Exploring Laser-Ablated Mesh for Enhanced Oil-Water Separation: Innovations in Environmental Remediation or Oil Water Separation Using Laser Ablated Copper Mesh

by

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Abstracts

Technical Abstract

This research investigates an innovative approach to oil-water separation using mesh filtration. After creating four distinct samples with varying scanning speeds, we developed a tailored setup employing two syringes to contain the samples, secured with gorilla glue mounting putty and binder clips. Following a preliminary validation test, experiments were conducted utilizing a micropipette to measure the oil and water content in each test tube. The findings reveal that each of our mesh samples exhibits effectiveness in oil-water separation applications. This method shows considerable promise for practical implementation in environmental cleanup and wastewater treatment.

General Abstract

Oil-water separation technologies have proven to be an effective and eco-friendly way to combat oil-water separation problems. This study focuses on the fabrication of copper mesh using laser ablation with different scanning speeds and accessing their effectiveness through a filtration experiment using an olive oil-water mixture. This method involves finding which scanning speed looks to be the most effective for efficient oil-water separation. Although the findings of this experiment contribute to the development of technology for oil-water separation, further research is warranted to explore numerous avenues for future investigation, such as long-term durability.

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1 Introduction

We have begun to have more and more large oil spills all over the world. Additionally, scientists are working to learn more about their environmental impacts and how this will impact our future. Oil spills do damage to wildlife like birds who often get small oil spots on their feathers which impact their normal insulation leading to hypothermia, and as the oil washes up on beaches or in tidal zones, it can poison the organisms that live there [1]. It turns out that oil also poisons many different types of algae eaters and thus allows more algae to grow on many rocky shores even years after oil spills. Although dispersing the oil helps protect birds and beaches, it increases the exposure of fish, crustaceans, mollusks, and other underwater living organisms [1]. Given that we continue to use oil and run the risk of large oil spills with significant environmental impacts, it is essential to create a better way to clean up the spills.

After discovering the potential of laser ablation for creating a textured mesh with enhanced oileophobic properties, researchers aimed to improve its efficacy in oil spill cleanup [2]. This textured surface, engineered through precise laser manipulation, exhibits enhanced repellence towards oil, thereby facilitating more efficient collection and separation processes. Not only would this successfully be able to aid in the cleanup, but having a mesh that we could wash and reuse would create a more eco-friendly solution as well.

While it would be great if this could all be accomplished quickly, my research is small-scale and focuses on both scanning speed and looking at the time at which it takes for the oil to start to leak through the mesh samples. Scanning speed refers to the rate at which a laser scans a surface within a given time and is typically measured in units like m/s or mm/s. The scanning speed during laser ablation significantly influences the amount of material removed from the metal surface, with higher speeds leading to faster material ablation, while lower speeds slow down the process. For my experiment, I focused on 2 different scanning speeds, 80 μm/ms and 40 μm/ms, with 2 different spacings, 10 μm and 20 μm. The measurement I focus on is looking at the microliters of liquid collected over small fractions of time. Our optimal material choice is copper given that it is easy to obtain and is a corrosion-resistant material. Additionally, we cleaned the mesh after each trial using isopropyl alcohol in an ultrasonic bath.

Despite the unlimited options and research that could be done, my experiments do have significant limitations. For instance, I do not account for different temperatures of water or oil. Nor have I tested different types of oil. Another example is the type of water, for example, if we are looking at oil spills in the ocean, we would need to test with salt water vs. tap water. Another large limitation is only looking at four different scanning speeds and thus I won't have a large amount to compare.

The next chapter will look at the necessary background of laser ablation, wettability, and previous experiments that have been explored. Chapter 3 will discuss our laser ablation setup. Chapter 4 will focus on our oil-water separation and our general setup with a fraction collector. Lastly, Chapter 5 will focus on our results and provide an outlook for future work.

2 Background

This section will provide the necessary information to understand the goals and accomplishments of the project. It will cover lasers, laser ablation, oil-water separation, and previous experiments.

