Hong Kong Student Science Project Competition 2023

Team Number: SABC020

Project Title: Facile synthesis and investigation into hydrophobic sponge for oil absorption

Project Type: Investigation

***To our best knowledge, there are similar works in the field*; (if there are,) related research links are as below:**

https://pubs.acs.org/doi/10.1021/acsami.7b13626
There is only one similar work, which does not specify the specific procedures for sponge synthesis.

The enhancement our project made:

We specified the exact procedures and studied the relationship between concentration used to make the sponge and its hydrophobicity and oil absorption capacity. We also investigated more on the mass of the melamine sponges before and after treatment.

I. Background

Our sponge acts as a countermeasure towards oil spills, an environmental problem that has plagued both marine and terrestrial environments around the world. Large-scale oil spills have damaged multiple ecosystems, causing lasting impact by not only killing off animals, but also contaminating food sources and worsening air quality. According to the International Tanker Owners Pollution Federation Limited, 15000 tons of oil were spilled from tankers in 2022 alone. Although there has been a decreasing trend in both the frequency and quantity of oil spills, the monetary cost along with socioeconomic and ecological damage a single spill can cause is immense, with oil spills costing at least $1000 per ton to clean up. The damage it causes is nearly impossible to quantify.

Currently, there are already technologies which can tackle oil spills and have been put to use, the most common measure being oil skimmers. Our team has identified some common and fundamental flaws in these skimmers. They all consist of moving parts which not only require energy to run, but are also prone to breakdowns, adding to upkeep and maintenance costs. Besides, they only work on water, limiting their utility to marine oil spills.

Our sponge addresses both of these weaknesses while maintaining the oil absorbent characteristic that is required to clean up oil spills. According to the paper by Ding, Y., Xu, W., Yu, Y., Hou, H., & Zhu, Z. (2018, January 29), the sponge gains hydrophobicity while still allowing oil to be absorbed into the sponge through capillary action, effectively separating the two liquids.

As the treated melamine sponge is a passive system that does not require external forces or energy input to operate, it cuts down on the cost of upkeep and maintenance. It can also be used terrestrially, which would be especially useful towards cleaning up coastal oil spills.

II. Objectives

1. Specify and investigate the optimal process of $FeCl_3$ solution treatment of the melamine sponge to maximise its oil absorption.
2. Investigate how different concentrations of $FeCl_3$ affect hydrophobicity, measured by water contact angle.
3. Investigate the difference in sponge mass before and after the treatment.
4. Explain the mechanism behind the sponge's hydrophobicity.

III. Hypothesis

Under the assumption that only the outer coating of the melamine sponge needs to be treated for maximising functionality while reducing the concentration of iron(III) chloride used to minimise leakage of iron(III) ions, the optimal concentration of 1.5 mM is deduced. By varying the range of concentrations of iron(III) chloride used to prepare the hydrophobic melamine sponge, the team was able to come up with a specific and accurate procedure on the synthesis of such sponges.

As the concentration of the $FeCl_3$ solution used to treat the pristine melamine sponge increases, it is predicted that more iron(III) complexes will form, causing a rise in non-polarity. Therefore, the hypothesis is that there would be a rise in hydrophobicity and water contact angle with higher concentration of $FeCl_3$. In regards to oil absorption capacity, the oil to sponge mass ratio would also increase as the rise in non-polarity of the material could improve oil absorption.

IV. Methodology

The materials utilised in this investigation are NaCl and $FeCl_3$ crystals, deionised water and melamine sponge (obtained from local Hong Kong supermarket), paraffin oil and other common laboratory equipment.

$FeCl_3$ aqueous solutions at different concentrations were prepared, followed by the preparation of the oleophilic melamine sponge. We soaked the melamine sponges in $FeCl_3$(aq) for 5 minutes, then squeezed the sponge to remove excess solution. The treated sponges were then placed in an oven for drying overnight. This process was repeated for the preparation of negative control group 1 (treating the sponge with NaCl(aq)), and negative control group 2 (treating the sponge with deionised water). NaCl(aq) was used as a negative control group to rule out the possibility that chloride ions are the agents responsible for the oleophilic properties. Deionised water was used as a negative control group to rule out the possibility that water, the solvent for $FeCl_3$ and NaCl, is responsible for oleophilicity.

The oleophilicity and hydrophobicity of the treated and untreated sponges were measured on the surface of the sponge. Oleophilicity was tested by adding dyed oil, whereas hydrophobicity was tested by adding dyed deionised water. A photo was then taken and contact angles were measured using Geogebra software. For a contact angle above 90°, the material is considered to be oleophobic when the tested solution is oil, or hydrophobic when the tested solution is water, and vice versa.

V. Results

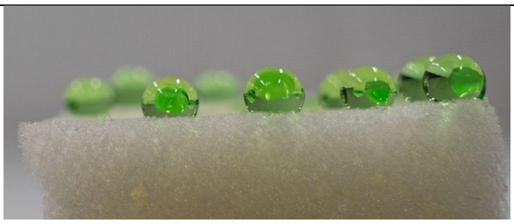

Fig. 1: Treated hydrophobic melamine sponge with dyed deionised water droplets

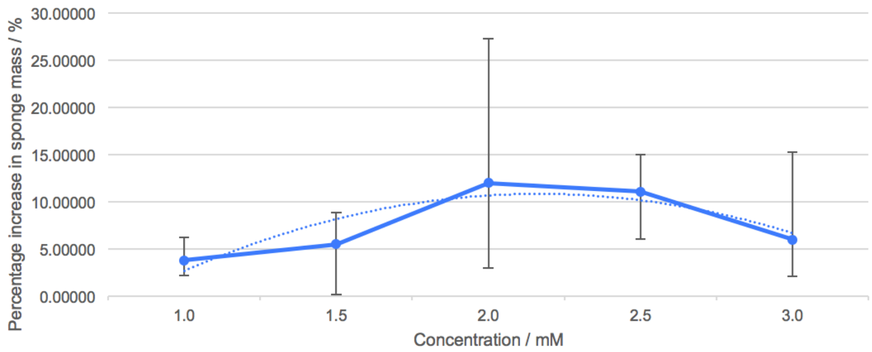

Fig. 2: Percentage increase in sponge mass against concentration of $FeCl_3$ solution

