of Wool (Weigh and record actual mass)
or
5-1" squares of Non-Woven Wool Pad (Weigh and record actual mass)

OIL SPILL CLEANUP EXPERIMENT:

(Non-woven wool pads will be used in the procedure)

1. Cut out 5-1"x1" squares of non-woven wool padding.
2. Label 5 Petri dish halves with lab tape. (ie. #1 Crude, Wool Pad/#2 Crude, Wool Pad)
3. Label 5 more Petri dish halves with lab for the recovery process. (ie. #1 Recovery Crude, Wool Pad)
4. Use a balance to find the mass of each of the Petri dish halves. Record in data table under "Mass of Petri Dish." (See below) Place one of the small trash bags in the hood for waste materials.
5. Fill the bottom of a Petri dish halfway with tap water.
6. Add 5 mL of Crude oil to the water in the Petri dish with the syringe. (Now in the hood)
7. Place the first sample in the simulated oil spill.
8. Use the forceps to turn the sample over to adsorb more oil.
9. Remove the sample and place it in the #1 Crude, Wool Pad Petri dish. Set aside and repeat steps 6-9 for the other four samples. (Remove gloves after all 5 samples are saturated-place in crude oil trash bag)
10. Use a balance to measure the mass of the saturated samples. Record in the "Mass Post Soak" row.

11. Use MS Excel to subtract the "Mass of the Petri dish" from the "Mass post soak." Record in "Mass Oil and Water Absorbed."
12. Then calculate the absorbency ratio by dividing the "Mass Oil and Water Absorbed" by "Mass of Material."

Recovery:

1. Place the recovery Petri dishes next to their corresponding samples. Put new gloves on, this gets messy!
2. Take sample one and squeeze out as much oil as possible into the #1 Recovery Petri Dish (or corresponding number). Set aside. Wipe gloves off with paper towels and discard in the crude oil trash bag.
3. Repeat step 2 (recovery section) for each of the remaining four samples. Remove gloves and discard in crude oil trash bag)
4. Use a balance to find the mass of each of the five samples. Record in the "Mass of Oil, Water, and Petri Dish Recovery" row in the data table.
5. Use MS Excel to subtract "Mass of Recovery Petri Dish" from the "Mass of Oil, Water and Petri Dish Recovery. Record in "Mass Oil and Water Recovered."
6. Calculate the Recovery Ratio by dividing "Mass Oil and Water Absorbed" by "Mass Oil and Water Recovered."
7. Now the experiment can be repeated using the same samples for a second run. This will give more data and show a possibility for a second use.
8. Triple bag the crude oil trash and take it to the nearest hazardous waste receptacle. (In Gleeson Hall this is located in the basement by the loading ramp double doors. There are two red bins that collect the hazardous waste for the building)
9. Repeat the procedure for other materials.

Data Table: (Normally in MS Excel)

	#1	#2	#3	#4	#5	Average	Standard Deviation
Mass of material (g)							
Oil added for each trial (mL)							
Mass Post Soak (g)							
Mass of Petri Dish (g)							
Mass Oil and Water Absorbed (g)							
Mass of Recovery Petri Dish (g)							
Mass Oil, Water and Petri Dish Recovered (g)							
Mass Oil and Water Recovered (g)							
Absorbency Ratio of Oil and Water =(Mass oil and water absorbed)/(Mass of material)/Oil Density							
Recovery Ratio=(Mass oil and water recovered)/(Mass Oil and Water Absorbed)							

Appendix B: Oil Spill Clean-Up Information

Oil Spill Clean Up Information and Background

Summer 2010

On April 20, 2010 the Deepwater Horizon oil drill column exploded. Since then, approximately 210,000 gallons of oil a day have been released into the Gulf of Mexico. The blowout is at a depth of one mile below the surface of the ocean. Most of the oil rises to the surface of the ocean due to density differences, but some oil gets trapped in underwater currents and travels throughout the ocean. The surface cleanup is what we are looking into. There are several methods for cleaning up oil that have proved effective. We have tested recycled cellulose (tree fiber), loose Oregon-grown wool, oil absorbing polymer, and woven wool material. These four products are the most effective at cleaning up surface oil. Today we will be testing these materials to show how well they pick up oil and how much can be recovered after it is adsorbed.