2.1 Laser ablation

Laser ablation is a technique that utilizes a high-energy laser beam to deliver energy to a solid surface. In this process, a concentrated laser beam is applied to a solid material, inducing swift heating and vaporization. This results in the removal of material from the surface, generating a plasma plume composed of ions, electrons, atoms, and molecules. Only a few years after the creation of the first laser, Breech and Cross first documented laser ablation at a conference on spectroscopy. Still using a ruby laser, they used it to vaporize and energize atoms from solid surfaces, while the resulting plasma spectrum was utilized for determining the elemental composition of the sample [3].

Upon exposure to the laser beam, the sample becomes illuminated and mass leaves the surface of the sample in the form of electrons, ions, atoms, molecules, clusters, and particles, with each of the processes separated in time and space.

In essence, laser ablation is when a high-intensity laser beam is used to remove material from a solid surface. There are three main processes to be discussed regarding laser ablation: bond breaking and plasma ignition, plasma expansion and cooling, and particle injection and condensation [3]. You can see the processes illustrated clearly in figure 2.1

During the bond breaking and plasma ignition process, the laser beam irradiates the surface of the material thus delivering energy to the atoms or molecules at the surface. This energy absorption leads to the breaking of inter-atomic bonds within the material and therefore causes the material to undergo rapid heating which leads to a transformation into a highly energetic state, a plasma. Plasma ignition refers specifically to the ignition of the plasma expansion [3].

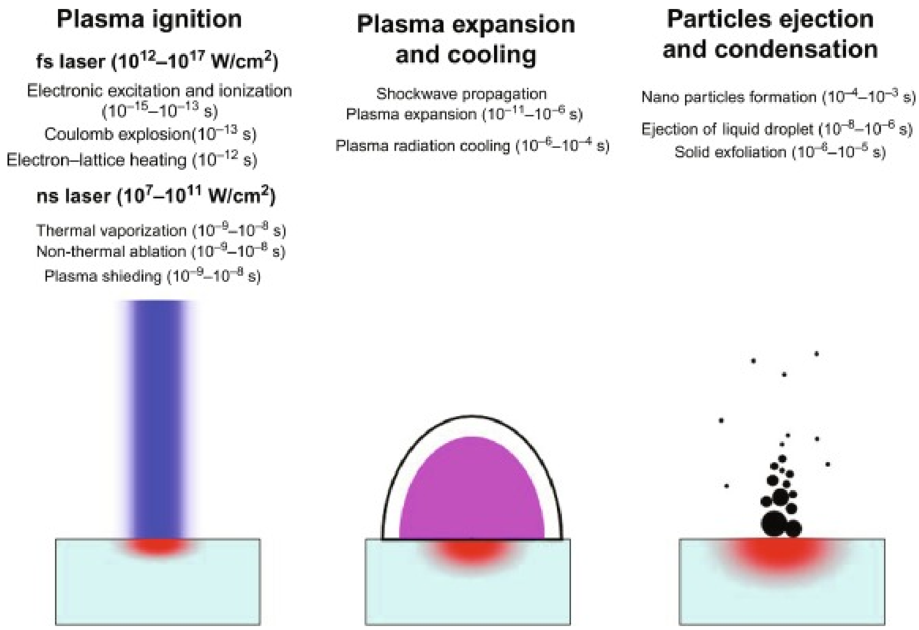

Figure 2.1: The processes in laser ablation starting with bond breaking and plasma ignition, plasma expansion and cooling, and particle ejection and condensation. Image taken from [3].

Following the plasma ignition, the plasma rapidly expands away from the ablated surface due to the extremely high temperature and pressure generated during the ablation process. As the plasma expands into the surroundings, it undergoes a rapid cooling process due to adiabatic expansion and interactions with the surrounding gases or ambient conditions. During this phase, the plasma then cools down and the high-energy particles within lose some of their energy resulting in a decrease in temperature and the recombination of ions and electrons [3].

Finally, as the plasma cools, the highly energetic particles within start to recombine, losing their energy and leading to the formation of clusters, atoms, and molecules. These recombined species can re-condense onto nearby surfaces or into the surrounding environment as nano-particles. Next, the condensed particles get released and may settle on surfaces or disperse in the environment forming a thin film or deposit, known as the particle ejection [3].

We can utilize laser ablation in many different projects including titanium textured coloring, but our primary focus lies in utilizing laser ablation for specific applications [4]. Additionally, laser ablation can be employed to create intricate microtextures on various surfaces, further expanding its versatility and applications. In the next section, we will outline how laser ablation can be utilized for oil-water separation.

