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Effects of Ambient and Laser Light on Water Evaporation from the Surface of Polyurethane Swabs Doped with Surfactant

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Honors Thesis

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ABSTRACT

Polyurethane swabs are a common instrument for environmental sampling in the food, medical, and forensic fields due to their high recovery of organisms like viruses, spores, and bacteria. For sampling microbes in food and medical facilities, storage of the collected samples occurs under the absence of light to promote growth for more accurate testing. In the forensic fields, microbial growth results in sample contamination so the inhibition of this growth requires the drying of the swabs. This work studies the evaporation rates of water from polyurethane swabs under zero watt incident light, 30 W fluorescent bulb, 50 mW 532 nm laser, and surfactant dopant conditions to determine the effects of each condition on the swab recovery. Overall, the zero-watt incident light condition resulted in the lowest evaporation rates without surfactant dopant, but with surfactant dopant, the zero-watt incident light had evaporation rates higher than that of the 30 W fluorescent light bulb. Under 50 mW laser irradiation, the evaporation rate of water from the polyurethane swabs was consistently higher under all conditions. A dynamic period was observed when irradiating the swabs with the laser, which showed that from 0-60 s, the laser resulted in lower evaporation rates but after 60 s, the laser irradiation resulted in higher evaporation rates than the other conditions. These results showed that for food and medical fields needing the swabs to have reduced water evaporation; use of swabs doped with surfactant would allow for increased intake as well as reduced evaporation, while forensic science fields could use a 532 nm laser to dry the swabs to minimize microbial growth.

1. Introduction

Polyurethane swabs are commonly used in the food, medical, and forensic fields due to higher recovery.[1–8] These industries use polyurethane swabs for environmental sampling to collect microorganisms or biological evidence. An estimated 48 million people each year get sick in the United States, where 128,000 are hospitalized and 3,000 die from foodborne diseases.[9] In the medical industry, 687,000 patients got a Healthcare Acquired Infection (HAI) and 72,000 people died during their hospitalizations due to an HAI in 2015.[10] In both the food and medical industries, an improvement in environmental sampling devices has the impact to save thousands of lives every year.[11–14] As the FDA switches from a reactive approach to a more proactive approach, environmental sampling will become instrumental in preventing contaminated foods from reaching consumers.[15] However, the FDA does not have a standard sampling tool but recommends using polyurethane or cotton swabs and sponges.[15–17] Collecting forensic evidence such as DNA, saliva, and blood, in the field is usually done under non-optimal conditions. Without a dedicated refrigerated storage for collected samples, a temporary storage method is required to preserve the evidence for future analysis, or a fast-drying method allowing for immediate testing is needed like adding a solvent of ethanol or isopropanol.[18] Experiments to determine the optimum conditions for both storage and drying were performed by analyzing water evaporation rates from a sampling device. Most forensic evidence is obtained using a cotton swab, however, a major limitation of cotton swabs is their inability to be used for PCR analysis, which is used for making copies of a DNA genetic identifier sequence.[19] Studies show that polyurethane swabs and cotton swabs are equivalent in real time PCR limit of detection.[20] The addition of hydrophilic surfactant to a polyurethane swab will likely lead to increased intake.[21] The effect of Triton in water, with cells, and with microbes has been studied.[22–25]

The present work observed water evaporation from polyurethane swabs under dark (0 W Incident), light (30 W fluorescent bulb), laser (50 mW, 532 nm), and surfactant (Triton X-100) conditions. The dark condition without surfactant had the least overall water evaporation. The light condition with surfactant had lower overall evaporation compared to the light and laser conditions with surfactant. The lower overall evaporation would be beneficial for the food and medical fields because higher water concentration leads to better microbial growth. The laser condition had the highest overall evaporation for all trials. The higher evaporation would be beneficial for forensic collection because less water inhibits microbial growth. An observed difference in evaporation over time occurs at 60 s. Before 60 s evaporation was under dynamic conditions and after 60 s the evaporation was under equilibrium conditions. The greatest difference between the dynamic and equilibrium evaporation rates occured for the laser condition.

