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Static Contact Angle and Large Water Droplet Thickness Measurements with the Change of Water Temperature

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Abstract:

The sessile droplet method is used to determine the contact angle and the thickness of a large droplet of water (puddle), and the contact angle of a growing droplet experimentally. The measurements are done as the water temperature is varied within the range of 0-90 C^{o}. Five kinds of substrates are used (iron, copper, aluminum, glass and brass) in the present work. It is found that as the temperature of the water increased both the contact angle values and puddle thickness values are decreased. Also it is shown that the contact angle is starting from 90^{o} for very small droplets to a steady value as the droplet increases in size. A curve fitting is done to obtain correlationsfor the variation of contact angle with water temperature values.

Keywords: contact angle, puddle thickness, sessile droplet.

Nomenclatures:

Symbol	Description	Units
a	Polynomial constant	
P	Pressure	N/m^2
T	Temperature	^{o}C
R	Radius of curvature	m

Greek symbols

θ	Contact angle	Degree
γ	Surface tension	N/m

Introduction:

In each fluid, molecules at the surface are less density and attract each other. Since half of their neighbors are missing, the mechanical effect is that the surface is in tension [1], where this effect is known as the surface tension. The effects of surface tension play an important role for most processes involving liquids with free surface, such as the disintegration of liquid jets, Marangoni flow, evaporation, and formation of bubbles and droplets [2]. Because of the surface energy of the substrate and the adhesion forces between the liquid and the substrate, drops of different liquids deposited on identical solid substrate behave differently, or an identical droplets deposited on different substrates behave differently[3]. The important different behavior is the difference in the contact angle, which is the angle between the material and the tangent line for the droplet as shown in figure (1).

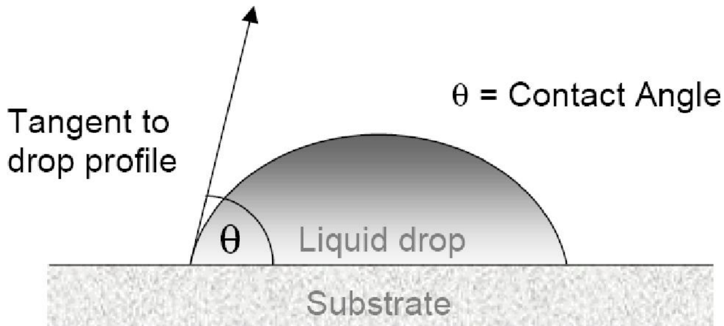

Figure (1): The contact angle.

This contact angle plays an important role, because it is the measurement for the wettability of the droplet for the substrate as shown in figure (2).

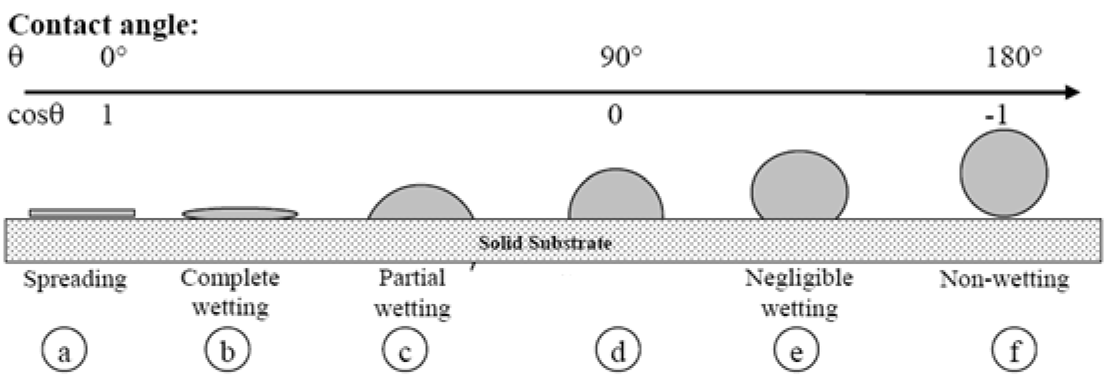

Figure 2.Liquid drop on solid surface.θ< 90° indicates that the solid is wet by the liquid, and θ> 90° indicates non-wetting, with the limits θ = 0 and θ=180°defining complete wetting and complete non-wetting, respectively.