2.2 Oil water separation

Although there are many different ways to accomplish an oil-water separation, we will focus on the use of laser ablated mesh. In this method, we take advantage of the mesh's superhydrophilic textured surface. The water will act as a bridge which then doesn't allow oil to pass through but will allow water to pass through.

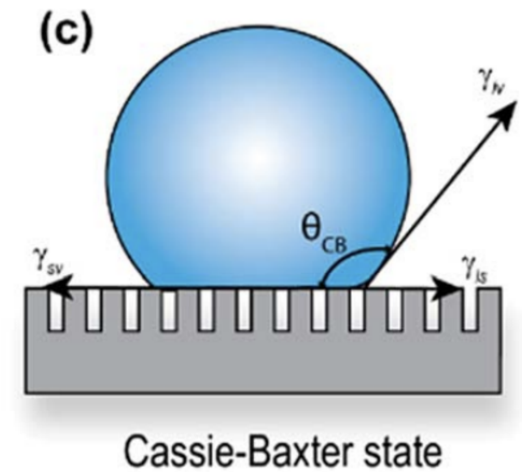

Figure 2.2: Illustration showcasing the Cassie state, where water droplets rest on a textured surface, supported by air pockets, enhancing water repellency and promoting self-cleaning properties. Image taken from [5].

Using the knowledge that oil is hydrophobic and will separate and not mix with water, we can take advantage of this as we aim to separate the oil from the water. Looking at figure 2.2, we will see the air trapped in the microstructures of the mesh, thus creating air cushions or bridges for the water to sit on. This combined with the non-mixing properties of water and oil, force the oil to be repelled by the layer of water on the mesh as depicted in figure 2.3

The following section will touch on experiments that other groups have worked on relating to laser ablated mesh in relation to oil water separation or reverse wettability.

2.3 Previous Experiments

Given that laser ablation is a well-known way to create an oleophobic surface and thus create a way for oil-water separation, there have been many different directions research has branched in an attempt to create a better oil-water separation.

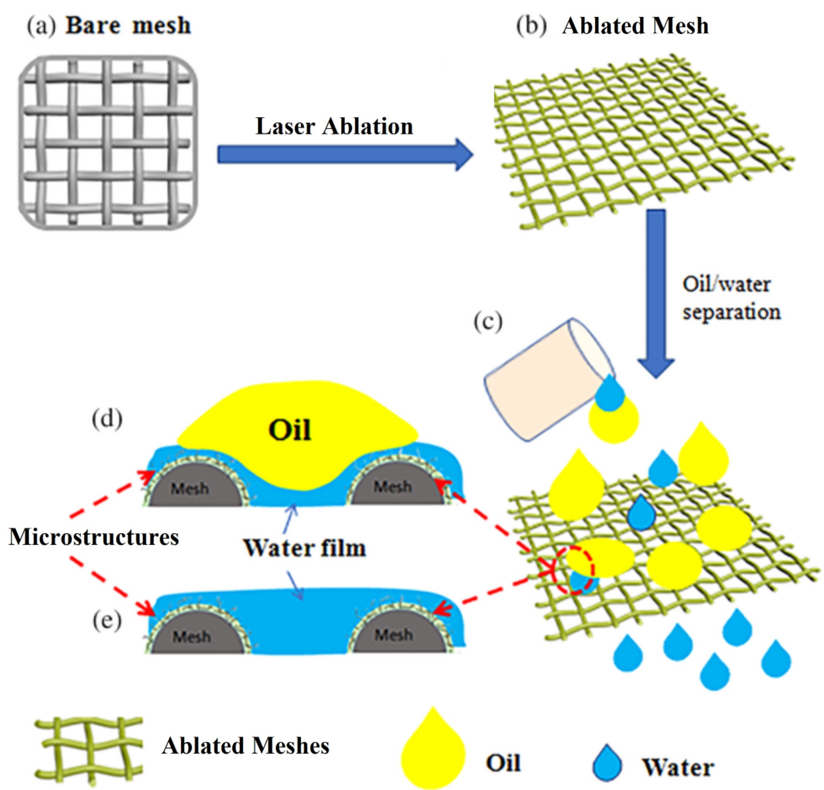

Figure 2.3: Illustration depicting the phenomenon of water bridging on a laser-ablated mesh surface, effectively blocking the passage of oil. The unique surface morphology created by laser ablation promotes the formation of water bridges, facilitating efficient oil-water separation. Image taken from [6].