2. Materials and Methods:

2.1 Dark, Light, and Laser Evaporation Measurements.

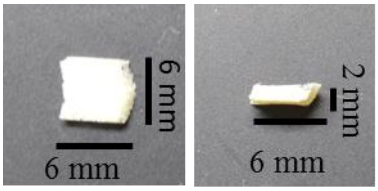
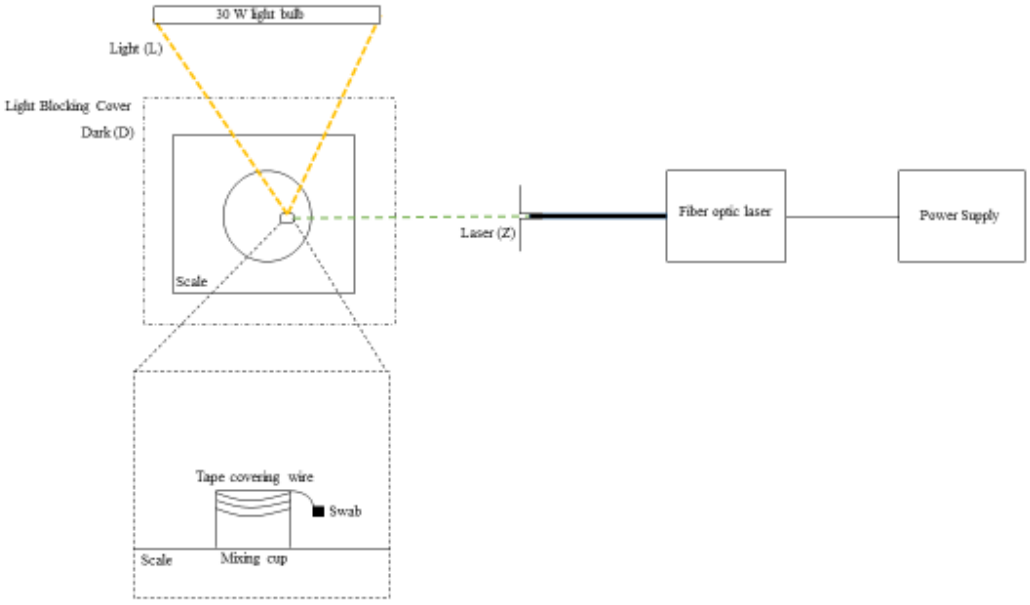


Figure 1. Images of the polyurethane swabs used for the water evaporation experiments with corresponding length, width, and thickness dimensions.

Polyurethane swabs (EZ-DRY-PUR, World Bioproducts, Libertyville, IL) were cut into 6 mm x 6 mm x 2 mm (length x width x thickness), as shown in Figure 1, and used to determine the effects of dark, light, and laser conditions on the water evaporation from the swab surface. Two

methods were used to add water to the swab surface: (1) a dip method consisting of soaking one corner of the swab in 1000 µL of water for 5 min and (2) a pipette method consisting of dropping 20 µL of water onto the surface of the swab and providing time for the water to soak into the swab (~ <1 min). The swabs were placed in a swab holder (a mixing cup wrapped in metallic wire with a small binder clip to hold the swab) on a Pioneer Analytical Balance (PA114, OHAUS, Pine Brooks, NJ) before the addition of water with the mass of the swab and swab holder being zeroed. Once the water was added onto the swab surface via either method, either dark, light, or laser conditions were applied to the system. For dark conditions (black dot-dashed line in Schematic 1), a light blocking cover was placed over the scale containing the swab and a 3-minute evaporation period was performed while the mass of water displayed on the scale was video recorded for later analysis. For light conditions (yellow dashed line in Schematic 1), the system was exposed to ambient room light consisting of a 30 W light bulb ~75 in. away from the system for 3 minutes with the mass of water displayed on the scale being video recorded for later analysis. The light bulb was ~60 in. overhead at an angle of ~30° from the system. For laser conditions (green dashed line in Schematic 1), a 532 nm laser (MXL-FN-532, CNI, Changchun, China) was used to irradiate the swab from a distance of ~8.5 in. at ~50 mW for 3 minutes while the mass of water displayed on the scale was video recorded for later analysis. During each experiment, the temperature, relative humidity, and pressure within the system was measured and recorded using an Omega Pressure, Humidity, and Temperature Logger (OM-CP-PRHTEMP2000, Omega, Bridgeport, NJ). After initial data analysis, the pipette method was determined to be a more consistent and accurate method and was used for all further experiments and analysis. Each dark, light, and laser experiments were performed in triplicate. Video recordings of each trial were used to determine the mass of water evaporated at 5 s intervals.