Cellulose (LITE-DRI® Oil-Only Loose Absorbent): (New Pig, 2013)

-http://www.newpig.com/
-Made of recycled cellulose — begins to absorb the moment it touches liquid
-Repels water while absorbing only oil-based liquids
-Ideal for use in machine shops, automotive shops, spill kits, and fluid storage areas
-Works well, but is much harder to recover oil

Oil Absorbing Polymer: (Spangler, 2013)

-http://www.stevespanglerscience.com/product/1265
-A small amount of polymer bonds with the layer of oil forming a sponge-like material
-This can be easily removed from the surface of water
-Specially formulated to bond quickly and safely to many types of liquid hydrocarbons including crude oil, diesel fuel and gasoline (Hydrophobic)

Wool:

-Oregon wool is not typically used in textile production because of its coarseness
-This means farmers have excess that cannot be sold for a profit
-Wool is a naturally oil absorbent material that can absorb approx. 8-10 times its weight in oil showing a clear option for the gulf clean-up

Needle Punched Wool Pad: (NW Woolen Mills, 2013)

-http://www.northwestwoolen.com/Disaster.aspx
-100% recycled wool blended fiber, made in the USA.
-Each pad is 36" x 36" and absorbs approx. 2.5 gallons of oil.

Other oil clean-up options:
Wikipedia Information on the Deepwater Horizon Oil Spill:
http://en.wikipedia.org/wiki/Deepwater_Horizon_oil_spill

Use of bacteria to clean up oil: (redOrbit, 2010)
http://www.redorbit.com/news/science/1878637/bacteria_strain_could_aid_in_oil_spill_cleanup/

Use of mushrooms to clean up oil: (Miller & Discover Magazine, 2013)
http://discovermagazine.com/2013/julyaug/13-mushrooms-clean-up-oil-spills-nuclear-meltdowns-and-human-health

Appendix C: Roller Procedure

ENGINEERING DESIGN: Deepwater Horizon Blowout Cleanup: Oil Absorbing Materials

Skip Rochefort and Audrey Oldenkamp
School of Chemical, Biological, and Environmental Engineering

Roller Style Procedure

Materials

In order to complete this investigation you will need the following supplies:

1-10 mL syringe
Crude Oil (approx. 35 mL/sample) or Red Oil
Bottom of a pipette tip box
1000 mL beaker
Tap Water
Gloves
3 small trash bags (for all crude oil soaked waste)
3- 2"x4" samples of non-woven wool pad (weigh and record actual mass)
Two Roller system for recovering oil
100 mL graduated cylinder
50 mL graduated cylinder

OIL SPILL CLEANUP EXPERIMENT:

1. Cut out 3- 2"x4" rectangles of non-woven wool padding. Use a balance to find the mass and record in the data table.
2. Use a balance to find the mass of the collection container (the bottom of the pipette tip box). Record in data table under "Mass of Collection Container." (See below) Place one of the small trash bags nearby for waste materials.
3. Fill the 1000 mL beaker halfway with tap water.
4. Add 30 mL of oil to the surface of the water with the syringe.
5. Place the first sample in the simulated oil spill.
6. Swirl the sample to pick up more oil. Pick the sample up and see if any oil immediately drips from it. If it does, continue to the next step, otherwise add oil in 1 mL increments until the sample drips oil. This indicates that the sample is saturated.
7. Remove the sample and place it in the collection container. Remove gloves, then use a balance to find the mass of the sample. Record under "Mass Post Soak."
8. Use MS Excel to subtract the "Mass of the Petri dish" from the "Mass post soak." Record in "Mass Oil and Water Absorbed."
9. Then calculate the absorbency ratio by dividing the "Mass Oil and Water Absorbed" by "Mass of Material."

