23rd IYPT Problem 10: Calm Surface

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Abstract

When wind blows across a water surface, waves can be observed. If the water is covered by an oil layer, the waves on the water surface will diminish. Investigate the phenomenon.

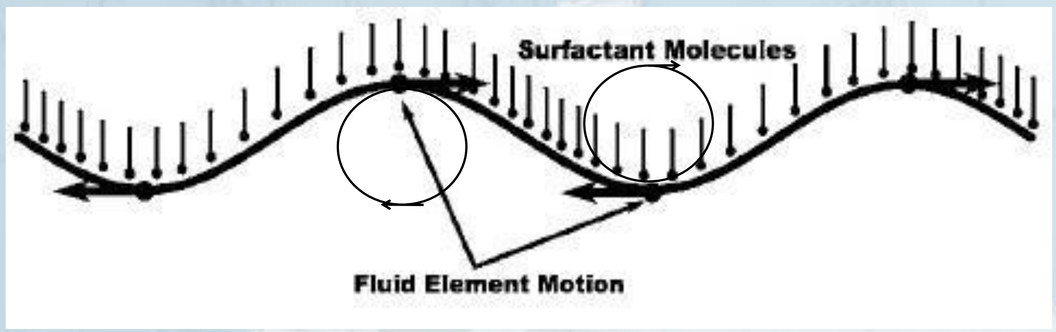
Two calming effects can be observed with increasing oil volume added to a water surface. First, when there is little oil, patches of oil form on the surface. The waves dissipate energy by scattering when hitting the interfaces of oil patches and water. Second, when there is sufficient oil such that the oil becomes one large layer. Here, the Gibb's elasticity of the oil layer causes energy to be dissipated when the water waves oscillate, hence diminishing the waves.

However, the oil layer loses its calming effect under some conditions, e.g. when the wind is too strong, causing the oil layer to break into droplets; or when the oil layer is so thick that waves form directly on the oil surface.

Experimental Setup

(a)Screen and camera
(b)Crossflow fan with vanes
(c)Wide ripple tank
(d) anemometer
(e)Wave generator

Theory



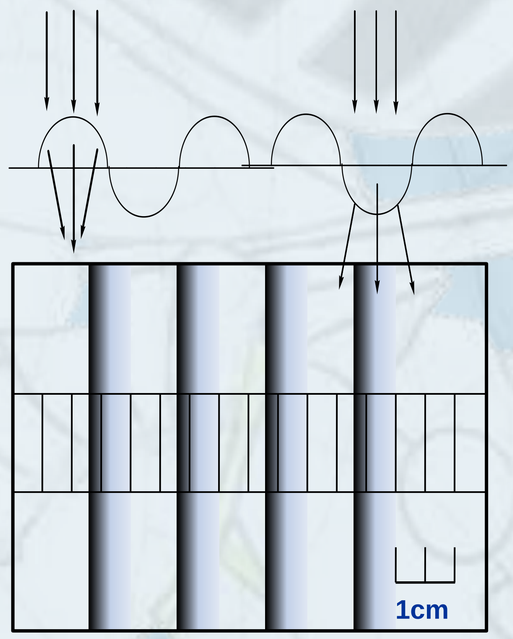
■Gibbs elasticity:

Change of surface tension to change of area of surfactant layer.

$$E \equiv 2\frac{d\sigma}{d\ln A}$$

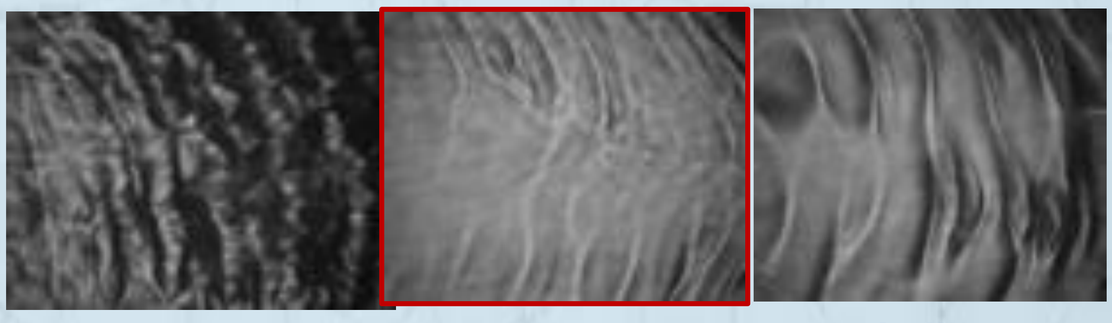
■Observation method:

Light bands indicate crests while dark bands indicate troughs. If the waves were larger, the brightness of the photos would be more contrasted. Thus, by analyzing the brightness deviation of the photo, we can compare the "roughness" of the surfaces.