Schematic 1. Experimental setup for measuring the water evaporation rates from the surface of polyurethane swabs when exposed to dark (D, black dot-dashed line), light (L, yellow dashed line), and laser (Z, green dashed line) conditions. The setup, as shown in the box outlined with a black dashed line, consisted of a swab holder, the swab, and a scale.

2.2 Addition of Surfactant Dopant.

The aforementioned experimental procedure for applying dark, light, and laser conditions to polyurethane swabs containing water was used for swabs that had been doped with Triton X-100 surfactant (Sigma Aldrich, St. Louis, MO). Two methods were used to dope the swabs with surfactant: (1) 3 µL of 1 wt% Triton X-100 was dropped on the swab surface, heated at 100 °C for 10 min, and cooled to room temperature for 10 min (Triton on swab) and (2) a solution of 1

wt% Triton X-100 was made and used for the water addition via the pipette method (Triton in water).

3. Results and Discussion.

3.1 Dip vs. Pipette Methods

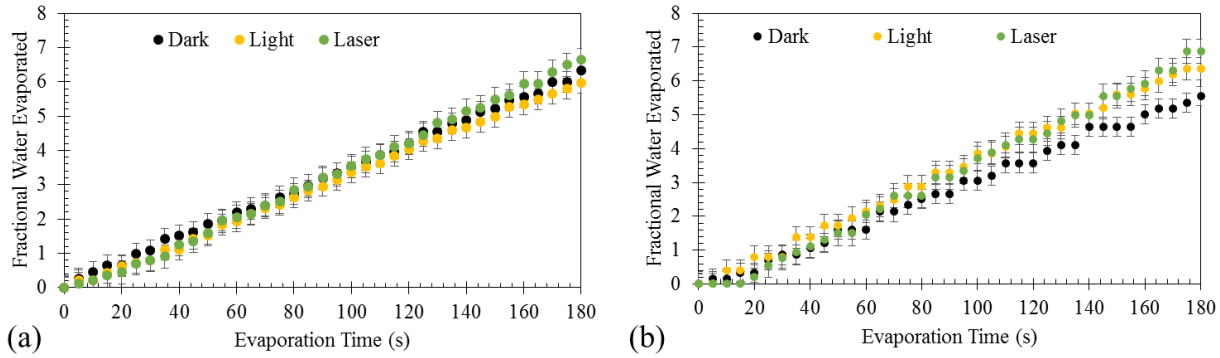


Figure 2. The fractional water evaporated from polyurethane swabs was measured under three conditions: dark, light, and laser. Two methods for applying water to the polyurethane swab were performed, in Figure 2 (a) the dip method is shown and in Figure 2 (b) the 20 µL pipette method is shown.

For the dip method in Figure 2 (a), the dark condition had the highest average fractional water evaporated at the end of 60 s followed by the light and then the laser conditions. The laser condition had the lowest initial fractional water evaporated average, however, after 60 s the laser condition had an increased average fractional water evaporated over time. At the end of the trials, the average fractional water evaporated for the laser had the highest average at 6.64%, followed by the dark at 6.34%, and the lowest was the light at 5.97%. All three conditions ended within .67% of each other. From 130 s onwards, the laser had the highest evaporation followed by the dark and the lowest was the light. For the pipette method in Figure 2 (b), the light condition had the highest

initial fractional water evaporated average ~60 s followed by the dark and then the laser conditions. The laser trial had an average of no fractional water evaporated for the first 15 seconds. After ~60 s, the laser condition's fractional water evaporated average surpassed the dark's and after ~140 seconds the laser surpassed the light condition's. At the end of the 3 min trials, the average fractional water evaporated was 6.87% for the laser condition, 6.36% for the light condition, and 5.55% for the dark condition. The difference between the three conditions was 1.32% at the end of the 3 min experiments. The light's fractional water evaporated overtook the dark's after ~30 s, while the laser's overtook the dark's after 60 s. The laser then overtook the light after ~155 s. The light and dark trials had constant evaporation throughout the 3 min experiment, while the laser was observed to have an increased evaporation rate after 60 s.

