

## Temperature Dependence of Density and Dynamic Surface Tension of Groundnut Oil and Palm Oil

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### -----ABSTRACT-----

In this paper, the density and surface tension of locally produced groundnut oil and palm oil in Yola, Nigeria were measured at different temperatures using the ‘catch overflow’ method and capillary rise method respectively. The results show that the density and surface tension of groundnut oil and palm oil decreases linearly with increasing temperature. The density regression line  $\rho_{gnut} = -0.6442T + 1089.6$ ,  $R^2 = 0.9994$  and  $\rho_{palm} = -0.6590T + 1093.3$ ,  $R^2 = 0.9929$  and that of surface tension  $\gamma_{gnut} = -0.08280T + 59.2360$ ,  $R^2 = 0.9913$  and  $\gamma_{palm} = -0.0860T + 59.8260$ ,  $R^2 = 0.9551$  show that the density and surface tension of groundnut oil decreases with temperature faster than those of palm oil. This is a good signature that groundnut oil is preferred to palm oil in cooking meals since lower surface tension medium to provide more surface area for digestion and transport of food from mouth to stomach.

**Keywords:** Density, Surface tension, Temperature, Capillary rise, Catch overflow, Oil

Date of Submission: 27-May-2015



Date of Accepted: 20-June-2015

### I. Introduction

Surface tension is the fundamental property of a liquid, which makes the free surface of a liquid, behaves like a stretched elastic membrane. It is also an inherent property of a liquid to alter its shape in such a way that the area of its free surface is minimum possible. According to the molecular theory, this arises, because the molecules in the bulk of the liquid experience zero resultant intermolecular force due to their nearest neighboring molecules while the molecules in the surface of the liquid experience finite resultant intermolecular force acting inwardly the bulk of the liquid due to excess neighboring molecules below them. Because of the inherent tendency of a liquid to contract, it behaves as if there exists in its surface a tension which acts equally in all directions. This surface tension of a liquid is defined as the force per unit length acting on either side of an imaginary line drawn in the surface at equilibrium. The direction of the force is tangential to the surface and perpendicular to the line (Emeka, 2003).

Whenever a liquid is placed in contact with a solid, the liquid surface is in general curved. When a liquid gets in contact with a solid, there exists a boundary in which there is the surface tension in solid-liquid interface. The angle between the solid surface and the tangent to liquid surface drawn from the point where the liquid surface meets with the solid surface measured through the liquid is called the angle of contact. Those liquids whose angle of contact is acute or less than  $90^\circ$  rise in the capillary tube while those liquids having angle of contact obtuse or greater than  $90^\circ$  fall or depress in the capillary tube. Similarly, liquids with concave meniscus fall in the capillary tube. Examples of liquids with acute angle of contact and meniscus concave include water, alcohol, ether, glycerin and so on. In practice, angle of contact for such liquids that rise in capillary is small, nearly zero, when they are in contact with glass. Examples of liquids with obtuse angle of contact and convex meniscus are mercury. It is crystal clear that the angle of contact also explains the shape of the liquid meniscus near a solid surface (Yerima and Ike, 2013).

In other words, surface tension can be explained in terms of cohesion and adhesion. Cohesion is the force of attraction between similar or like molecules while adhesion is the force of attraction between dissimilar or unlike molecules. Typical example of a situation where cohesion is greater than adhesion is cohesion existing between mercury molecules causing mercury to depress in glass tube. In another vein, adhesion between glass and water molecules is greater than cohesion between water molecules causing water to rise in glass capillary tube. So far has been established that liquid having acute angle of contact and concave meniscus have adhesion greater than cohesion and hence they rise in a capillary tube. Conversely, liquids with obtuse angle of contact and convex meniscus have cohesion greater than adhesion and they fall in capillary tube. Therefore the rise or fall in capillary tube due to surface tension depends on contact angle, liquid meniscus and adhesion or cohesion.

