Indian Institute of Technology Gandhinagar

Fluid Mechanics Lab
CL 251

Project Report

Group Number: **C**

Project Title: Marangoni Effect

20110105	Manav Gadpale
20110116	Mumuksh Tayal
20110161	Rajesh Kumar
20110164	Rishab Jain
20110193	Shikhar Agrawal

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Objective:

Our aim is to show the Marangoni effect-
(i) in water when a drop of soap solution is added.
(ii) when a drop of isopropyl alcohol solution is added to a thin layer of oil in a Petri dish.

Background:

The Marangoni effect (also called the Gibbs-Marangoni effect) is the transfer of mass along with an interface between two fluids due to a difference in surface tension. Essentially what that means is if you have two different fluids, each with a different surface tension, say water which has a fairly high surface tension versus, isopropyl alcohol which has a low surface tension, there will be a flow from the low surface tension to the high surface tension.

Molecules at the surface of the liquid form stronger bonds due to surface tension. Surface tension refers to the attractive force exerted upon the surface molecules of a liquid by the molecules beneath that tends to draw the surface molecules into the bulk of the liquid and makes the liquid assume the shape having the most minor surface area. The surface tension arises due to cohesive interactions between the molecules in the liquid.

$$Surface\ Tension \propto Contractile\ Force$$

Therefore, if the surface tension of a fluid is high, its contractile force will also be high. The Marangoni effect occurs due to the difference in surface tension between two different fluids.

For instance, if we consider two liquids A and B,

$$\sigma_A > \sigma_B$$
$$\Rightarrow F_A > F_B$$

where,

σ_A = surface tension of liquid A
σ_B = surface tension of liquid B
F_A = contractile force due to liquid A
F_B = contractile force due to liquid B

In other words, σ_A will pull more substantial than σ_B. This results in a net force directed from the region of lower surface tension to the region of higher surface tension, known as the Marangoni flow.

Materials required:

- Isopropyl alcohol
- Water
- Ink
- Soap
- Vegetable oil
- Pepper powder
- Petri dishes
- Pipette
- Dropper
- Tripod
- Camera phone

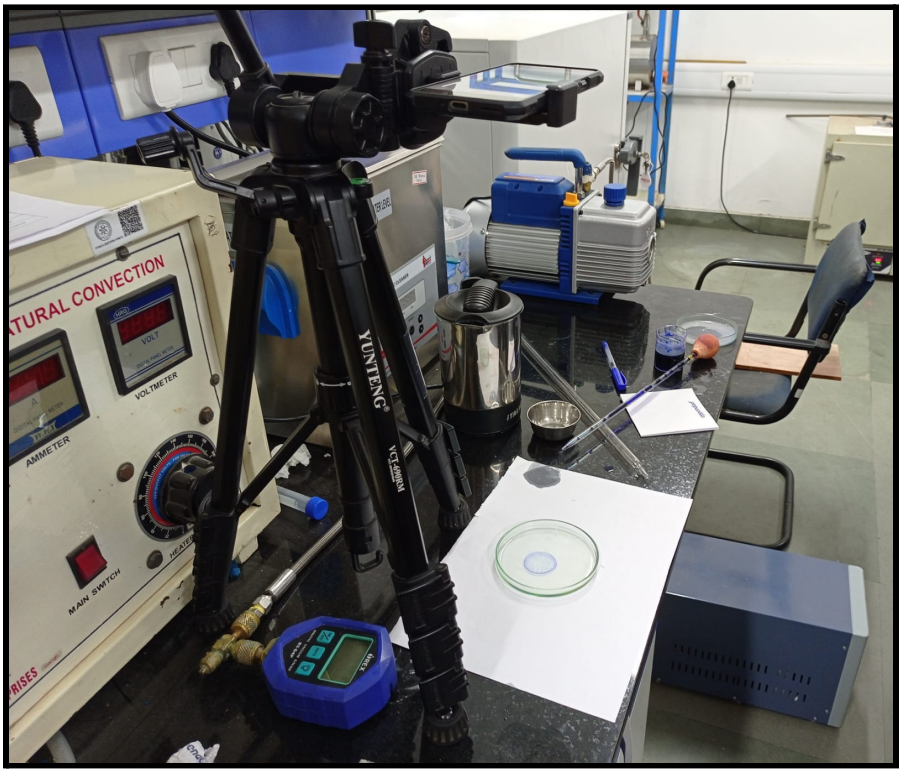

Image 1: Our experimental set-up

Procedure:

Experiment no 1:

- In a petri dish, add a little water to form a thin film of water.
- Then, spread the pepper powder on the water in the petri dish.
- Take some soap and add some water to the soap to form a soap solution.
- Add a drop of this soap solution to the petri dish containing a thin film of water.