Recovery:

10. Place the collection container under the rollers, positioning it so that the oil will flow into it from the rollers.
11. Position the sample and run it through the rollers. You may have to turn both rollers to make this work. The material is pretty thick. Press down hard on the top roller to get as much oil as possible out.
12. Run the sample several times until as much oil as possible has been removed. Run it both lengthwise and sideways. Some oil will collect between the rollers so use the sample to collect it. Then squeeze that collected out oil into the container.
13. Use a balance to find the mass of the collected oil and water in the container. Record in the data table under "Mass Oil and Water Recovered." (The mass of the recovery container is the same as the collection container from above)
14. Use MS Excel to subtract "Mass of Recovery Collection Container" from the "Mass of Oil, Water and Collection Container Recovered." Record in "Mass Oil and Water Recovered."
15. Calculate the Recovery Ratio by Mass by dividing "Mass Oil and Water Absorbed" by "Mass Oil and Water Recovered."
16. Now use a syringe to transfer the recovered oil to the 50 mL graduated cylinder. The oil and water will separate and you will be able to find how much oil and water was recovered. From there, record the needed data in the data table.
17. Calculate the "Absorbency Ratio by Volume" by dividing "Volume oil added" by "Mass of sample."
18. Calculate the "Recovery Ratio by Volume" by dividing "Volume Oil Recovered" by "Volume Oil Added."
19. Repeat steps 4-18 for the other two samples. Reuse the recovered oil for the second sample. Excess oil and water can be collected in the 100 mL graduated cylinder for re-use.
20. Triple bag the crude oil trash and take it to the nearest hazardous waste receptacle. (In Gleeson Hall this is located in the basement by the loading ramp double doors. There are two red bins that collect the hazardous waste for the building)

Data Table: (Normally in MS Excel)

	#1	#2	#3	#4	#5	Average	Standard Deviation
Mass of material (g)							
Oil added to saturation (mL)							
Mass Post Soak (g)							
Mass of Collection Container (g)							
Mass Oil and Water Absorbed (g)							
Mass of Recovery Container (g)							
Mass Oil, Water and Collection Container Recovered (g)							
Mass Oil and Water Recovered (g)							
Volume Oil and Water Recovered (mL)							
Volume Oil Recovered (mL)							
Volume Water Recovered (mL)							
Absorbency Ratio of Oil and Water =(Mass oil and water absorbed)/(Mass of material)							
Recovery Ratio=(Mass oil and water recovered)/(Mass Oil and Water Absorbed)							
Volume based Absorbency Ratio=(Volume Oil added)/(Mass of sample)							
Volume based Recovery Ratio= (Volume Oil Recovered)/(Volume Oil Added)							

Appendix D: Ecamp Experiment

ENGINEERING DESIGN: Deepwater Horizon Blowout Cleanup: Oil Absorbing Materials

Dr. Skip Rochefort, Stephanie Silliman, and Audrey Oldenkamp
Chemical Engineering Department
Oregon State University, Ecamp

Background

On April 20, 2010 the Deepwater Horizon oil drill column exploded. Since then, approximately 210,000 gallons of oil a day have been released into the Gulf of Mexico. The blowout is at a depth of one mile below the surface of the ocean. Most of the oil rises to the surface of the ocean due to density differences, but some oil gets trapped in underwater currents and travels throughout the ocean. The surface cleanup is what we are looking into with this experiment.

Objective

Our goal is to simulate a surface oil spill and test different oil absorbing materials for their effectiveness of oil cleanup as well as oil recovery. A variety of both natural and manmade materials will be tested and a conclusion as to which oil cleanup method would best serve the Deepwater Horizon blowout will be drawn.