It is popularly known that the factors affecting surface tension of a liquid include temperature, nature of the liquid itself, impurities or contaminations (Yerima and Ahams, 2011) and so on. For example, detergents and temperature decrease surface tension of water. Consequently, the knowledge of surface tension has found useful applications in everyday life which include quality control in industries, upward movement of kerosene in wicks of lamp for lighting and stoves for cooking, enhances cleansing effect of soaps and detergents, movement of pond skater on water, and design of umbrella, raincoat and tents to mention not a few.

In this study, the surface tension of groundnut oil and palm oil is investigated at various temperatures. Over the years the author noticed through private communications with traders (sellers) and customers (consumers or users) of these oils patronize particularly oil based on its color, odor, taste, cost, advert slogans made by manufacturers through news media and so on. Consequently, the traders are ignorant of the effect of temperature on surface tension of the oils, displaying them under hot sun and the consumers buy out of ignorance. Consequently, in search for the effect of temperature on these oils, this work has revealed that their surface tension decrease with temperature. It has been observed that the lower the surface tension of a liquid the better it is a digestion and transport medium (Yerima and Ike, 2013) and the more its cleansing effect (Yerima and Ahams, 2011). That is, these oils are recommended to be good digestive and transport media.

## II. Theory of density and surface tension

### (a) Catch overflow method of measuring density

The density of a substance is defined as its mass per unit volume. In the catch overflow method, a liquid in a container of fixed volume  $V_o$  is slowly heated to a particular temperature by means of standard temperature regulator system in such a way that the excess liquid overflowing is collected in a beaker of known mass until the overflowing stopped. Suppose the initial mass of the liquid is  $M_o$  and the mass  $M$  of liquid overflowed when it is heated to a particular temperature, then the mass of liquid remaining in the container is  $M_o - M$ . Therefore, the density  $\rho$  of the liquid remaining in the container of constant volume  $V_o$  at temperature  $T$  is given as

$$\rho = \frac{M_o - M}{V_o}$$

### (b) Capillary rise method of measuring surface tension

Consider a fine capillary tube of uniform radius  $r$  with one end dipped in a liquid that wets the walls of the tube. Because of surface tension which acts along the inner circumference of the liquid, the liquid will rise in the capillary tube. The liquid keeps on rising until the upward force  $F_1$  due to surface tension balanced by the downward force  $F_2$  due to the weight of the liquid.

Since force due to surface tension is acting at contact angle  $\theta$ , the upward force  $F_1$  is given by (Sharma and Sharma, 1999)

$$F_1 = 2\pi r \gamma \cos\theta \tag{1}$$

If the liquid rises to a height  $h$  in the tube above the level of the liquid outside, the downward force  $F_2$  is given by

$$F_2 = \pi r^2 h g \rho \tag{2}$$

Where  $\rho$  is the density of the liquid and  $g$  is the gravitational acceleration. At equilibrium, the two forces are equal  $F_1 = F_2$ . Thus

$$\gamma = \frac{r h g \rho}{2 \cos\theta} \tag{3}$$

But in practice, for most liquids, the contact angle is small, i.e.  $\cos\theta \approx 1$ . Thus, equation (3) becomes

$$\gamma = \frac{r h g \rho}{2} \tag{4}$$

Since the surface of the liquid is not perfectly flat, it curves up or down at the wall to form a meniscus. The material in this region also contributes to the of gravity, so one often finds a correction factor to equation (4) to yield (Yerima and Ahams, 2011)

$$\gamma = \frac{r g \rho (h + \frac{r}{3})}{2} \tag{5}$$

Comparing equation (4) and (5) yields the correction factor  $f$  as

$$f = (1 + \frac{r}{3h}) \tag{6}$$

Similarly, comparing equations (3) and (5) yields  $f = \frac{1}{\cos\theta}$  and equating (6) becomes

$$\cos\theta = \frac{1}{(1 + r/3h)} \tag{7}$$

In particular, where  $r = 0.50$  mm and  $h$  in mm, equation (7) becomes

$$\cos\theta = \frac{1}{1 + \frac{0.50}{3h}}$$

$$\theta = \cos^{-1} \left( \frac{1}{1 + \frac{0.50}{3h}} \right) \tag{8}$$

Thus equations (5) and (8) can be used to calculate surface tension  $\gamma$  and contact angle  $\theta$  respectively.

