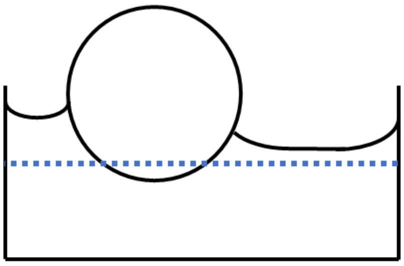
INFLUENCE OF SURFACE TENSION ON FLOATING RIGID BODIES

Taras Kuzyk,
11th form student Lyceum 1, ***Chernivtsi city, Ukraine,*** ***kuzyktaras@yahoo.com***
Supervisor: Oleg Orlyansky, Dnipro National University

Problem definition

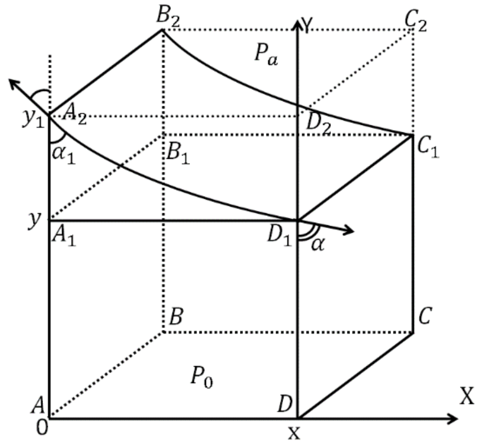
There is a common way of showing surface tension in action: if we put a ping-pong ball into a glass filled with water, it starts "*sticking"* to the edges, and if we overfill the vessel so that some of the water is above the edges of the glass, the ping-pong ball will start *moving towards the center*. To explain this sort of movement we need to concider two factors, the latter of which is often overlooked: the surface tension itself, and the *difference in pressure* on the two sides of the ping-pong ball. The difference of pressures comes from the cappilary effect, meaning that if the object is closer to the vessel's walls, the water inbetween the two will start rising upwards (Pic. 1). Due to the decrease in pressure with increase in heightm pressure will be lower on the side of the object with the higher level of liquid. Consequently, the object will move towards the walls in the given example.



Pic. 1. Schematical depiction of the ping-pong ball experiment. The water level at which pressure is equal to atmospheric is shown as a blue line. The ball is moving to the left.

We decided to develop a mathematical model that would describe movement of a ***rigid object*** *on top of a* ***liquid surface****.*

Mathematical Model



Pic. 2. A piece of the meniscus that we considered. This is an imaginary cut, were the bottom half (below the line A_2D_1) is water and the upper one is air.

To develop an accurate mathematical model, we needed to take into account the height at which the object is positioned at every point of its motion, which is something other studies neglect. Since our vessels are small, the capillary effect cannot be ignored, meaning that previous models (such as that proposed by Markus Deserno in 2006 [2]) that describe the shape of the meniscus will not be applicable. This is why we created our own mathematical model.

The proposed model considers a small slice of the liquid as shown in Pic. 2. It resulted in the following equation

$$x = -\int_{y_1}^{y} \frac{\sin\alpha}{\sqrt{1-\sin^2\alpha}}\, dy,$$

$$where\ \sin\alpha = \sin\alpha_1 + \frac{\rho g (y_1^2 - y^2)}{2\sigma}$$

Differentiating the above equation describes the shape of the meniscus. However, being an elliptical integral, there is no straight forward analytical solution, so a numerical solution was used.

A computer model was built using Maple software, which allowed to vary parameters and see their effects on the solution. Experimental data was then collected, and found to be in close agreement with the model.

Applications

Surface tension is widely used in the industry for separating materials (waste-water treatment, minerals processing etc.) using froth flotation. We proposed two new ways of separating materials using the different behaviour of hydrophobic and hydrophilic objects on water surface. Our model can be used to analyze these methods and optimize the equipment design (sizes of parts, efficiency, etc.) The model could also potentially be used in some medical analysis [4].

References

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4. A. Fathi-Azarbayjani, A. Jouyban, 'Surface tension in human pathophysiology and its application as a medical diagnostic tool, 2015.

5. V. A. Saranin 'Ravnovesiye zhidkostey i yeho ustoichivost', 2002, p.35-43.