Materials

In order to complete this investigation you will need the following supplies for each group:

1 Petri Dish
1-5 mL syringe
Marvel Mystery Oil (Approximately 200 mL)
0.5 g of Wool (use scale to measure mass)
0.5 g of Oil Absorbing polymer (use scale to measure mass)
0.5 g of Recycled Cellulose Material (use scale to measure mass)
Tap water
3 ziplock bags

OIL SPILL CLEANUP EXPERIMENT

1. Examine your three oil cleanup materials. What do you notice about each one? What are their relative densities to one another? Are any of the materials similar? Record observations.
2. Weigh out approximately 0.5 g of wool into a Petri dish and record the exact mass.
3. Fill the bottom of the Petri dish halfway with tap water.
4. Using a syringe, add 3 mL of marvel mystery oil to the surface of the water.

5. Add 0.5 g of wool to the oil and water and swirl it around.
6. Remove oil soaked wool, using a balance record its mass.
7. Calculate the weight of oil and water that was absorbed by your wool.
   Calculate the Absorbency Ratio (AR) = mL oil/g wool
8. Repeat steps 2-4 using oil with 1 g oil absorbing polymer.
   Calculate AR = mL oil/g oil absorbing polymer.
9. Repeat steps 2-4 using oil with 1 g recycled cellulose material.
   Calculate AR = mL oil/g recycled cellulose material.

Appendix E: IB World Conference Experiment

ENGINEERING DESIGN: Deepwater Horizon Blowout Cleanup: Oil Absorbing Materials

Dr. Skip Rochefort, Stephanie Silliman and Audrey Oldenkamp
School of Chemical, Biological, and Environmental Engineering
Oregon State University, IB World Conference

Background

On April 20, 2010 the Deepwater Horizon oil drill column exploded. Since then, approximately 210,000 gallons of oil a day have been released into the Gulf of Mexico. The blowout is at a depth of one mile below the surface of the ocean. Most of the oil rises to the surface of the ocean due to density differences, but some oil gets trapped in underwater currents and travels throughout the ocean. The surface cleanup is what we are looking into with this experiment. We are also concerned about the amount of recovery with different materials.

Objective

Our goal is to simulate a surface oil spill and test different oil absorbing materials for their effectiveness of oil cleanup as well as oil recovery. A variety of both natural and manmade materials will be tested and a conclusion as to which oil cleanup method would best serve the Deepwater Horizon blowout will be drawn. Recovery of oil from each material will also be tested to see which material is the most effective in clean-up and recovery.

Materials

In order to complete this investigation you will need the following supplies for each group:

- 4-8 oz cups
- 1 paper towel (one quarter torn out)
- 1-5 mL syringe
- Marvel Mystery Oil (Approximately 15mL)
- Small amount of Wool (about the size of a quarter)
- Small amount of Oil Absorbing polymer (about the size of a quarter)
- Small amount of Recycled Cellulose Material (about the size of a quarter)
- 1 square of needle punched wool material
- Tap water
- 4 ziplock bags
- 1 pair of gloves per person

OIL SPILL CLEANUP EXPERIMENT

1. Examine the four oil cleanup materials. What do you notice about each one? What are their relative densities to one another? Are any of the materials similar? Record your observations.
2. Fill the bottom of the plastic cup halfway with tap water.
3. Using a syringe, add 3 mL of marvel mystery oil to the surface of the water.
4. Add a small amount of wool to the oil and water and swirl it around using your finger. Record observations.
5. Remove oil soaked wool and place in a plastic bag.
6. Repeat steps 2-5 using oil with small amount of oil absorbing polymer.
7. Repeat steps 2-5 using oil with small amount of recycled cellulose material.
8. Repeat steps 2-5 using oil with 1 square of needle punched wool material.

Extra Credit: Move the wool or other oil absorbing material to the top of the sealed plastic bag. Squeeze the wool to let the oil drain to the bottom of the bag. Observe results.

