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Using Jolly Balance Spring Method to Determine Pure Water Surface Tension Coefficient

Duden Saepuzaman*, Muhamad Gina Nugraha, Regiana Dewi, Fitri Kafiyani and Fanny Herliyana Dewi

Departemen Pendidikan Fisika, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi, Bandung 40154, Indonesia

ABSTRACT

The surface of a liquid at rest behaves in an interesting way, almost as if it was a stretched membrane under tension. A steel needle can be made to float on the surface of water even though it is denser than water. The surface of a liquid acts like it is under tension, and this tension, acting along the surface, is a product of attractive forces between the molecules. This effect is called surface tension. There are various methods to determine the surface tension coefficient of a liquid. This research focused on determination of pure water surface coefficient using Jolly's Spring Balance. The parameter measured is the height of the liquid bubbles at critical condition that in the right condition will break. Repeated measurement methods that are statistically processed are used to measure uncertainty. The magnitude of pure water surface value using Jolly Balance Spring Apparture's obtained γ (water) = $(3,620 \pm 0.0028) \times 10^{-2}$ N / m at temperature (27 ± 0.25)°C and pressure (68.8 ± 0.005) cmHg. Liquid used in this research is pure water at temperature 27°C.

Keywords: Altitude, jolly's balance spring, surface tension

INTRODUCTION

Surface tension is the surface property of a liquid that behaves like a thin layer of skin that is supple due to stress (Chappuis, 1982). Mathematically, the surface tension is the force of each unit of length parallel to the surface to compensate for the inward pull force of a fluid (Brakke, 1992). This happens because on the surface, the adhesion force (between fluid and air) is smaller than the

cohesive force between the fluid molecules causing the inward force on the fluid surface (Wu, 1973).

A liquid consists of molecules. The forces acting on each molecule have the same magnitude and work in all directions, so that the molecules between them are pulled together (Eijkel & Van Den Berg, 2005). The molecular force resistivity in the liquid is zero. While on the surface, the resultant force points downward and tends to depress the surface layer but only to the extent that the downward force is offset by the upside-down force. Thus, the surface tension is defined as the magnitude of force experienced by the liquid surface per unit length (or equivalent to the energy per unit area) (McConney, Singamaneni, & Tsukruk, 2010). It can be mathematically expressed as (Reyssat, 2014):

$$\gamma = \frac{F\gamma}{l} \tag{1}$$

with γ is the surface tension (N m^{-1}), $F\gamma$ is the force acting on the fluid surface (N), and l is the length of the object on the fluid surface (m). The determination of the magnitude of the surface tension is characterised by the coefficient of surface tension having unit force per unit length, N m^{-1}, or energy per unit area, J m^{-2}.

There are several methods to measure the surface tension coefficient, for example, pull-off method. As for the pull-off method, a du Noüy ring or Wilhelmy plates (Gaonkar & Neuman, 1984) will be hung under a dynamometer and immersed into the test liquid. Then the dynamometer is used to measure the force used to pull the ring or plate out of the liquid. By analysing the force on the ring or the plate, the surface tension coefficient of the test liquid can be calculated. For the du Noüy ring method, the wetting properties of the surface or interface have little influence. The Wilhelmy plate method is a universal method that is particularly suited to check surface tension over long intervals. Many studies have examined the pull-off method on using a silicon piezoresistive force sensor to improve measurement accuracy, reduce operational complexity and simplify the steps (Tang, Liu, Qian, Sun, & Zhang, 2016).

This study used the pull-off method to measure the surface tension coefficient using Jolly Spring Balance method with circular ring used as force gasifier on fluid surface . This method is simple because we observe the critical condition before the water surface tension break-off.

METHOD

The surface tension of a liquid using Jolly balance uses a thin ring as an indicator of the breaking of the surface tension of the liquid. Tools used are shown in Figure 1.
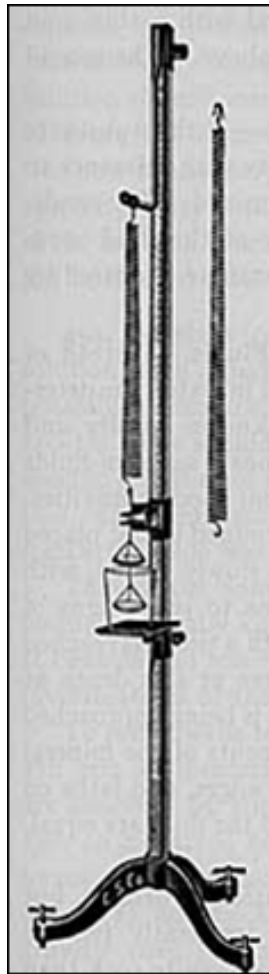
Figure 1. Jolly balance apparatus