### III. Experiments

There are many standard methods of determining surface tension of liquid (Addison, 1945; Bendure, 1971; Bogert and Joos, 1979; Rakshif, 1997, Yerima *et al*, 2012). In this paper, two set of different experiments were carried out to measure the density and surface tension of groundnut oil and palm oil at various temperatures.

#### (a) Measurement of density

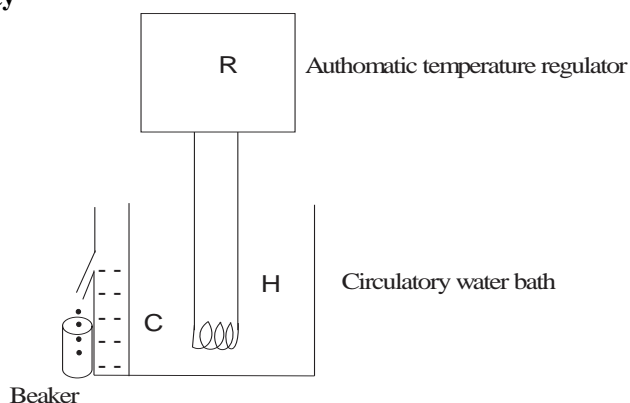


Fig.1 Schematic diagram for density measurement (Yerima et al, 2012)

The circulatory water bath is in form of an open rectangular box containing an electric heater H with automatic stirrer and temperature regulator R. the small cylinder C of fixed volume (65 ml) is sample container with slanting short open tube connected to the outside through one side of the box. A beaker is placed on top of automatic digital balance directly below the opening of the slanting tube to collect any excess liquid flowing out from C. On heating, the temperature regulator was set at a particular temperature and the heater connected to power source was used to heat the water in the bath until the oil in C ceased to overflow into the beaker. The excess mass of oil collected due to its expansion at this temperature was measured and hence the mass of oil remaining in C was calculated. The density  $\rho$  of oil at this temperature is calculated from the ratio  $\rho = m/V_o$  where m is mass of oil remaining in container C of volume  $V_o$ . This procedure was repeated for several other temperatures.

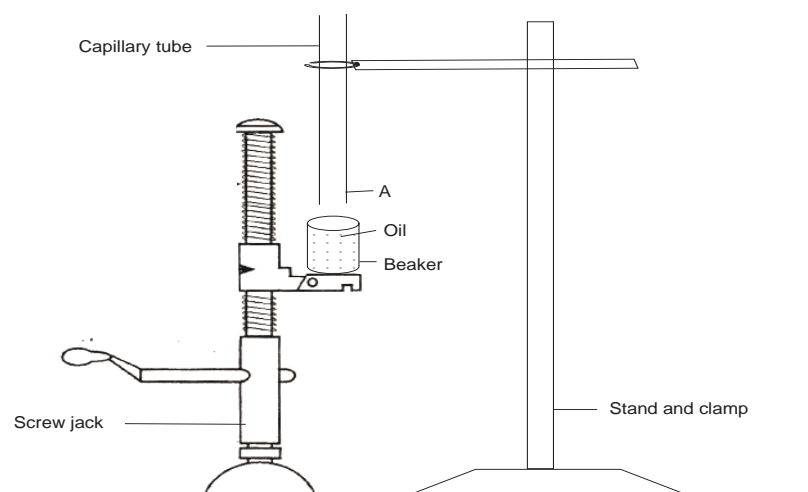


Fig. 2 Schematic diagram for measuring surface tension

The oils used in this work were brought in bottles from Jimeta modern market Yola, Nigeria. A fixed volume of oil at known temperature was poured into a beaker and placed on a flat adjustable table directly under a capillary tube of radius,  $5 \times 10^{-4}$  m suspended vertically by means of retort stand and clamp. The adjustable table was gently adjusted in a way that the beaker of water on it moved upward until the level of water in the beaker coincided exactly with a mark made on the length of the capillary tube. At this junction, the height of water, h in the capillary tube due to surface tension was measured using traveling microscope. The temperature of the water in the beaker was noted at the beginning and end of the experiment and the average recorded. This procedure was repeated for each sample of the oils at different temperatures. The diameter, d of the capillary tube was measured using a traveling microscope and hence its radius, r calculates from  $r = d/2$ . Using the measured