Appendix F: CBEE 101 Class Lab and Assignment

ENGINEERING DESIGN: Deepwater Horizon Blowout Cleanup: Oil Absorbing Materials

Dr. Skip Rochefort, Stephanie Silliman, and Audrey Oldenkamp
School of Chemical, Biological, and Environmental Engineering
Oregon State University

CBEE 101 Class Lab and Assignment

Background

On April 20, 2010 the deepwater horizon oil drill column exploded. Since then, approximately 210,000 gallons of oil a day have been released into the Gulf of Mexico for a total of ***210 million gallons of oil***. The blowout is at a depth of one mile below the surface of the ocean. Most of the oil rises to the surface of the ocean due to density differences, but some oil gets trapped in underwater currents and travels throughout the ocean. The surface cleanup is what we are looking into with this experiment.

Vocabulary

Absorption:
Adsorption:
Hydrophobic:
Polymer:
Dispersant:
Absorbency Ratio:
MSDS:

Experiment Objective

Our goal is to ***simulate a surface oil spill*** and test different oil absorbing materials for their effectiveness in **oil removal** and **oil recovery**. A variety of both natural and manmade materials will be tested and a conclusion as to which oil cleanup method would best serve the *Deepwater Horizon* blowout will be drawn.

MATERIALS

In order to complete this investigation you will need the following supplies for each group:

Marvel Mystery Red Oil -approximately 25mL
Tap water
4 plastic Petri dishes (2 tops and 2 bottoms)
1-10 mL syringe
1 plastic fork (to probe and remove materials)
1 pair of gloves per person
Paper towels to clean up spills

Absorbant Materials

- **Wool (raw sheep fleece)**
- **Non-woven Wool Pad**
- **Oil Absorbing Polymer**
- **Recycled Cellulose Material**
- **BOOM (nylon stocking) with wool (raw fleece) filling**

OIL SPILL CLEANUP EXPERIMENT

NOTE: Wear GLOVES for these experiments!

1. Examine the four oil cleanup materials. What do you notice about each one? What are their relative densities to one another? Are any of the materials similar? Record your observations.

2. Fill a Petri dish bottom (deeper half) halfway with water and add 3 mL red oil on top.

3. Weigh out approximately 1 g (approx.) of wool (raw sheep fleece) and record the exact mass, place wool on top of oil in the salt water.

4. Note how the wool soaks up the oil. Slowly stir the wool with a fork. Allow 30-60 sec. for the wool to absorb the oil. Remove the wool, add more oil, replace the wool and continue this process until it appears to be "saturated". When the wool no longer absorbs the oil, the oil will begin to float on the surface of the water. **This is a subjective determination, so have the group agree when the experiment is complete!**

5. **Oil Recovery.** Pick-up wool (**wear gloves!**) and squeeze it out oil into a Petri dish. Measure using a syringe.

6. Record the volume of oil that was absorbed by your wool (raw fleece) and the amount recovered.
   Calculate the Absorbency Ratio (AR) = mL oil/g wool
   Calculate percent oil recovered = (mL oil recovered/mL oil absorbed) * 100%

7. Repeat steps 2-4 using oil with **1.0 g (approx) non-woven wool blanke**t.
   Calculate AR = mL oil/g oil absorbing polymer.
   Calculate percent oil recovered = (mL oil recovered/mL oil absorbed) * 100%

8. Repeat steps 2-4 using oil with **2 g recycled cellulose** material (use Petri dish top – shallow).
   Calculate AR = mL oil/g recycled cellulose material.
   Calculate percent oil recovered = (mL oil recovered/mL oil absorbed) * 100%

9. Repeat steps 2-4 using oil with **0.25 g (approx.) oil absorbing polymer** (use Petri dish top – shallow).
   Calculate AR = mL oil/g oil absorbing polymer.
   Calculate percent oil recovered = (mL oil recovered/mL oil absorbed) * 100%

10. Repeat steps 2-4 using oil with a **boom material** (1g raw wool in a nylon stocking).
    Calculate AR = mL oil/g recycled cellulose material.
    Calculate percent oil recovered = (mL oil recovered/mL oil absorbed) * 100%

11. **Record your DATA for all absorbent materials tested on the data sheet provided**. This data will be later shared with the class for an analysis of the average absorbency ratio (AR) and experimental error (standard deviation).