At the end of the Jolly's balance apparatus, there is a hanger that serves to hang the spring. There is a stage where the height can be adjusted, the stage is used as a place to store the cup, which is used as a liquid site to determine the value of surface tension coefficient. At the bottom of the stage there is a micrometre screws which are used to lower the cup. Care had to be taken the jolly spring balance stands upright by adjusting the screw on the bottom of the jolly spring balance tripod. This situation can be ensured by using a water pass placed on the stage. In determining the surface tension, a wire ring is used. This wire rings are attached to the springs, which slowly rotate the screw micrometry so as to raise the cup closer to the wire ring until the bottom of the ring reaches the liquid surface directly. The height indicated by the micrometre is the initial height (h_0). After that, the saucer is lowered slowly until the surface tension / liquid membrane breaks precisely. The height at that condition is the final height (h_1). The difference between h_1 and h_0 ($h = h_1 - h_0$) is a parameter calculated repeatedly in the experiment of determining the surface tension by using this Jolly spring balance.

The force acting on the ring is shown in Figure 2.
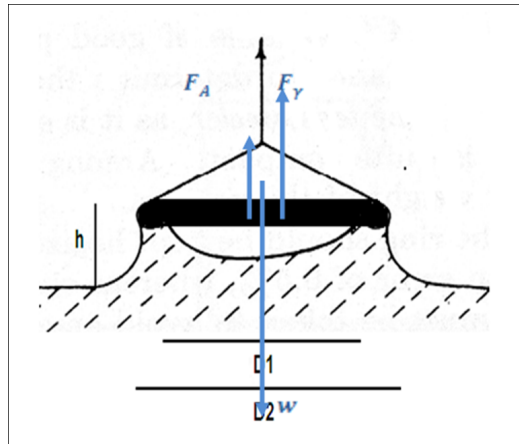
(a)

(b)

Figure 2. The critical condition at the time of the surface membrane / surface tension will break

To keep the object moving on the surface of the fluid (the object is in equilibrium), a total force downwards is required, where the total force is $F_{res} = w - F_\gamma + F_A = 0$ or $w = F_\gamma + F_A$. With the weight of the ring, $w = m.g$; liquid surface tension; $F_\gamma = \gamma . l$; and the magnitude of the buoyant force $F_A = \rho f . g . V$ (Wu, 1973)

Since the object used is a ring, the following satisfies the condition (1) of the ring on the obtained surface tension force:

$$F_\gamma = \gamma \frac{(l_2 + l_1)}{2}$$

$$F_\gamma = \gamma \frac{(2\pi d_2 + 2\pi d_1)}{2}$$

$$F_\gamma = \gamma \pi (d_2 + d_1) \tag{2}$$

The volume (in the floating force equation) is the difference in the volume of the outer diameter tube (d_2) with the inner diameter (d_1). Therefore, we have the following:

$$F_A = \rho_f . g . (V_2 - V_1)$$

$$F_A = \rho_f . g . \left(\frac{1}{4}\pi d_2{}^2 h - \frac{1}{4}\pi d_1{}^2 h\right)$$

$$F_A = \rho_f . g . \frac{1}{4}\pi h \left(d_2{}^2 - d_1{}^2\right) \tag{3}$$

Substituting equations (2) and (3) to w = $F_\gamma + F_A$, the following is obtained:

$$m.g = \gamma \pi (d_2 + d_1) + \rho_f . g . \frac{1}{4}\pi h \left(d_2{}^2 - d_1{}^2\right)$$

$$\gamma \pi (d_2 + d_1) = m.g - \rho_f . g . \frac{1}{4}\pi h \left(d_2{}^2 - d_1{}^2\right)$$

$$\gamma = \frac{m.g}{\pi(d_2 + d_1)} - \frac{1}{4}\frac{\rho_f . g . \pi h \left(d_2{}^2 - d_1{}^2\right)}{\pi(d_2 + d_1)}$$

$$\gamma = \frac{m.g}{\pi(d_2 + d_1)} - \frac{1}{4}\frac{\rho_f . g . \pi h (d_2 - d_1)(d_2 + d_1)}{\pi(d_2 + d_1)}$$