Many researchers have focused on the reversible wettability of created meshes, specifically their ability to transition from an oleophobic surface to hydrophobic through methods such as heating the mesh [7, 8]. In contrast, others, like us, have directed their attention to investigating the effects of scanning speed variations [9]. One notable distinction is observed in the starting materials utilized across these experiments; while some employ copper sheets or foil, others begin with a mesh substrate. An alternative approach involves assessing the effectiveness of meshes for oil-water separation with different types of oil [10].

3 Methods

This section outlines the methodologies used in this study to address the research questions and objectives outlined in the Introduction. Each subsection details the experimental procedures, data collection methods, and analytical techniques, ensuring transparency and reproducibility.

3.1 Setup

This experiment investigated the filtration efficiency of oil and water as they passed through mesh samples featuring distinct laser-ablated textures, created using varying laser scanning speeds. Specifically, we examined scanning speeds of 80 μm/ms with 10 μm spacing, 40 μm/ms with 20 μm spacing, and 80 μm/ms with 20 μm spacing. These mesh samples, constructed from copper, were subjected to controlled flow conditions to mimic real-world scenarios involving mixed oil-water situations.

Given our goals, we needed an apparatus that would allow us to hold a mesh sample and run liquid through the sample to some type of collection vessel at the bottom. To achieve this, we used multiple different parts to create a working apparatus.

3.1.1 Fraction Collector

Our primary apparatus consisted of a fraction collector, as depicted in Figure 3.1. A fraction collector is a device designed to automate the collection of liquid samples at predefined intervals. It typically consists of a basin with multiple test tubes and a programmable arm that dispenses the liquid being measured. Once set to a specific interval, the basin rotates, allowing the arm to deposit liquid into designated test tubes. This process continues until the desired volume or number of samples is collected. By systematically collecting samples at regular intervals, fraction collectors enable researchers to obtain precise measurements for their experiments. It's important to note that while the term "fraction" in "fraction collector" refers to portions or segments of the separated mixture, not time intervals, the collector operates at a consistent rate to ensure precise separation.

This device enabled us to precisely capture the volume of liquid passing through our mesh collected within specific time intervals. To enhance the functionality of the fraction collector, we affixed a metal pole to its arm, onto which a test tube holder was securely attached using hot glue. This modification allowed us to collect the liquid samples accurately and efficiently during the experimental procedures. A visual of our apparatus looking specifically at the fraction collector's arm can be seen in figure 3.2.

Figure 3.1: An unaltered Amersham Biosciences fraction collector like the one we used. Image taken from source [11]

3.1.2 Syringes

To secure our sample, we utilize a dual-syringe configuration where the sample is sandwiched between two syringes, allowing the liquid to flow through them and pass through the mesh. For a comprehensive understanding of this setup, refer to Figure 3.3, which delineates the various components of a syringe. One syringe is prepared without the needle and plunger, featuring a small drilled hole near the

Figure 3.2: This is an image of our real setup including the needle placed inside the small hole drilled in the lower syringe.

tip to prevent a vacuum effect. Additionally, a needle is inserted at a downward angle to inhibit liquid flow through this aperture. The second syringe has its hub trimmed slightly into the barrel for a smooth edge and lacks a plunger. These modifications yield two distinct pieces, which are utilized to sandwich the sample. Gorilla glue mounting putty is applied as a sealant to prevent liquid spillage, and small binder clips are affixed to the syringe's nubs for added security in holding the assembly together. Additionally, we used a small length of heat shrink to ensure the liquid running through the apparatus would run through the hole in the fraction collector's arm and would run right into the test tube. Refer to Figure 3.2 for a visual depiction of our setup.