Wetting of solid substrates by liquids is a fundamental phenomenon with relevance toboth the technological and natural worlds. Applications include the spreading behavior of liquid coatings , as well as flows in oil reservoirs and chemical reactors[3]. And also the condensate removal rate is a function of the curvature of the droplet and contact angle [4]. The measurement of contact angle takes an attention on recent researches for both static droplets[5, 6, 7, and 8], and moving contact angle [9, 10, 11, 12, 13, and 14].In the present work the contact angle and the thickness of water puddle will be measured experimentally for four metals iron, copper, aluminum, and brass. The readings will be taken for varying temperature for the range 0-90 C^o. A fitting will be done for the results in order to obtain a relation between the contact angle and temperature.

Theory:

The physical and chemical behavior of liquids can not be understood without taking surface tension into account. It governs the shape that small masses of liquid can assume and the degree contact a liquid can make with another substance for the reason the interfacial energies at the solid-liquid (γ_{sl}), solid-vapor (γ_{sv}), and liquid-vapor(γ_{lv}) interfaces are related to the contact angle θ by the Young equation[12], as shown in figure (3):

$$\gamma_{lv}\cos\theta = \gamma_{sv} - \gamma_{sl} \quad \text{...(1)}$$

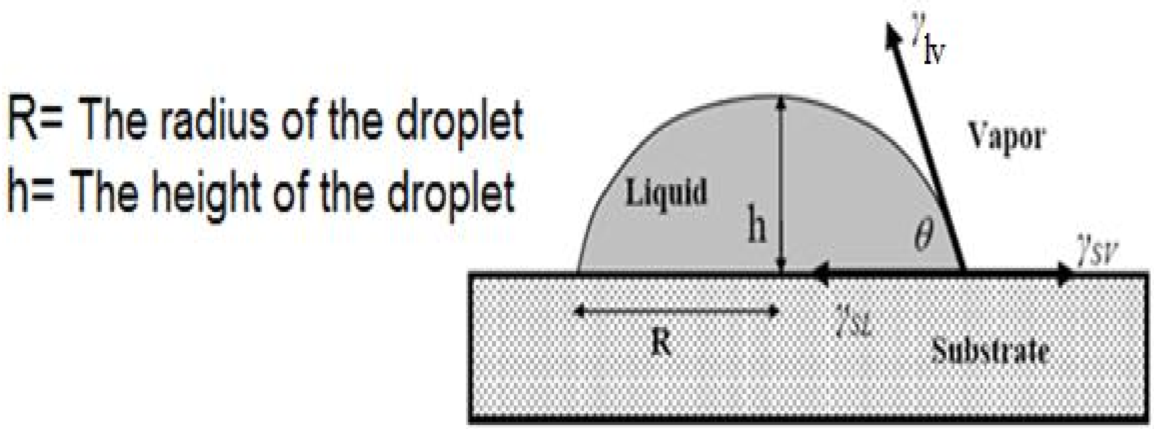

Figure 3. Interfacial tensions at the three phase contact line. R is the radius of the drop base and h is the height of droplet.

Where the previous equation is necessary to balance the forces on the sessile drop. The shape of this droplet is determined by Young-Laplace equation:

$$\Delta P = \gamma\left(\frac{1}{R_x}+\frac{1}{R_y}\right) \quad \text{...(2)}$$

ΔP: Pressure difference.

γ: Surface tension.

R_x,R_y:are the radii of curvature in each of the axes that are parallel to the surface.

The contact angle thus directly provides information on the interaction energy between the surface and the liquid. It is not possible to evaluate the contact angle theoretically, so it is necessary to evaluate it experimentally.