values of  $h$  and the calculated values of  $\rho$  and  $r$ , the surface tension  $\gamma = \frac{\rho g r}{2} \left( h + \frac{r}{3} \right)$  for oil at different temperatures was computed, where  $g = 9.81$  m/s. The contact angle  $\theta$  was calculated using the relation  $\theta = \cos^{-1} \left( \frac{1}{1 + \frac{r}{3h}} \right) = \cos^{-1} \left( \frac{1}{f} \right)$ , where  $g = 9.81$  m/s. where  $f = 1 + \frac{r}{3h}$  is the correction factor.

Table 1 Density and surface tension of groundnut oil and palm oil at different temperatures

| T(K) | Density (kg/m <sup>3</sup> ) |          | Height of oil column (mm) |          | Surface tension (mN/m) |          | Contact angle ( $\theta^\circ$ ) |          |
|------|------------------------------|----------|---------------------------|----------|------------------------|----------|----------------------------------|----------|
|      | G/nut oil                    | Palm oil | G/nut oil                 | Palm oil | G/nut oil              | Palm oil | G/nut oil                        | Palm oil |
| 313  | 887.88                       | 888.65   | 15.2                      | 15.3     | 33.33                  | 33.55    | 8.45                             | 8.43     |
| 323  | 881.35                       | 879.81   | 14.9                      | 14.5     | 32.54                  | 31.62    | 8.52                             | 8.64     |
| 333  | 875.00                       | 873.08   | 14.5                      | 14.4     | 31.43                  | 31.14    | 8.64                             | 8.67     |
| 343  | 869.23                       | 865.96   | 14.3                      | 14.0     | 30.81                  | 30.05    | 8.70                             | 8.79     |
| 353  | 862.69                       | 860.96   | 14.2                      | 13.8     | 30.32                  | 29.33    | 8.74                             | 8.88     |
| 363  | 855.58                       | 853.08   | 13.8                      | 13.5     | 29.12                  | 28.44    | 8.88                             | 8.97     |
| 373  | 849.04                       | 849.00   | 13.5                      | 13.4     | 28.25                  | 28.25    | 8.95                             | 8.98     |

In Table1, the density, height of oil column in the capillary tube and surface tension and contact angle of those oils are recorded at different temperatures. The results show that these quantities except contact angle decrease with increasing temperature. The variations of these oil properties can be explained in terms of molecular theory that all substances are made up of small tiny building units called molecules as follows:

- (i) According to the molecular theory, when a liquid is heated the molecules move apart i.e. it expands, the number of molecules or mass remains the same but the volume increases and as a result the density decreases. The plot of density versus absolute temperature in Fig 1, the correlation coefficient  $R^2$  has value 0.9994 and 0.9929 for groundnut and palm oil respectively. Also the decrease in density per Kelvin for palm oil is  $-0.6590 \text{ kg m}^{-3}\text{k}^{-1}$  which is relatively lower than that of groundnut oil  $-0.6442 \text{ kg m}^{-3}\text{k}^{-1}$  i.e. groundnut oil expands faster on heating than palm oil. The linear density regression lines at absolute zero temperature give the values of densities of groundnut oil and palm oil as  $1089.6 \text{ kgm}^{-3}$  and  $1093.3 \text{ kgm}^{-3}$  respectively. At the absolute temperature, the molecules of the oils are expected to be at rest with zero kinetic energy and minimum intermolecular distance with maximum potential energy.