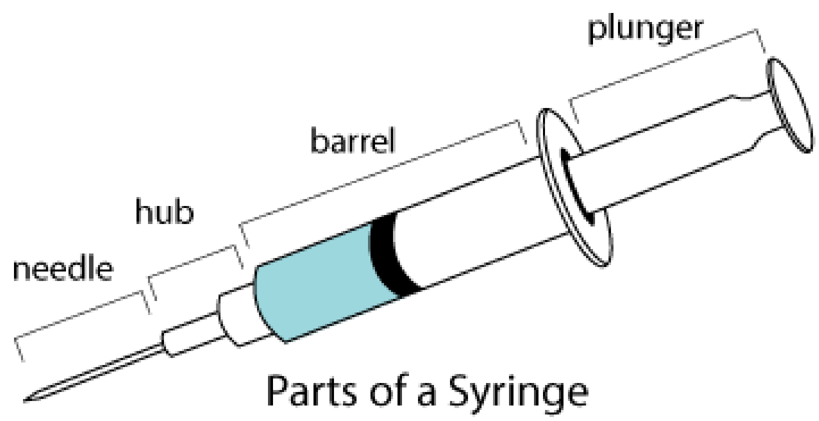

Figure 3.3: Labeled parts of a normal syringe[12]. Our model was one normal barrel and hub without a needle and plunger and the second piece consisted of only a barrel with hub cut off.

3.1.3 Miscellaneous

To mitigate potential factors such as evaporation during the separation process of our oil-water mixture, we have implemented a precautionary measure. Following a test run, rubber plugs are inserted into each test tube within the fraction collector. To further enhance security, the plugged tubes are then carefully covered with aluminum foil. This strategy aims to minimize any loss or alteration in the composition of the sample while awaiting measurement.

3.2 Taking Data

To collect data, we utilized a graduated cylinder to precisely measure 4 mL of olive oil, transferring it into a larger graduated cylinder. To accommodate the capacity limitations of our graduated cylinder, we added water in two separate steps, ensuring precise measurements and accurate data collection throughout the experiment. Subsequently, a drop or two of food coloring was introduced into the initial graduated cylinder, and water was carefully added up to the 6 mL mark. This colored water mixture was then combined with the olive oil in the larger graduated cylinder. Following this, an additional 10 mL of water was measured and added to the larger graduated cylinder, resulting in a final mixture comprising 4 mL of oil and 16 mL of food coloring and water. Before analysis, the solution was gently twirled to ensure thorough mixing.

Next, we confirm that our fraction collector is configured to the appropriate fraction setting, precisely 0.04, with a 0.1 delay, ensuring consistent results. Subsequently, we affix a funnel atop our syringe, initiate the start command, and patiently await the countdown. Once the wait period elapses, we carefully pour the oil-water mixture into the syringe, exercising caution to prevent overflow, particularly if the flow rate is slow. While pouring the liquid, the fraction collector rotates, yielding the quantity of liquid that has passed through the mesh within a specific time interval. For each trial, we allow the liquid to flow into a total of 30 test tubes, where the 30th tube is the remainder where we will stop the fraction collector and push the remainder of the liquid from the syringes into the tube.

3.3 Measurements

To measure our trial, following a waiting period of several days for the oil and water to undergo separation, we initiated the measurement procedure. Initially, we removed the foil covers and plugs from all test tubes. Subsequently, equipped with our measuring instrument, a micropipette, we meticulously measured the contents of each test tube. Using primarily three distinct settings: 500 microliters, 200 microliters, and 100 microliters, we diligently quantified the proportion of oil and water within each tube, recording the obtained data for further analysis.

4 Results

This section presents the study's key findings, providing insights gleaned from quantitative and qualitative analyses, as well as experimental results. Together, these findings offer a comprehensive overview of the outcomes achieved.

4.1 Findings

Our investigation into the effectiveness of three different scanning speeds, 80 μm/ms with 10 μm spacing, 40 μm/ms with 20 μm spacing, and 80 μm/ms with 20 μm spacing, revealed promising results for oil-water separation. Figure 4.1 illustrates the trends observed across these configurations. In all three tests, earlier tubes exhibited minimal oil presence, with the majority of oil retained in the remainder tube (number 30).

Analysis of the results indicates variations in the efficiency among the tested configurations. Notably, the 40 μm/ms with 20 μm spacing configuration appeared to be the least efficient, as evidenced by the higher oil content observed in tubes other than the remainder. Conversely, the 80 μm/ms with 10 μm spacing demonstrated rapid separation, with most water passing through the mesh by tube 6, compared to tubes 7-8 for the other configurations.

