Exploring the interaction between Isopropyl alcohol mixture and oil

探討異丙醇水溶液與油的交互作用

TZ-CHING, TSENG 曾梓晴 ; YU-LIN, TU 涂鈺琳
u090024@chgsh.chc.edu.tw ; u090013@chgsh.chc.edu.tw
National Changhua Girls' Senior High School

Abstract

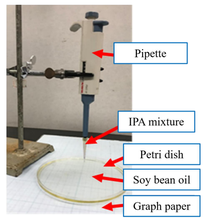
In the experiment, we use Isopropanol alcohol (IPA) mixture and soybean oil to carry out the experiment. First, we drop the IPA mixture on the surface of soybean oil, and the shape is like an ellipse, so the thickness of the center droplet is higher and that of the edge is thinner. As gravity in the down direction, the concentration in the center will gradually become thinner. Due to the difference in thickness between the center and the edges, after evaporating, the concentration will be different, resulting in a poor surface tension gradient, which will further promote Marangoni effect.
In our study we will mainly focus on explaining all the observed phenomena, like the edge of a droplet breaking up into smaller droplets. We will also discuss the conditions whenever this phenomenon occurs, such as expansion and shrink

Introduction

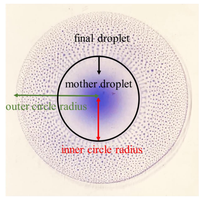
• Motivation
When a bowl is filled with water, sprinkling pepper powder, and dripping dishwashing liquid, the pepper particles floating on the water will be expelled to the edge of the bowl. It is related to the Marangoni effect, which is caused by surface tension gradient difference. We try to explore the conditions whenever this phenomenon occurs in further detail. So, we design the experiment between hydrophobic liquid and hydrophilic liquid.
• Experiment statement
We have tried a variety of hydrophobic mixtures and found that the mixture of Isopropanol (IPA, C_3H_8O) and water is the most prone to droplet fragmentation. Therefore, we use isopropyl alcohol solution and use a pipette to drop this mixture on the surface of soybean oil. We define the initial droplet as the mother droplet.
• Aim
1. Investigate the conditions under which the Marangoni effect occurs and how it affects droplet fragmentation.
2. Find out the parameters formula that affects the process of droplet expansion and fragmentation.
3. Understand the fluid instability behind this droplet fragmentation phenomenon.
4. To find out the role of surface tension in the process of mother droplet expansion.

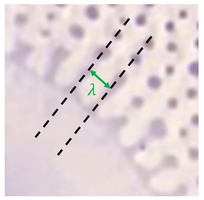
Experimental method

Experimental setup



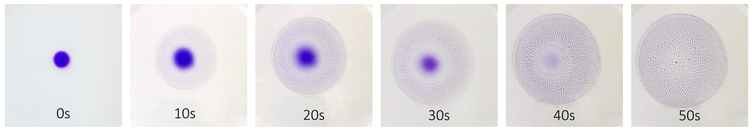
Definition for the research





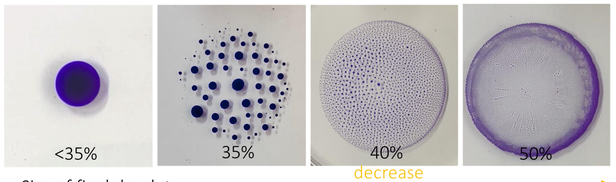
Experiment observation

The process of droplet explosion



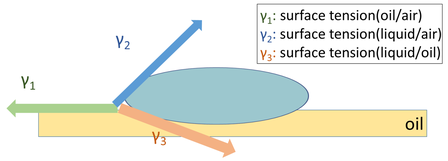
1.The outer circle radius increases over time.
2.The inner circle radius first increases and then decreases over time.
3.The color of the center of the mother droplet gradually becomes shallow.
4.The thickness of the center of the mother droplet gradually becomes thinner.