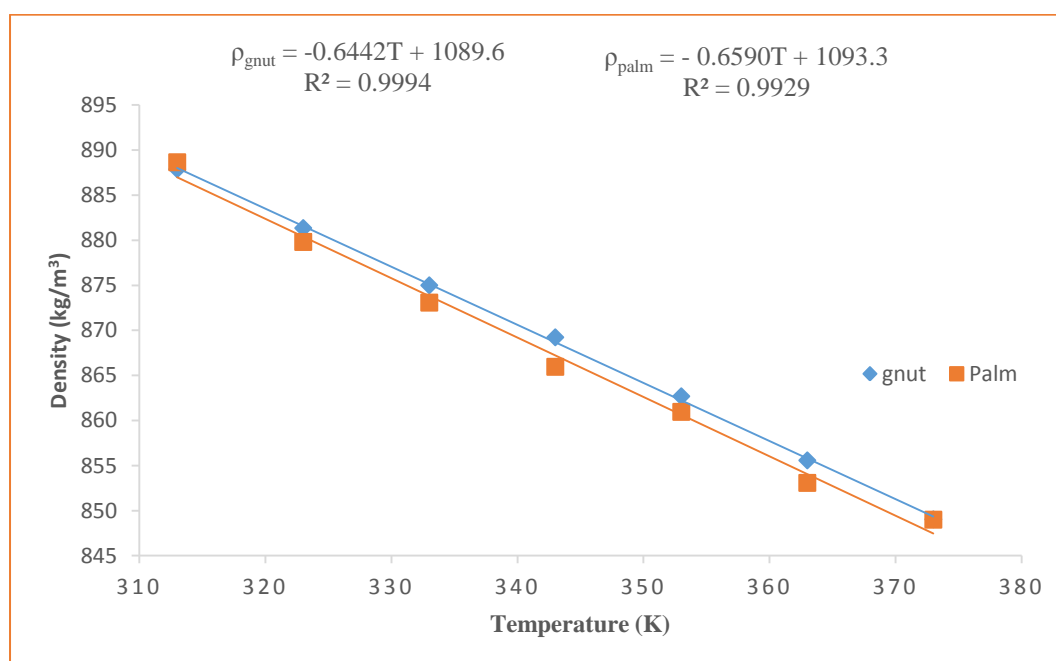


Fig. 3 Densities of groundnut and palm oils as functions of temperature

- (ii) The molecular theory explains that when a liquid in a glass capillary tube is heated, the sum of the cohesive forces existing between the molecules of the liquid and the adhesive forces between the molecules of the liquid and glass decreases. That is, the weaker the resultant intermolecular force becomes as the temperature increases, the smaller the height of the liquid column in the capillary tube (Table 1). This means that the surface tension decreases with increasing temperature (Table 4). Fig. 4 shows the surface tension-temperature regression lines have the decrease of surface tension per Kelvin as  $-8.28 \times 10^{-5} \text{ Nm}^{-1}\text{K}^{-1}$  and  $-8.60 \times 10^{-5} \text{ Nm}^{-1}\text{K}^{-1}$  with  $R^2$  values of 0.9913 and 0.9551 for groundnut oil and palm oil respectively. This reveals that the rate of decrease in surface tension of groundnut oil is faster and yet smoother than that of palm oil which may be due to the nature of the entanglement of the molecules in the surface tension of the oils. Also, from the linear regression analysis, we deduced the critical temperatures at which surface tension vanishes or becomes zero to be 723.9 K and 695.7 K for groundnut oil and palm oil respectively.