$$\boldsymbol{\gamma = \frac{m.g}{\pi(d_2 + d_1)} - \frac{(d_2 - d_1)}{4}\rho_f . g . h} \tag{4}$$

with γ surface tension (N /m), m mass of object (kg), acceleration of earth gravity g (m/s^2), d2 outer diameter of ring (m), d_1 inner diameter of ring (m), ρ_f density of fluid (kg / m^3), and h height of fluid when attached to the object (m). Temperature is one of the factors that affect the value of surface tension of the fluid. Generally, when there is an increase in temperature, the surface tension value decreases. This is because when the temperature increases, fluid molecules move faster so that the interaction effect between fluid molecules is reduced. As a result, the surface tension value also decreases. Value of surface tension is influenced by several factors, among others, temperature, pressure, density and concentration of solute (Harrison, Johnston, & Sanchez, 1996).

Measurement of necessary data is done repeatedly to minimise the magnitude of uncertainty. The determination of the surface tension value, $\gamma = (\overline{\gamma} \pm \Delta\gamma)$ N / m, with the uncertainty value

used based on the uncertainty value on the single variable over and over. With $\overline{\gamma}$ is the average surface tension value and $\Delta\gamma$ the number of uncertainties can be expressed as:

$$\Delta\gamma = \left(\frac{(d_2 - d_1)}{4}\rho_f \cdot g\right)(\Delta h)\sqrt{\frac{1}{n-1}} . \tag{5}$$

RESULTS AND DISCUSSION

Data was obtained from the experimental results to determine the surface tension. Water density (ρ_f) value of 1000 kg/m^3 measured using Aerometer instrument, inner (d_1) and outer (d_2) diameter of metal rings, 1.84 cm and 1.98 cm respectively were measured using a Vernier Caliper, and a gravity acceleration value of the research site (g) of 9.8 m/s^2 obtained from literature. The height of water data at the critical condition (Δh) was obtained using jolly balance with repeated measurement 5 times as shown in Table 1.

Table 1
The results of height water surface in critical condition

No	h_1 (± 0.05)x10^{-3} m	h_0 (± 0.05)x10^{-3} m	Δh (± 0.05)x10^{-3} m
1	20.3	14.7	5.6
2	20.4	14.7	5.7
3	20.5	14.9	5.6
4	20.4	14.8	5.6
5	20.3	14.6	5.7
Mean			5.64
Standard deviation			0.0548

Based on Table 1, it could be seen that water level at critical condition has a consistent value with the average of 5.64 cm (5.64 x 10^{-3} m) and standard deviation 0.0548. This value is then processed with other data to obtain the surface tension value using the above formula.

Based on the data processing result, water surface tension value of water γ water is (3.620 $\pm$ 0.0028)$\times$10^{-2} N/m at temperature (27 $\pm$ 0.25)°C and pressure (68.8 $\pm$ 0.005) cmHg. The result is inconsistent with literature findings, i.e. at water temperature 0°C, water surface tension value γ is 7.6$\times$10^{-2} N/m; at water temperature 20°C, water surface tension value γ is 7.2$\times$10^{-2} N/m; and at water temperature 100°C, surface tension value $F\gamma$ is 5.9$\times$10^{-2} N/ m. (Vazquez, Alvarez, & Navaza, 1995)

The inconsistency in findings is due to several factors, namely the presence of convex nature of meniscus in water resulting from the interaction between water molecules and different molecules (in this case with molecules in the ring) (Nandiyanto, Hagura, Iskandar, & Okuyama, 2010). The meniscus symptoms result in an inaccuracy when determining the initial height of the ring just as it touches the surface of the liquid. In addition, the precise bubble conditions where it breaks should be achieved in equilibrium where the resultant force acting on the system is equals to zero, and the resultant force measured in the formula comes only

from the gravity of the ring, the buoyant force of the liquid and the surface tension force (Wu, 1973). However, when experimenting there are external disturbances, such as the presence of vibrations that result in oscillating springs. Thus, the precise of surface tension conditions will break apart by other unmeasured forces in the formulation.

Although the value of surface tension obtained is different from what was reported in the literature, it is not due to the pure water used, but it could also be due to the procedure and the set of tools that still need to be reviewed and further developed.

CONCLUSION

Determination of pure water surface value using Jolly Balance Spring obtained γ (water) = $(3{,}620 \pm 0.0028) \times 10^{-2}$ N / m at temperature $(27 \pm 0.25)°$C and pressure (68.8 ± 0.005) cmHg. Further studies and research are needed to obtain the accuracy of surface tension values.

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