Experimental work:

In order to evaluate the contact angle experimentally, the sessile droplet method will be used. As shown in figure (4):

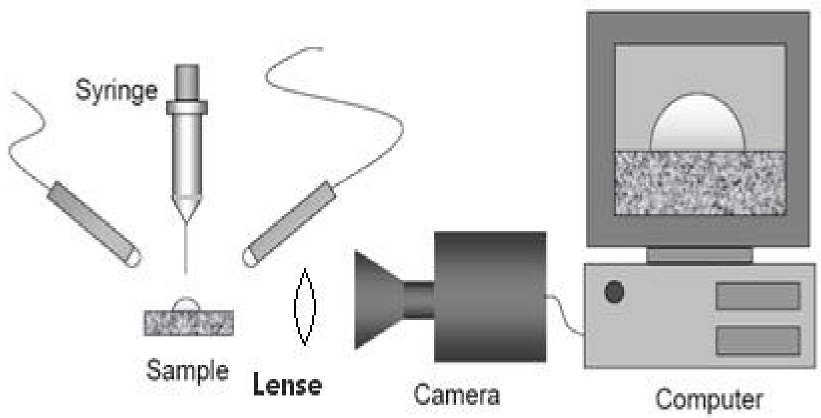

Figure (4): The measurement devises.

The sessile droplet will be rested on a horizontal substrate by a syringe. The substrate will be illuminated by a light source, and then a picture will be taken by using a high resolution camera (10.1 Mpixle SONY camera). The image will be processed by computer either by a software made for this reason, or (as in the present work) by using Autocad. This procedure is repeated for water droplets of different temperatures from the range 0 ^{o}C to 90 ^{o}C by the using of heater and thermometer to control the temperature increment. Four kinds of substrates are used (iron, copper, aluminum, and brass) for the present work. For each stage of the experiment more than 45 images are taken and processed.

Results and Discussion:

After applying the first experimental procedure, the following results are obtained. The values of the contact angle is decreased as the temperature of the water increase as shown in figures (5,6,7,8, and 9), which means that the contact angle is a function of the liquid temperature.

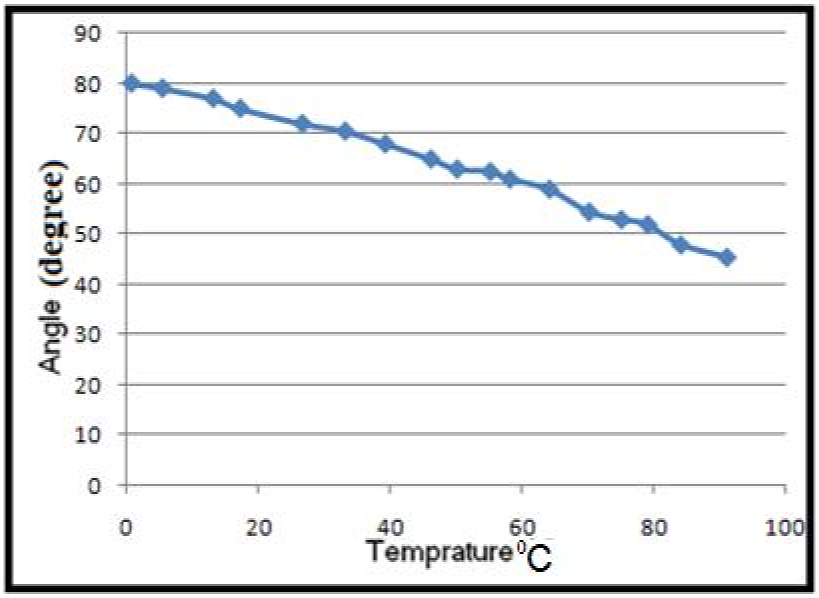

Figure (5): The contact angle values (degree) versus water temperature (Co) for Brass.