Furthermore, the 80 μm/ms with 20 μm spacing configuration emerged as the most effective option. It exhibited superior oil-water separation, evidenced by the lowest oil content in tubes other than the remainder and the least amount of water retained in the remainder tube. These results highlight the critical role of scanning speed and spacing in optimizing the efficiency of oil-water separation processes, providing valuable insights for future research and practical applications.

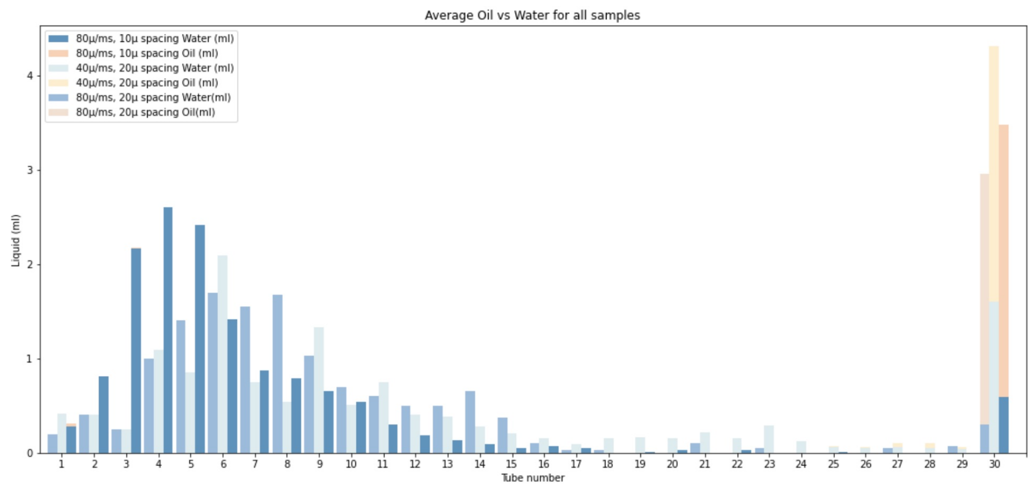

Figure 4.1: This bar plot illustrates the liquid content (comprising both oil and water) measured in test tubes 1-30 for copper mesh samples. The samples were subjected to three different conditions: (1) a mesh with a scanning speed of 80 μm/ms with 10 μm spacing, (2) a scanning speed of 40 μm/ms with 20 μm spacing, and (3) a scanning speed of 80 μm/ms with 20 μm spacing

5 Conclusion and Outlook

This section focuses on the problems that arose and the future research that can be done with this topic.

5.1 Conclusion

However, it is important to acknowledge the significant limitations encountered during our experiment and setup. For example, we faced challenges with the fraction collector, which exhibited unexpected behavior. It intermittently failed to produce consistent results, exhibiting sudden jolts upon startup or skipping several tubes without apparent cause. Moreover, the inconsistencies stemming from the malfunctioning fraction collector resulted in us being able to perform only a single test run with the final sample. This restriction hindered our capacity to collect extensive data, potentially compromising the thoroughness of our analysis and findings. Furthermore, while we maintained accuracy in our measurements using the micro pipette, there remains the potential for human error in visually assessing the precise volume of oil or water within each tube. Despite our efforts to mitigate losses using plugs and foil, some liquid was inevitably lost, possibly due to evaporation or adherence to the sides of the graduated cylinder or syringes.

5.2 Outlook

Extensive research efforts have been dedicated to seeking an environmentally sustainable solution for oil spill cleanup. Central to this quest are investigations into various scanning speeds and spacing configurations of mesh samples. However, the horizon of exploration extends far beyond these parameters. Future inquiries could delve into the influence of water temperature on oil-water separation efficiency, exploring how variations in temperature affect the process. Additionally, there's a compelling need to investigate the potential impact of small solid particles on mesh, probing whether their presence alters the efficiency of oil-water separation. Moreover, the type of oil and water involved presents another avenue for investigation; comparing the efficiency of separation in different oil-water combinations, such as saltwater versus tap water, could yield crucial insights. This multifaceted approach underscores the complexity of the challenge and the necessity for comprehensive research to pave the way for effective, environmentally friendly solutions in oil spill cleanup.

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