Experiment no 2:

- In a petri dish, add some vegetable oil to form a thin film of oil on the petri dish.
- Make isopropyl alcohol solutions by adding water to isopropyl alcohol. Make two solutions with slightly different concentrations.
- Then, add some ink to the isopropyl alcohol.
- Take a drop of this solution and add it to the Petri dish containing a thin film of oil.

Observations and Discussion:

Experiment no 1:

- We observed that when we added a drop of soap solution to the Petri dish containing a thin film of water, the pepper powder spread over the thin film got pushed to the boundaries of the Petri dish.

Image 2: Pepper powder spread over the thin film, soap solution is added

Image 3: Pepper powder when a drop of

Experiment no 2:

- When a drop of isopropyl alcohol is added to the Petri dish containing the thin film of oil, the drop of isopropyl alcohol solution disintegrates into many tiny droplets. The drop of an isopropyl alcohol solution is called a mother droplet. The mother droplet fragments into tiny droplets via fingers formed on the perimeter of the mother droplet. The isopropyl alcohol solution used has a 0.4-weight fraction of isopropyl alcohol.

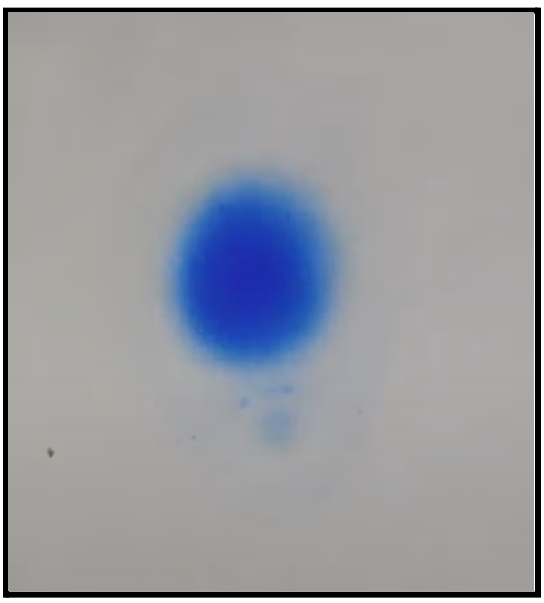

Image 4: The mother droplet

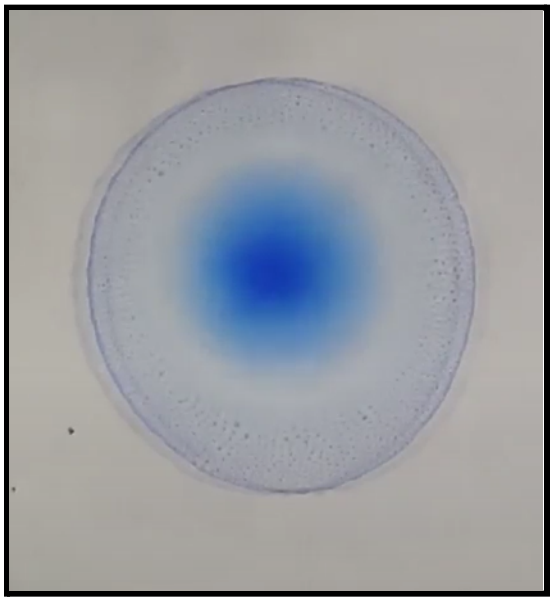

Image 5: The mother droplet disintegrating into tiny droplets

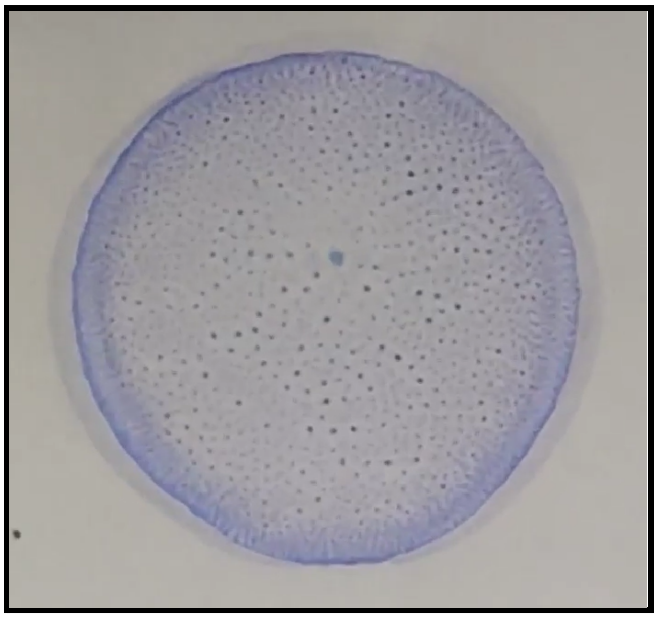

Image 6: The mother droplet disintegrated into droplets

- The effect is still observed when we take a thin oil film, but the mother droplet has a cavity in the center.