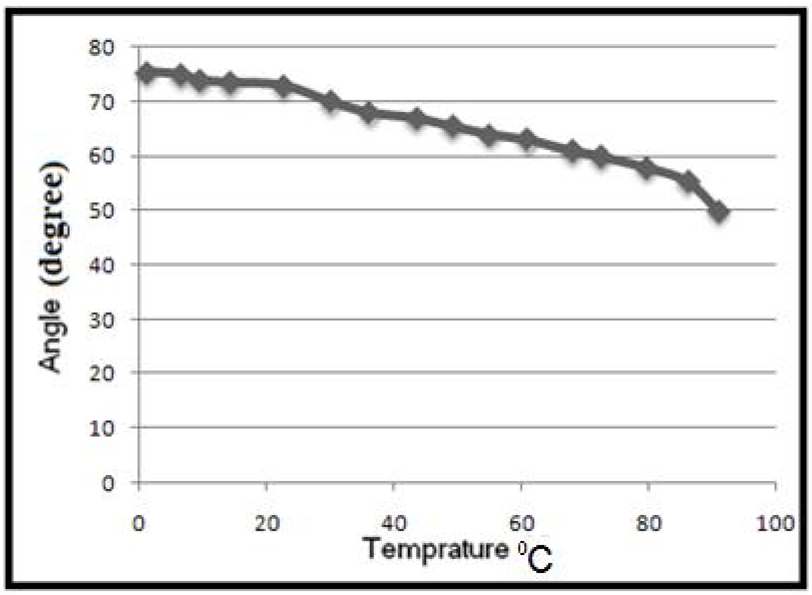

Figure (6): The contact angle values (degree) versus water temperature (Co) for Aluminum.

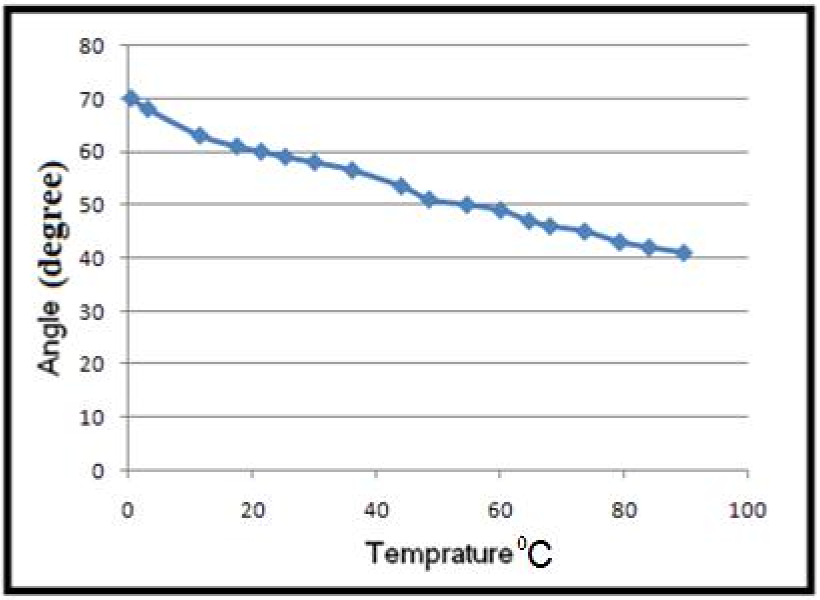

Figure (7): The contact angle values (degree) versus water temperature (Co) for Copper.

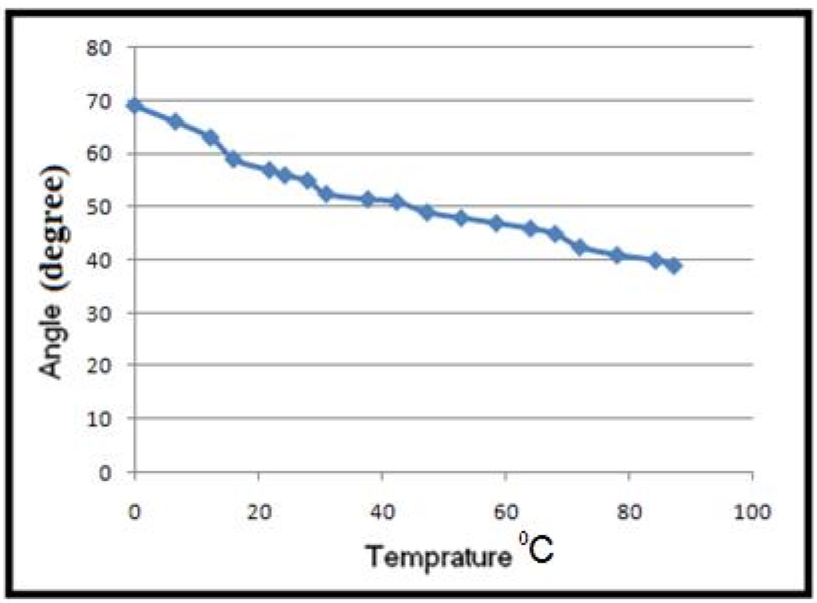

Figure (8): The contact angle values (degree) versus water temperature (Co) for Iron.