ENGINEERING DESIGN: Deepwater Horizon Blowout Cleanup: Oil Absorbing Materials
Lab Worksheet

Group Members____

LAB Session   T1100   T1300   W1100   W 1300   W1500(HC)   Th1100   Th1300

Data Table

Material	**Weight of Material**	**mL of Oil Absorbed**	**Absorbency Ratio (mL oil/g material)**	**% Oil Recovery**	**Observations**
Polymer (SAP)					
Cellulose (Regenerated)					
Wool (Raw Sheep Fleece)					
Wool (non-woven blanket)					
Boom (with raw wool)					

Brainstorming – Group Design Process
How would your group engineer an oil spill clean-up method in the gulf? How would you get your material to the polluted waters? How would you remove the material? What would you do with the waste products? Use the space below **(and back of sheet)** to address these issues. **DRAW a SKETCH of your process.**

CBEE 101 First Year Experience Fall 2013

Oil Spill Clean-Up Technology Laboratory Report

1) Analysis of Absorbency Ratio (AR) of Oil Spill Clean-up Technologies
There is an Excel file on Blackboard in the Oil Spill Lab Folder that contains lab group AR data (by lab meeting time). Download this file and calculate the **AVERAGE** and **STANDARD DEVIATION** of the **Absorbency ratio (AR)** and **% Oil Recovery** for each of the technologies tested – *polymer, cellulose, wool (fleece), wool blanket, and boom (wool).*
- Lab Session (your lab time only)
- Entire Class

2) Column Chart of AR data for ALL the technologies
a) **Absorbency Ratio (AR) Plot**
Use a COLUMN CHART to show the **average** and **standard deviation** of the **Absorbency Ratio (AR)** for each of the technologies tested on **ONE PLOT**. Use GROUP and CLASS Data.
NOTE: This will give you ONE Plot with TEN (10) columns with *average value* and the *standard deviation* as *error bars (+/-)*

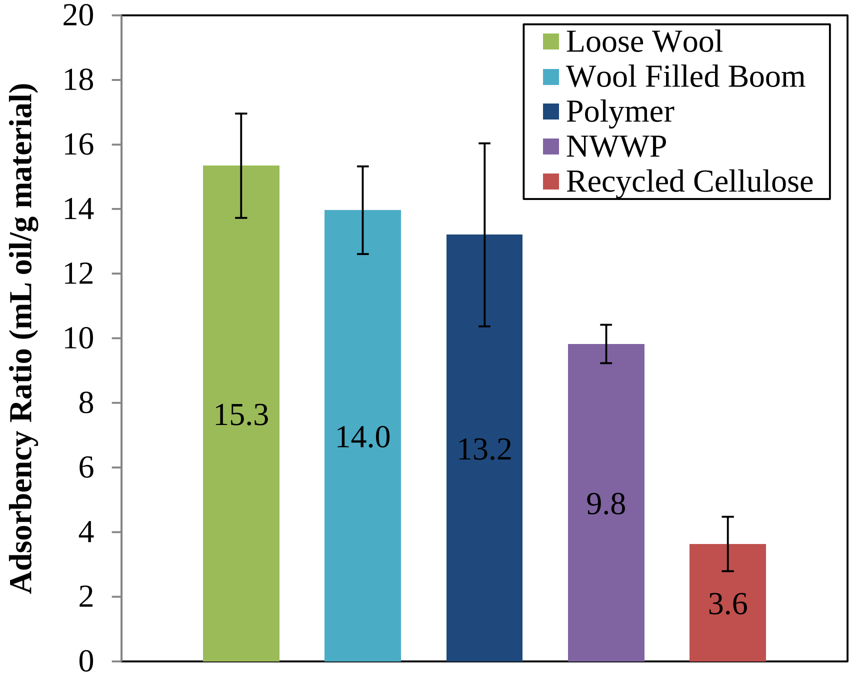
b) **% Oil Recovery Plot**
Use a COLUMN CHART to show the **average** and **standard deviation** of the **% Oil Recovery** for each of the technologies tested on **ONE PLOT**. Use GROUP and CLASS data
NOTE: This will give you ONE Plot with TEN (10) columns with *average value* and the *standard deviation* as *error bars (+/-)*