- When we take the less concentrated solution of isopropyl alcohol solution(slightly less concentration), the size of the droplets becomes big. The isopropyl alcohol solution used has a weight fraction of 0.5 of isopropyl alcohol.

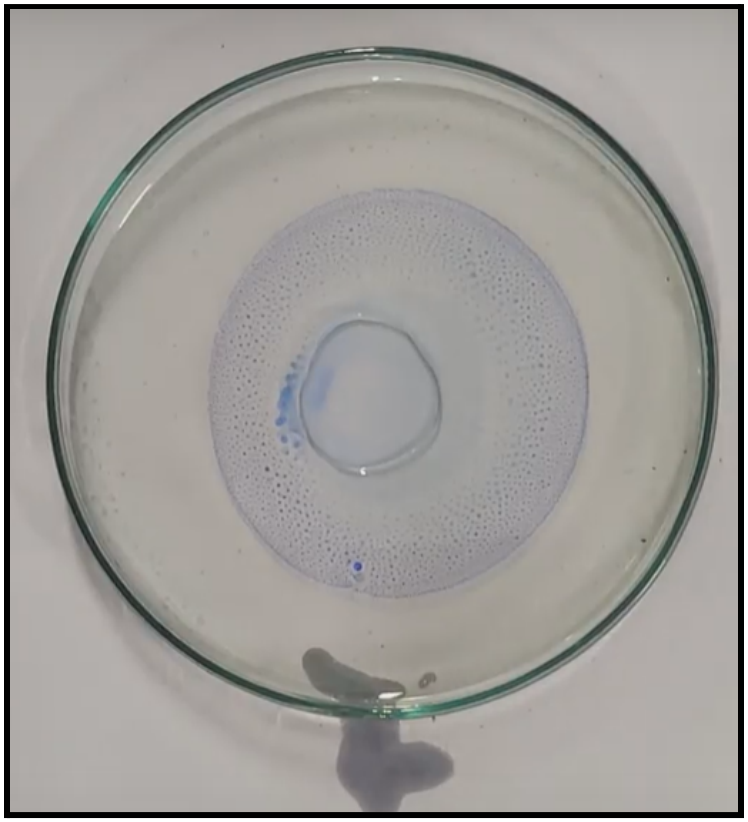

Image 7: The mother droplets disintegrate into smaller droplets for a more concentrated isopropyl alcohol solution.

Sources of error:

- There might be impurities in the water.
- The pepper is not powdered and is heavy enough to sink in water film.
- The concentration of isopropyl alcohol solution may change because isopropyl alcohol is highly volatile and it evaporates with time.
- The film of oil might be very thin.

Challenges faced:

Originally, our experiment was Taylor's column, and we encountered many challenges while making the setup of that experiment. We changed our project because of the multiple issues that we faced while making the rotating platform of the experiment. We worked continuously for numerous days, and then we reached a point where it was impossible to complete the experiment in the given duration. The challenges we faced are:

- Initially, we thought of making the platform using a servo motor or an automatic turntable, but it was not possible because of expensive parts and the non-availability of parts.
- Then, we thought about making the rotating turntable using parts of the cycle. We used bearings and a shaft to make a rotating mechanism. Nevertheless, when we welded the bearing to the cycle gear, the bearing components expanded due to thermal expansion, and the free movement of the bearing was lost, due to which our rotating mechanism failed.