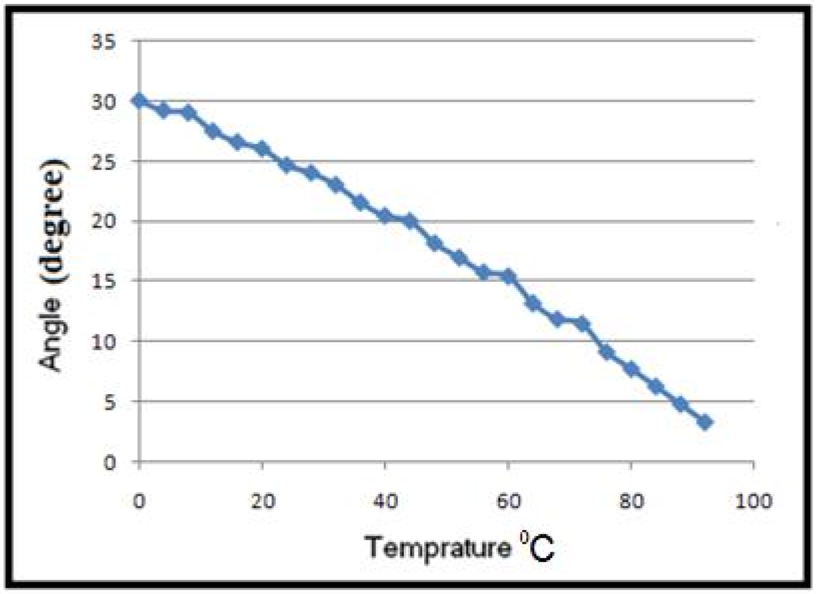

Figure (9): The contact angle values versus temperature for glass.

The results show that the maximum contact angles are obtained for Brass, while the minimum contact angles are obtained for Glass.. Now the results of the previous figures can be fitted to the following relations:

$$\theta = a_0 + a_1 T + a_2 T^2 \quad (3)$$

Where the constants a_0, a_1, and a_2 can be listed in the following table:

Table (1): Coefficients of equation (3).

Kind of substrate	a_0	a_1	a_2
Brass	80	-0.29	$-9.78 * 10^{-4}$
Aluminum	76	-0.1576	$-1.41 * 10^{-3}$
Copper	70	-0.4325	$1.2 * 10^{-3}$
Iron	69	-0.501	$1.8 * 10^{-3}$
Glass	30	-0.2	$-9.78 * 10^{-4}$

Where θ is the contact angle of water. The general behavior can be shown as the contact angle decrease when the temperature is increased may make sense, because the puddle may be considered as a biggest version of a droplet, and since the reason behind the holding of the liquid structure in its known shape is the surface tension force, and since the surface tension force is decrease as the temperature increased as shown in figure (10), then it make the all sense to see that behavior of the contact angle values versus temperature values.