SUMMARY of Required Documents (Hard Copy)
1) Excel spreadsheet containing only CLASS SUMMARY DATA – ONE SHEET

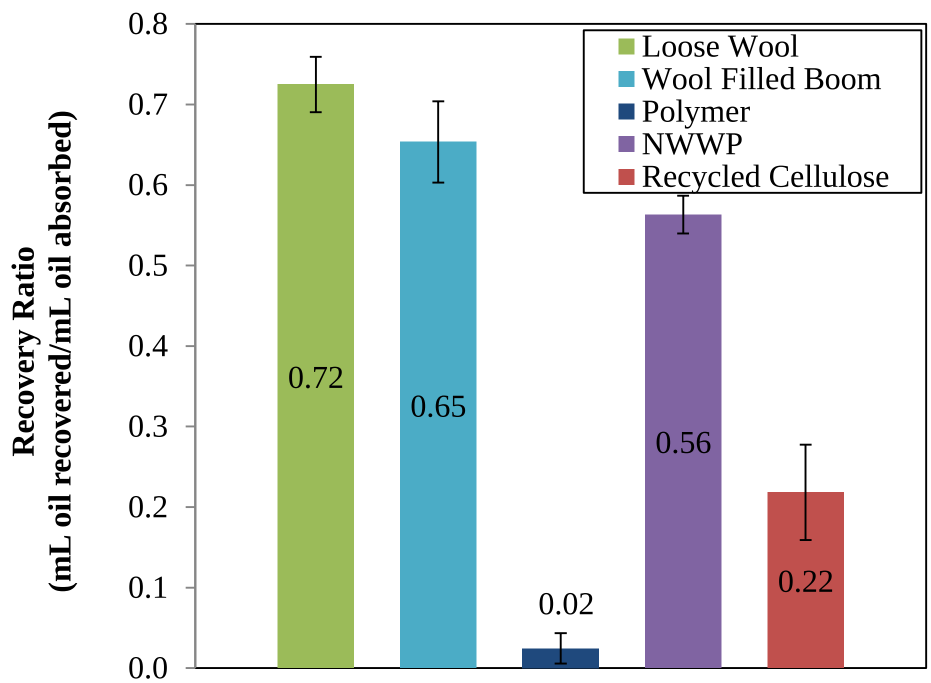
2) Excel Column Plot (ONE) of **average** and **standard deviation** (+/- error bars) for **Absorbency Ratio** for ALL the technologies for your lab group and the entire class (10 columns).

3) Excel Column Plot (ONE) of **average** and **standard deviation** (+/- error bars) for **% Oil Recovery** for ALL the technologies for your lab group and the entire class (10 columns).

CBEE 101 Lab Synthesized Results



(a)



(b)

Figure 18 (a) and (b): Absorbency and Recovery Ratio data from CBEE 101 in 2014.

Appendix G: Artificial Sea Water Recipe

Artificial Sea Water Recipe	
23.926 g	NaCl
4.008 g	Na_2SO_4
0.677 g	KCl
0.192 g	$NaHCO_3$
0.026 g	H_3BO_3
10.33 mL	CaCl solution (1 M $CaCl_2 \bullet 2H_2O$)
53.27 mL	$MgCl_2$ solution (1 M $MgCl_2 \bullet 6H_2O$)
0.09 mL	$SrCl_2$ solution (0.1 M $SrCl_2 \bullet 6H_2O$)
Fill remaining 1 L volumetric flask with DI water	