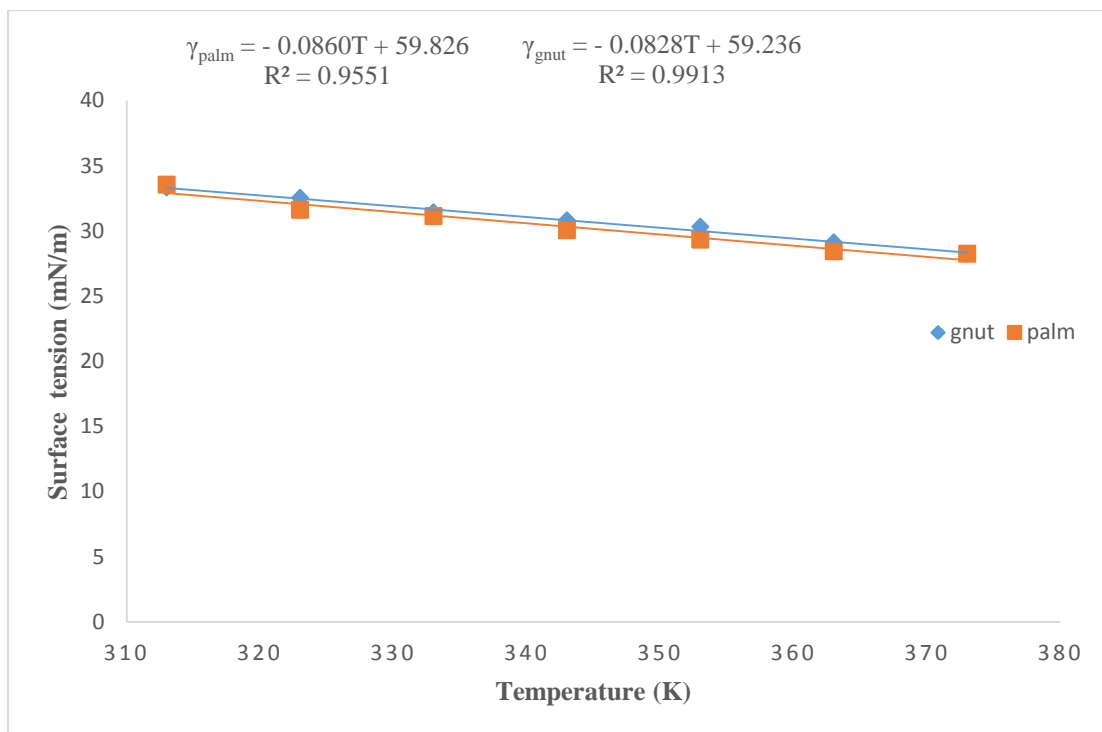


Fig. 4 Variation of surface tension of groundnut oil and palm oil with temperature

- (iii) In the light of the molecular theory, the decrease in the intermolecular force with temperature affects the curvature of the meniscus of the liquid in the capillary tube and hence the contact angle. When the adhesion is greater than cohesion, the liquid has concave meniscus and when cohesion dominates it has convex meniscus. Let us consider the case of concave meniscus. Suppose the liquid, say water, is at its melting point where we have the solid (container)-liquid (water at 0 °C) interface to be in equilibrium with the solid (container)-solid (ice) interface, the tangent AB drawn from a point where the water/ice surface meets the container surface is alongside or parallel to the surface of the container. i.e. the contact angle is zero (Fig. 5a). That is, at the melting point, the tangent to the concave meniscus is parallel to the surface of the container because adhesion tends to zero and cohesion in the water/ice surface is maximum resulting to maximum surface tension of the solid-water/ice interface. On heating, the adhesion increases as cohesion decreases such that the molecules of the container attract the molecules of the liquid at the surface giving rise to concave meniscus and increase in contact angle (Fig. 5b). The contact angle increases with temperature until at the vicinity of boiling point when the liquid-vapour interface replaces the solid-liquid interface it tends to be maximum value of 90° (Fig. 5c). Therefore, at boiling point, the solid-liquid interface surface tension becomes immeasurable and the liquid-gas interface surface tension becomes measurably significant. This means that at the melting and boiling temperatures, the contact angle takes values 0° and 90° as the meniscus tends to a vertical straight line and horizontal line respectively.