The dip method and pipette method had similar fractional water evaporated for the laser condition at the end of the 3-minute trial: 6.64% and 6.87% respectively. Another similarity was the laser condition having a slower evaporation rate before 60 s (dynamic period) and higher evaporation after 60 s (equilibrium period). However, in the dip method, the dark condition was higher than the light condition at the end of the 3 min trial, and in the pipette method, the light condition was higher than the dark condition.

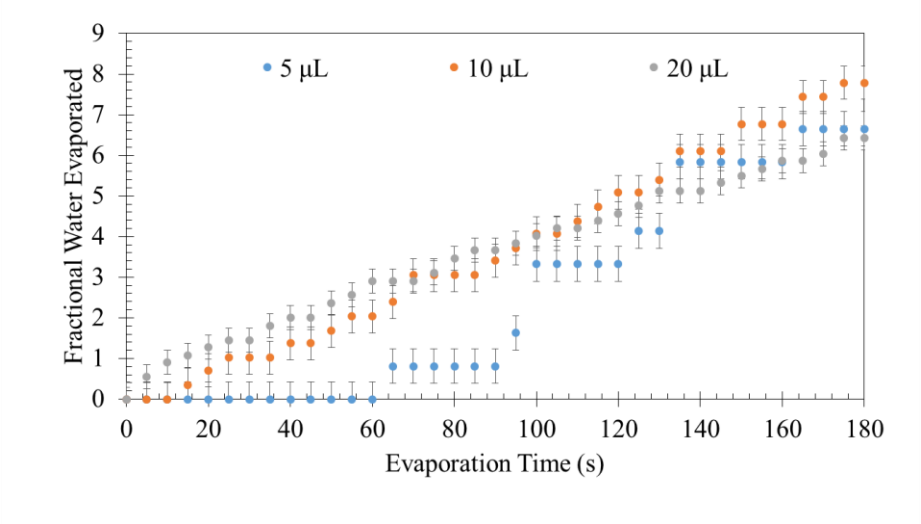


Figure 3: The pipette method was tested with three volumes of water pipetted onto the surface of the polyurethane swabs under dark conditions with 5 µL (blue), 10 µL (orange), and 20 µL (grey). The 5 µL had large spikes of fractional water evaporation followed by a long time period with no water evaporation. The 10 µL had less extreme spikes and shorter time periods of no evaporation. The 20 µL had the most consistent water evaporation.

3.2 Triton on Swab Evaporation

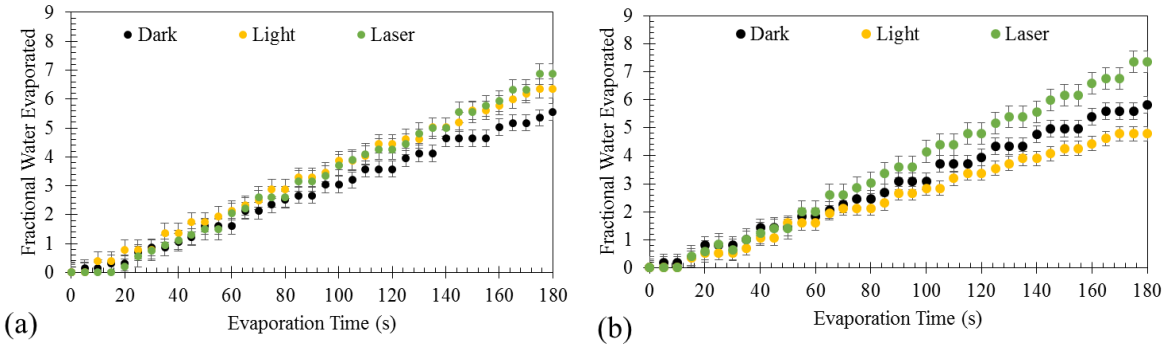


Figure 4: The water evaporation from polyurethane swabs was tested under the dark, light, and laser conditions. In Figure 4 (a), the 20 µL pipette, also seen in Figure 3 (b), was compared with

Figure 4 (b), where 3 µL of 1 wt% Triton X-100 was dropped on the swab surface, heated at 100 °C for 10 min, and cooled to room temperature for 10 min.