Image 8: The rotating mechanism which does not rotate freely.

Still, we learned a lot from this experience, such as how to cut steel, weld, grind, file, and many other things.

In the Marangoni effect experiment, we faced challenges like:

- Finding a substance that would spread on the water surface without settling down and dissolving was challenging.
- Having the droplet with a sufficient concentration of ethyl alcohol creates an adequate surface tension gradient due to the evaporation of alcohol on the boundary of the spreading droplet.

Applications:

❖ **Industrial Application**

- In integrated circuit manufacturing, the Marangoni Effect is commonly used to dry silicon wafers after a wet processing phase. During wet processing, the liquid patches on the wafer surface can lead to oxidation, harming the wafer's component.
- The Marangoni Effect in Nanoemulsion is used to improve the Waterflooding Technology for Heavy-Oil Reservoirs.
- This effect has been used to self-assemble nanoparticles into ordered arrays and generate ordered nanotubes artistically. It can be achieved by spreading the alcohol-containing nanoparticles on the substrate, and the alcohol evaporates. Water condenses and creates microdroplets on the substrate. Meanwhile, the nanoparticles in the alcohol are transported into the microdroplets, where they eventually dry to create many coffee rings on the substrate.
- The Marangoni effect is also significant in welding, crystal development, and metal electron beam melting.
- The Marangoni Effect can also obtain fresh water from the sea.

❖ **Everyday life Application**

Tears of wine, sometimes also called legs of wine, are a fluid dynamic phenomenon based on the Marangoni effect, which occurs due to a gradient of surface tension within the mixture of alcohol and water. A location with a lower concentration of alcohol will exert a more potent force on the surrounding fluid than a region with a greater concentration of alcohol. As a result, the liquid flows away from areas with greater alcohol concentrations. At the surface, due to the higher volatility of alcohol, it evaporates and creates a low alcohol concentration region. Water droplets rise up the glass's surface, lowering the glass's surface energy and dropping back into the wine. Therefore, the dropping of the droplets of wine appears to be like tears, and this effect is referred to as Tears of wine.

Image 9: Shadow reflection shows "tears" in a glass of wine.
Source:
https://www.nasa.gov/mission_pages/station/research/news/marangoni.html

Future Scope:

- Marangoni negatively affects crystal growth quality such as semiconductors, optical materials, or biotechnology materials. The convection also occurs in a heat pipe for heat radiation devices in personal computers and degrades the radiation performance. Therefore, increased understanding of Marangoni convection expands our knowledge of fluid behavior and has great significance for the production of semiconductor materials and equipment development for both space and ground use.
- It might have significant consequences for creating a new generation of desalination materials and devices, enabling them to self-clean the accumulated salt and ensure stable and long-term functioning.

Conclusion:

When the soap solution is added to the water, the surface tension near the soap solution drop decreases because soap decreases the surface tension of water. Due to this decrease in the surface tension, the pepper powder spread across the surface is pulled backward by the high surface tension fluid(water). This observation is due to the Marangoni effect. When the drop of soap solution is added, a surface tension gradient is introduced across the film's surface, due to which mass transfer takes place.

- When the isopropyl alcohol solution is added to the Petri dish containing a thin film of oil, a surface tension gradient is introduced over the surface. Due to the surface tension gradient, the isopropyl alcohol solution drop forms a ring. Then, as time passes, the solution in the middle is slowly pulled by the outer ring. This is because the alcohol in the drop keeps on evaporating, due to which a surface tension gradient is present until all the alcohol is evaporated. Due to this continuous surface tension gradient, the pattern is observed.
- When isopropyl alcohol solution with less concentration is used, bigger droplets are formed because the evaporation rate is faster; hence the surface tension gradient is more significant, and more mass is pulled.

References:

- On certain curious Motions observable at the Surfaces of Wine and other Alcoholic Liquors. The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science. 1855. pp. 330–333
- Marangoni Convection". COMSOL. Archived from the original on 2012-03-08. Retrieved 2014-08-06.
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