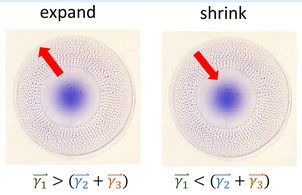
Final droplet sizes in different concentration



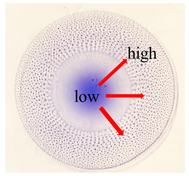
Theoretical Model

I. Force Analysis-Young's equation



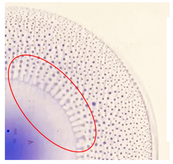


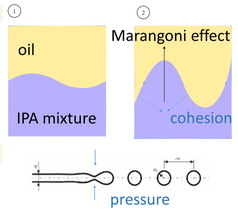
II. Marangoni effect



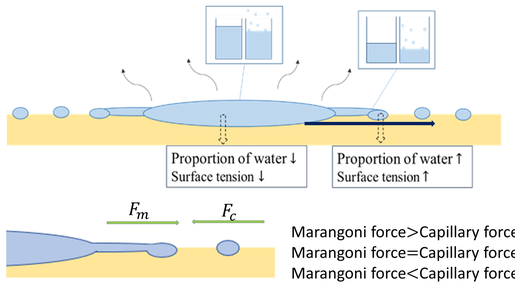
Marangoni flow goes is through lower surface tension to higher surface tension. Since the evaporation rate of IPA is faster than that of water, the center concentration of the mother droplet is higher than the edge concentration. And cause the surface tension gradient.

III. Plateau-Rayleigh instability





IV. Surface Tension Analysis



Because the center of the droplet and the edge surface contact the same air area, the same amount of liquid is evaporated. Because the edge is thinner, the proportion of the edge evaporated is higher, and the water content of the edge is higher than that of the center. The surface tension of water is greater than that of IPA, so the surface tension of the edge is higher than that of in the center.

Marangoni force>Capillary force ⟶mother droplet expand
Marangoni force=Capillary force ⟶mother droplet reach maximum radius
Marangoni force<Capillary force ⟶mother droplet shrink

IV. Model-formula

1.Marangoni effect velocity $V \sim \frac{\Delta\gamma H}{R\eta_0}$ (Equ. 1)
2.Expand time $\tau \sim \frac{R}{V}$ (Equ. 2)
3.Conservation of evaporation $(\emptyset_0\Omega_0 - \emptyset_c\Omega_f) \sim j_v R^2 \tau$ (Equ. 3)
4.Conservation of volume of water $(1-\emptyset_0)\Omega_0 = (1-\emptyset_c)\Omega_f$ (Equ. 4)
After we combine equation 1 to 4, we will get

$$R \sim \left(\frac{(\emptyset_0-\emptyset_c)\Delta\gamma H\Omega_0}{(1-\emptyset_c)\eta_0 j_v}\right)^{1/4} \text{(Equ.5)}$$

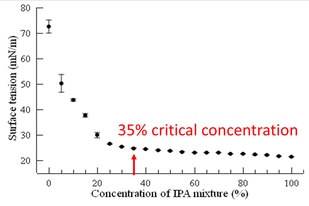
$$\tau \sim \left(\frac{(\emptyset_0-\emptyset_c)\eta_0\Omega_0}{(1-\emptyset_c)\Delta\gamma H j_v}\right)^{1/2} \text{(Equ. 6)}$$

R	The inner circle radius
τ	total experiment time
$\emptyset_0$	initial alcohol concentration
$\emptyset_c$	critical concentration
Ω_0	initial volume
H	depth of the oil
γ	effective tension
η_0	viscosity constant
j_v	evaporation constant

Experimental Result & Discussion

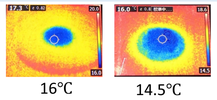
I. Surface tension

Surface tension of different IPA concentration at 20℃



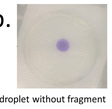
II. Evaporation

a.



Since evaporation cause the loss of heat, lower temperatures indicate evaporation.

b.

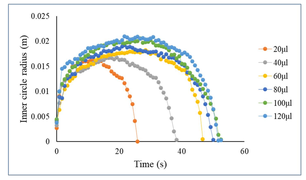


We covered the experimental device with a transparent acrylic cover and sprayed it with isopropyl alcohol to saturate the internal environment and no longer evaporate. The mother droplet does not fragment into small droplets, which proves that evaporation is a very important factor.