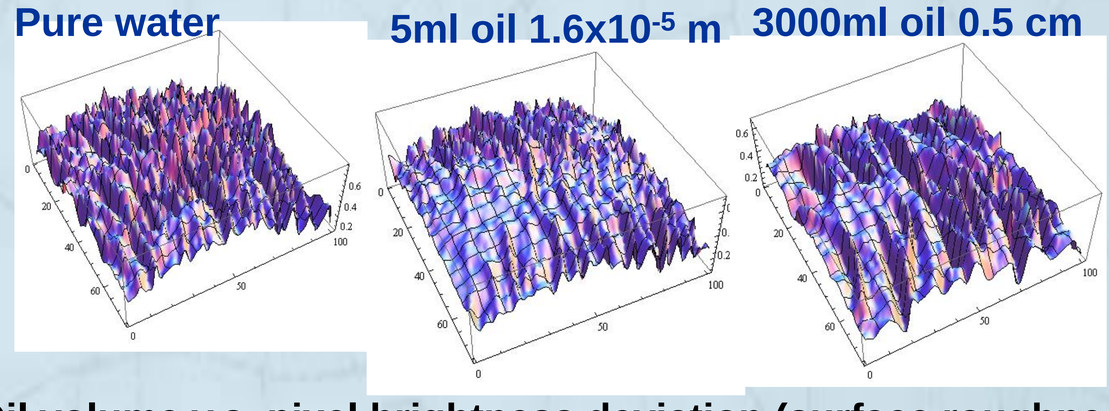


Results

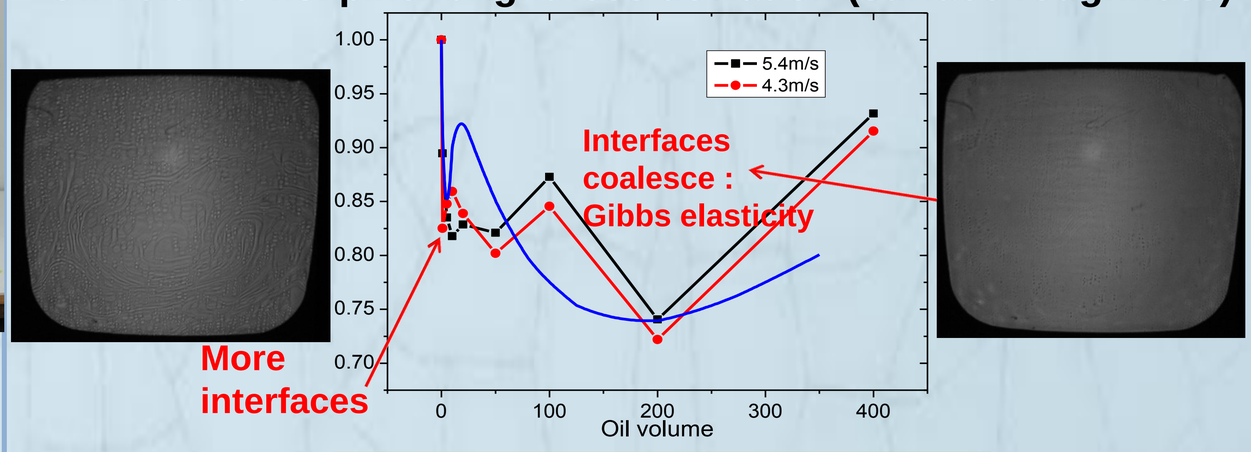
■Wind blown waves:



Pure water | 5ml oil 1.6x10^{-5} m | 3000ml oil 0.5 cm

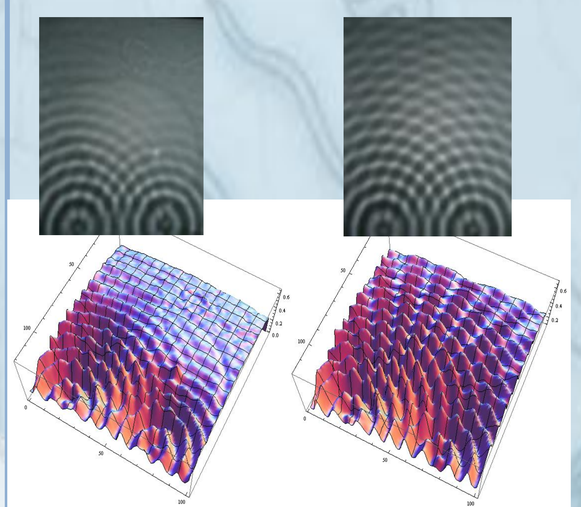


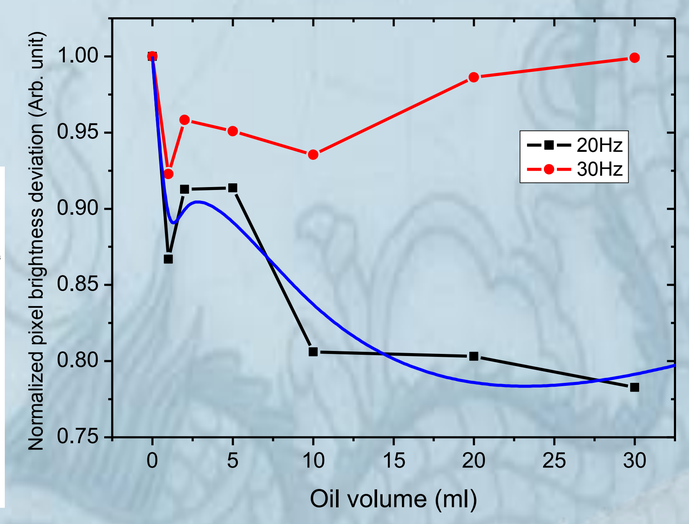
•Oil volume v.s. pixel brightness deviation (surface roughness)



$$S=1-c_{r1}Vexp(-V/c_{t1})-c_{r2}Vexp(-V/c_{t2})$$

■Ripple generator waves:





Conclusion

- There are two calming effects observed when oil is gradually added to water. Interfaces of oil patches and water can scatter waves, dissipating energy. Gibb's elasticity may also cause wave energy loss due to expansion and contraction of the oil layer.
- Two minimum pixel brightness deviation (surface roughness) can be observed for both wind blown waves and generator waves, indicating the two calming effects.

Reference

[1] Behroozi, Peter. Et. Al. The calming effect of oil on water. AJP, Vol. 75, Issue 5, pp. 407-414 (2007)