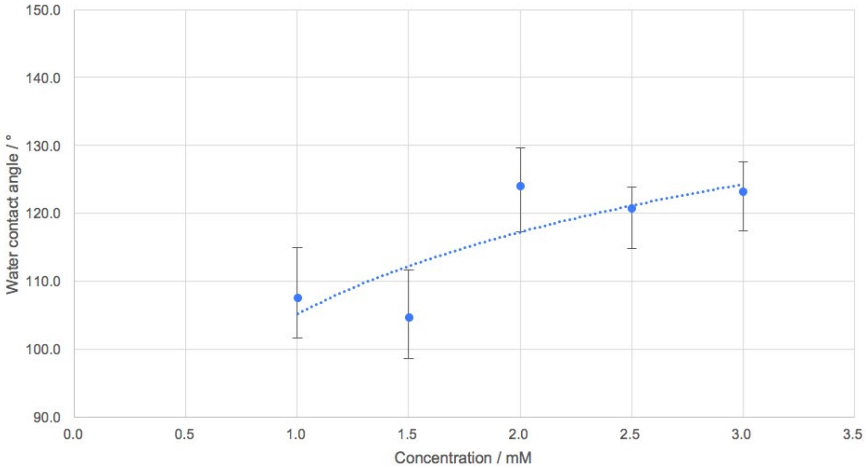

Fig. 3: Water contact angle against the concentration of $FeCl_3$ solution

Figure 2 shows the relationship between the concentration of the $FeCl_3$ solution used to prepare the sponges and the percentage increase in the sponge mass. As the concentration of $FeCl_3$ increases, there is a greater percentage increase in mass of the sponge, meaning more iron(III) ions are incorporated into the structure of the sponge to form coordinate bonds. However, beyond the concentration of 2.0mM, the percentage increase in mass falls. There can be two interpretations for this result:

1. Iron(III) ions are in excess beyond the 2.0 mM concentration.
2. There is a different arrangement between the melamine molecules and the iron(III) ions, causing a more efficient use of iron(III) ions by the melamine sponge, thus less iron(III) ions is needed to fully "saturate" the melamine sponge.

Figure 3 shows the relationship between concentration of the solution and the water contact angle. As concentration increases, there is a general increase in the water contact angle. As more iron(III) ions are absorbed by the melamine molecules, the more non-polar the sponge becomes and thus the more hydrophobic it is. However, there is a sharp increase in the water contact angle and hydrophobicity when the concentration of $FeCl_3$ increases from 1.5mM to 2.0mM, which correlates with the interpretation of different reaction geometry suggested above.

Limitations:

1. The procedure of making melamine sponge is manual, such as the non-uniform squeezing before drying in the oven, creating sponges with inconsistent characteristics due to human error.
2. Analysis of water contact angle may be erroneous as human observation is involved.
3. Some oil may have been squeezed out the sponge, as pressure would be applied while transferring it from the beaker to the electronic balance, causing systematic error.
4. The investigation is small-scale and should not be used as a prediction of the actual usage of the sponge out in the field.

Relation to the real world problem:

1. The sponge can absorb a significant amount of oil, and its hydrophobic quality helps maximise oil absorption, thus it is a viable and efficient strategy to combat oil spills.
2. The treatment process and quality of sponge can be standardised and improved to ensure maximum and uniform hydrophobicity and oil absorption.

VI. If your team will compete the Sustainable Development Award, please indicate the specific sustainable development goal the project is related to, and provide justification for competing for this award. *(Word limit: 300 words)*

Our project tackles the Sustainable Development Goals (SDGs) 6 and 14, referring to clean water and sanitation, and life below water respectively.

Our project helps to achieve SDG 6, which aims to "ensure availability and sustainable management of water and sanitation for all". The project helps clean up oil spills, which minimises the release of hazardous hydrocarbon chemicals and improves water quality by reducing the impact of pollution in both natural bodies of water and industrial wastewater flows, which is aligned with target 6.3 and indicated by both indicators 6.3.1 and 6.3.2.

In addition, our project aligns with SDG 14, which aims to "conserve and sustainably use the oceans, sea and marine resources for sustainable development". Specifically, it helps achieve target 14.1 "prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris and nutrient pollution". Although the consequences of oil spills are not factored in the 2 indicators, oil spills are still a source of marine pollution. Developing technologies such as our sponge which serves as a quick and effective countermeasure to various sources of pollution is crucial to ensure the sustainable development and protection of marine resources.

VII. Conclusion

Through this investigation we have achieved all our objectives, concluding that increasing treatment solution concentration causes an increase in water contact angle and therefore hydrophobicity. In regards to oil:sponge mass ratio, there is no clear correlation between it and the treatment solution concentration.

✖ Our project is developed based on previous project and the enhancement is below:

We specified the procedures for hydrophobic melamine sponge synthesis, and investigated the particular relationship between the mass of the sponge before and after treatment, the oil absorption capacity and the water contact angle, and devised possible explanations to the data obtained.

B