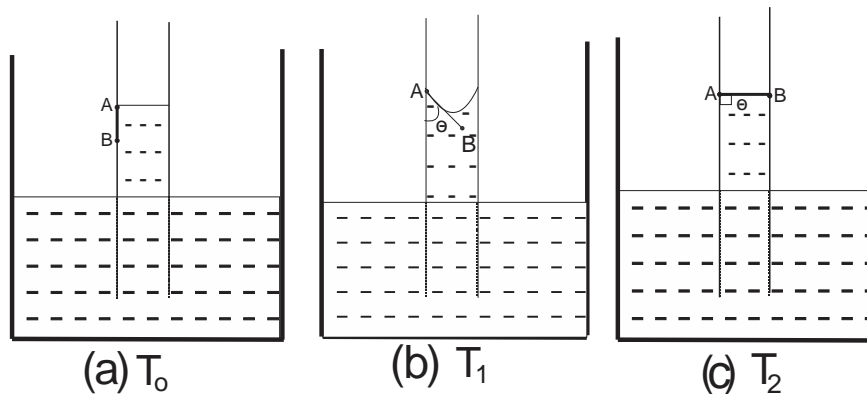


Fig. 5 Shape of meniscus of liquid and contact angle at different temperatures

- (iv) In the light of intermolecular force, on heating, the adhesive force which is responsible for the rise of liquid in the capillary tube decreases which in turn increase the curvature of the meniscus of the liquid and hence increase in contact angle. That is, the contact angle increases with temperature (Fig. 6). The plot of contact angle ( $\theta_{gnut}$  or  $\theta_{palm}$ ) versus absolute temperature  $T$  yields the linear regression lines  $\theta_{gnut} = 0.0083T + 5.8551$ ,  $R^2 = 0.9861$  and  $\theta_{palm} = 0.0090T + 5.6787$ ,  $R^2 = 0.9491$  for groundnut oil and palm oil respectively. The results shows that the increase in contact angle per unit temperature for groundnut oil ( $0.0083^\circ \text{K}^{-1}$ ) is less than that of palm oil ( $0.0090^\circ \text{K}^{-1}$ ).

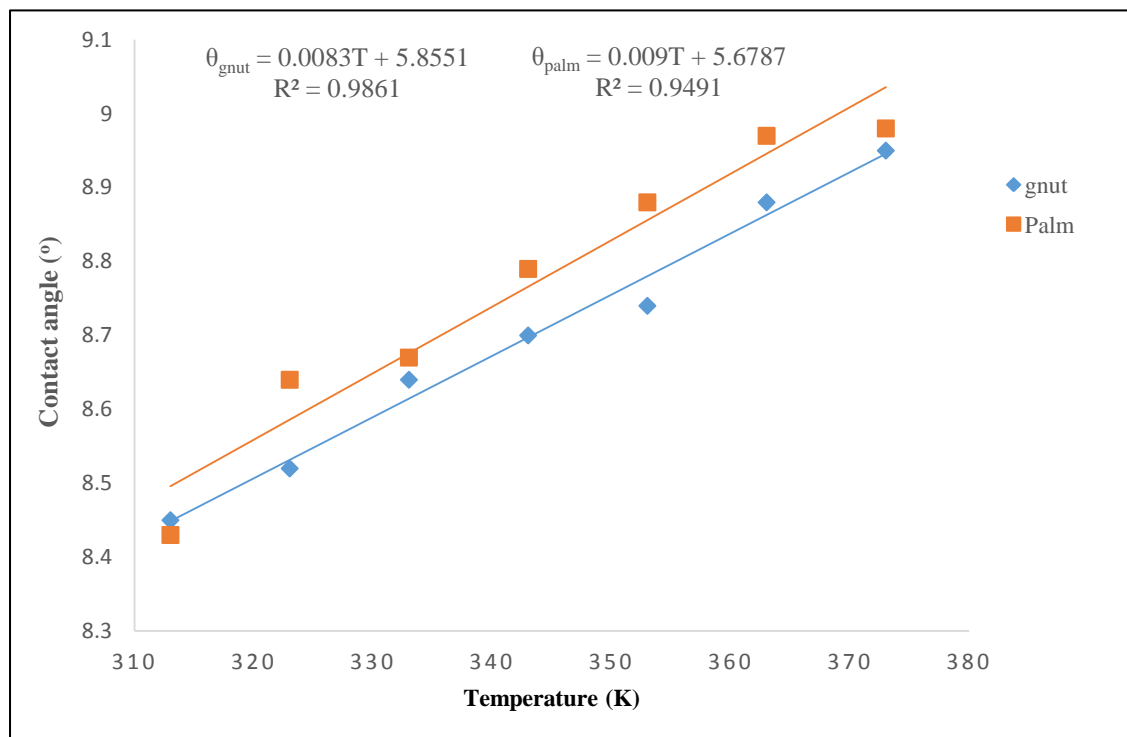


Fig. 6 Variation of contact angle with temperature

- (v) The densities of groundnut oil and palm oil increase linearly with surface tension (Fig. 7). This is true since both quantities decrease with increasing temperature (Fig. 3 & 4). The regression lines are  $\rho_{gnut} = 7.7199\gamma + 630.69$ , with  $R^2 = 0.9932$  and  $\rho_{palm} = 7.4419\gamma + 641.43$ , with  $R^2 = 0.9796$  for groundnut oil and palm oil respectively. For  $\gamma = 0$ , we have critical density values of  $630.69 \text{ kgm}^{-3}$  and  $641.43 \text{ kgm}^{-3}$  for groundnut oil and palm oil respectively.