Experimental Result & Discussion

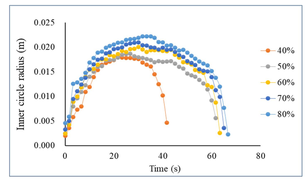
Variable I. Isopropyl alcohol volume

Control variables: thickness of oil (0.5cm), initial concentration of IPA mixture (40%), and temperature (20°C), humidity (68%)

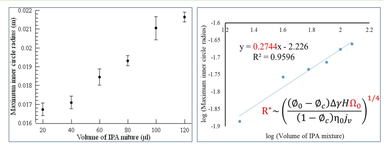


Variable II. Isopropyl alcohol concentration

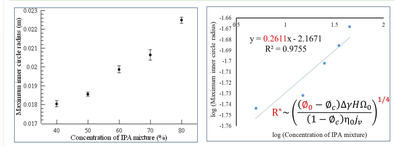
Control variables: thickness of oil (0.5cm), initial volume of IPA mixture (40μl), and temperature (20°C), humidity (68%)



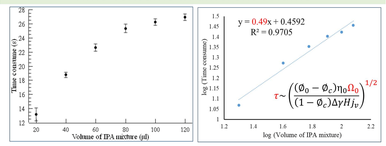
Maximum inner circle radius in different volume



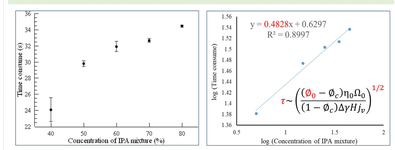
Maximum inner circle radius in different concentration



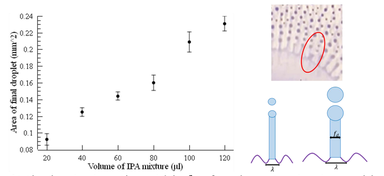
Time consume in different volume



Time consume in different concentration

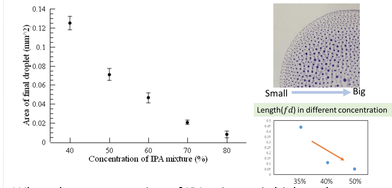


Final droplets size in different volume



At the beginning, the width f_d of each protrusion is roughly the same. When inner circle radius begins to shrink in the later period, two bumps combined into a bigger one. When f_d is wider, the area of the resulting droplet also becomes larger. The larger the amount of IPA mixture dropped, the larger the radius of the inner circle that can be reached. larger the droplet formed.

Final droplets size in different concentration



When the concentration of IPA mixture is higher, the continuous evaporation will cause the greater difference in the tension between the center and the edge of the droplet. The relative wavelength of the protrusions will be smaller, and the smaller the wavelength will cause the width of the protrusions f_d .

Conclusion

The difference in surface tension gradient caused by evaporation leads to the Marangoni effect which makes the droplet expand outward. As for the Plateau-Rayleigh instability, it is the reason that causes the jagged edges of the droplets at first, and then eventually breaks into small droplets. According to our research, when changing the volume of isopropyl alcohol solution, the larger the volume is, the longer time it would take, and the larger the final droplet size and the maximum radius of the inner circle would be. On the other hand, we change the concentration of isopropyl alcohol to make differences of tension gradient between the inside and outside of the droplet. We found out that the greater the tension gradient is, the longer time it would take, and the larger the maximum radius of the inner circle would be, but the smaller the final droplet size becomes.

Application

The theory of the Marangoni effect can be applied to welding, where the temperature distribution and flow conditions affected, resulting in a change in the shape of the material. Therefore, if we can find out the critical value at which this effect occurs, it will help to avoid the defect rate during welding.

Reference

[1] Phys. Rev. Lett. Marangoni Bursting. 118, 074504 (2017).
[2] R Mead-Hunter, AJC King, BJ Mullins. ACS Publications. Langmuir, 2012.
[3] R.T. van Gaalen, C. Diddens, H.M.A. Wijshoff, J.G.M. Kuerten. Marangoni circulation in evaporating droplets in the presence of soluble surfactants. Science direct. 18 August 2020.
[4] Pijush K. Kundu. Science Direct. 2016.