Figure 4 (a) shows the 20 µL pipette trials seen in Figure 3 (b). The trends discussed earlier are now compared to the 100-X Triton added to the swab in Figure 4 (b), where the laser condition's fractional water evaporation average at 60 s was the highest followed by the dark then the light conditions. After 60 seconds, the laser trial had a much higher evaporation rate than before 60 seconds. At the end of the experiment, the laser had the highest average fractional water evaporated at 7.35%, while the dark trial average was 5.83%, and the light's average was 4.79%. The difference between the laser and light conditions was 2.56%. Triton caused the light condition to have lower fractional water evaporated than the dark and laser conditions. The laser condition continued to have both dynamic and equilibrium evaporation rates even with Triton added to the swab.

3.3 Triton on Swab vs. Triton in DI Water

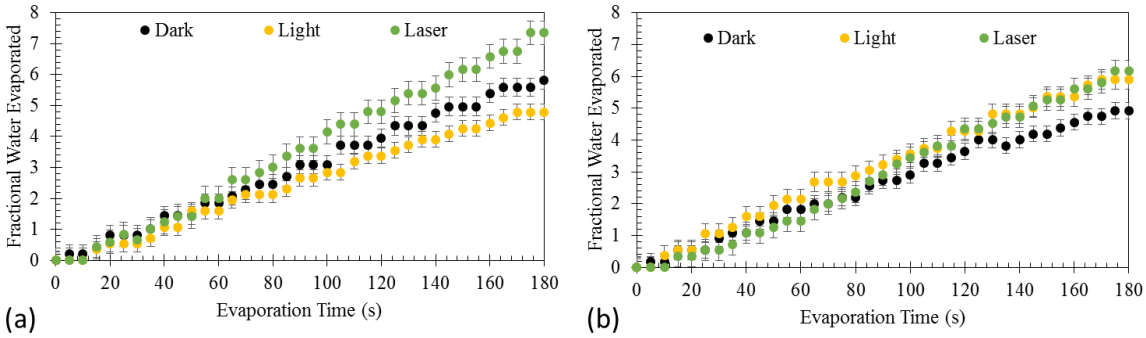


Figure 5: The water evaporation from polyurethane swabs was tested under the dark, light, and laser conditions. In Figure 5 (a), 3 µL of 1 wt% Triton X-100 was dropped on the swab surface,

heated at 100 °C for 10 min, and cooled to room temperature for 10 min. In Figure 5 (b), a solution of 1 wt% Triton X-100 was made and used for the water addition via the pipette method.

In Figure 5 (a), the same trends seen in Figure 4 (b) with the Triton on Swab method were compared with the Triton in solution method seen in Figure 5 (b). In Figure 5 (b), the laser condition had the lowest fractional water evaporated for the 60 s. The light condition had the highest and the dark condition was in between. After 60 s, the laser percentage was higher than the dark's at 80 s, and higher than the light's at 160 s. However, the difference between the light and laser's average (6.17% vs 5.90%) was not significant. Both were significantly higher than the dark's at 180 seconds (4.92%). In Figure 5a, the fractional water evaporated from highest to lowest was the laser, dark, and then light condition. In Figure 5b, the order was laser, light, and then dark, which was the same order of conditions as the pipette method seen in Figure 2 (b).

Conclusions.

In conclusion, incident light had a positive impact on water evaporation from polyurethane swabs. This should lead to an increase in swab recovery of microorganisms and biological evidence in the food, medical, and forensic fields. 100-X Triton on the swab, however, inversed that trend by decreasing the water evaporation in the light below that of the dark conditions. A difference was found between the dynamic (0-1 min) and equilibrium (1-3 min) evaporation from the polyurethane swabs. The results of this experiment show that for the food and medical sampling industry, the dark conditions could allow the microorganisms to recover and revive for culture testing. For the forensic industry, the laser condition could allow a quick and cheap drying method to preserve the biological evidence from microbial growth. The next steps would be to test nanoparticles on the polyurethane swab to increase the water evaporation rate even more under

laser conditions. These tests would allow polyurethane sampling devices to provide better results for the food and healthcare industries.

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