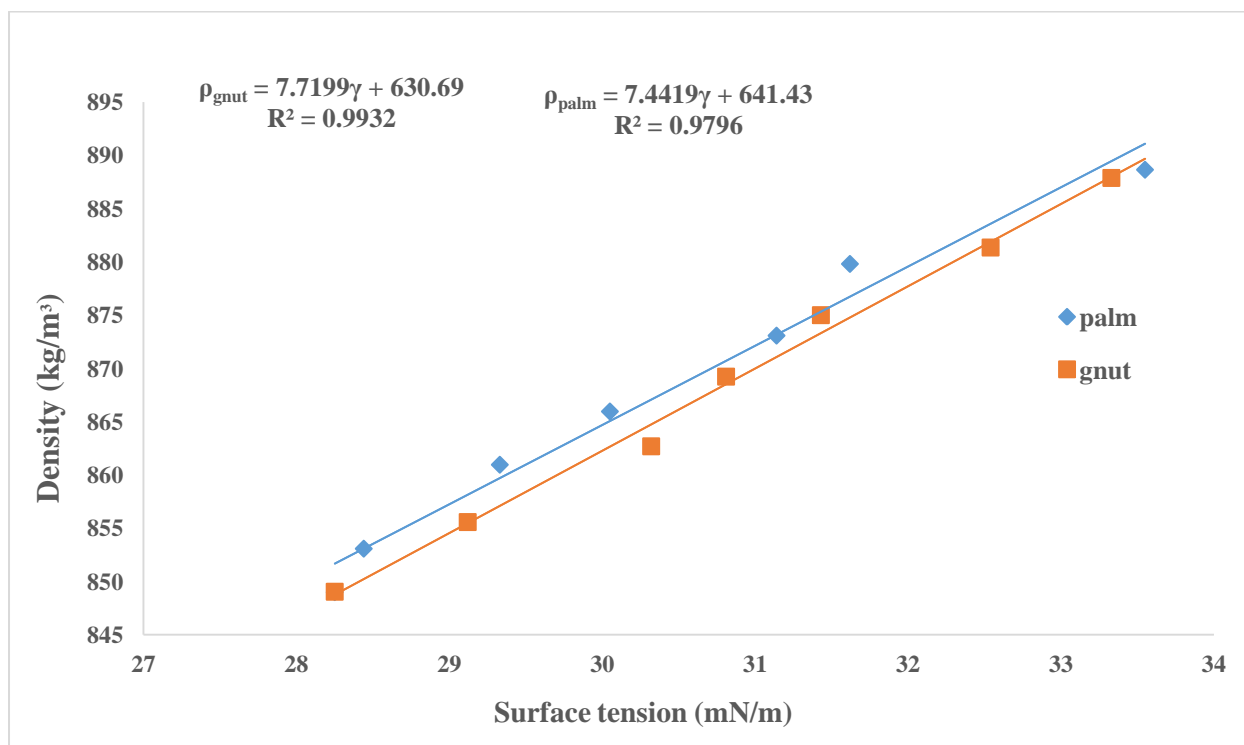


Fig. 7 Density as function of surface tension

#### IV. Conclusion

The density and surface tension of groundnut oil and palm oil were studied at various temperatures using the 'catch overflow' method and capillary rise method respectively. The results shows that density, height of oil column in capillary tube and surface tension linearly decreases with temperature as opposed to contact angle and correction factor. Also, the linear regression analysis reveals that the rate of decrease of these quantities of groundnut oil with temperature is faster than that of palm oil. This implies that since these are cooking oils, groundnut oil may be a better medium for digestion and transport of food in the stomach through capillary blood vessels to other parts of the body. We recommend this for further research.

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