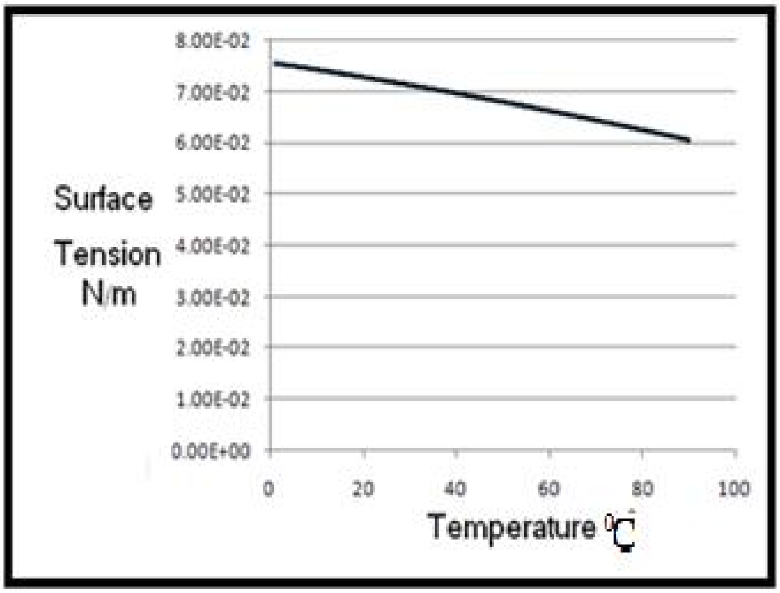

Figure (10): Surface tension values of water versus temperature.

This figure is based on the values enlisted in [1]. Now if this is the behavior of a big droplet, now what about the smaller droplets?
The behavior of small droplets can be shown in figures (11, 12, 13, and 14).

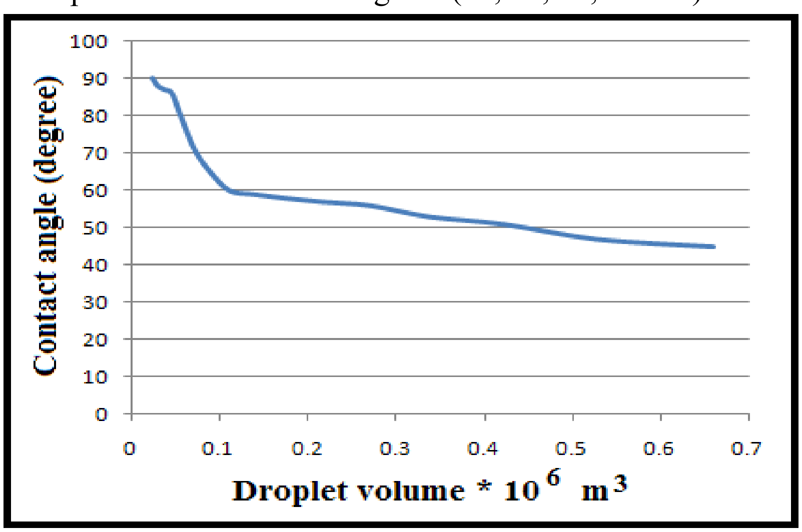

Figure (11): The variation of contact angles withthat of droplet volume for Brass.

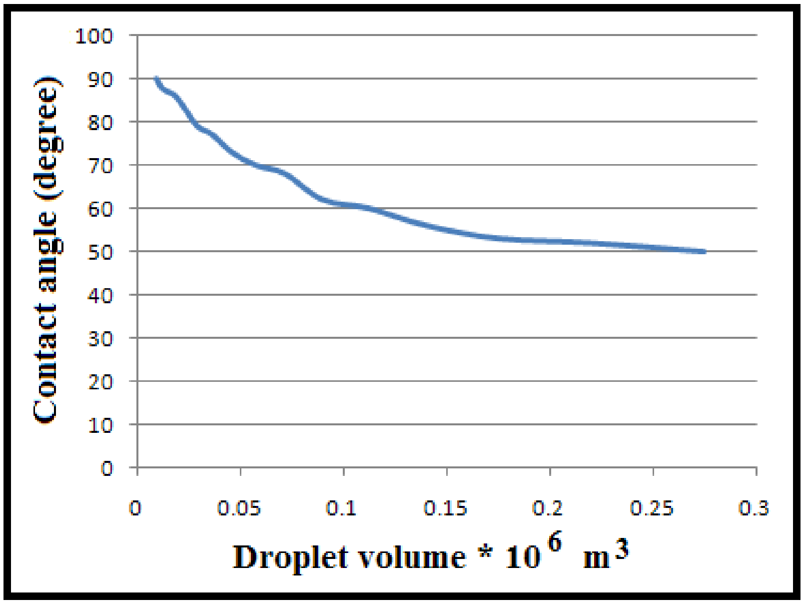

Figure (12): The variation of contact angles with that of droplet volume for Aluminum.

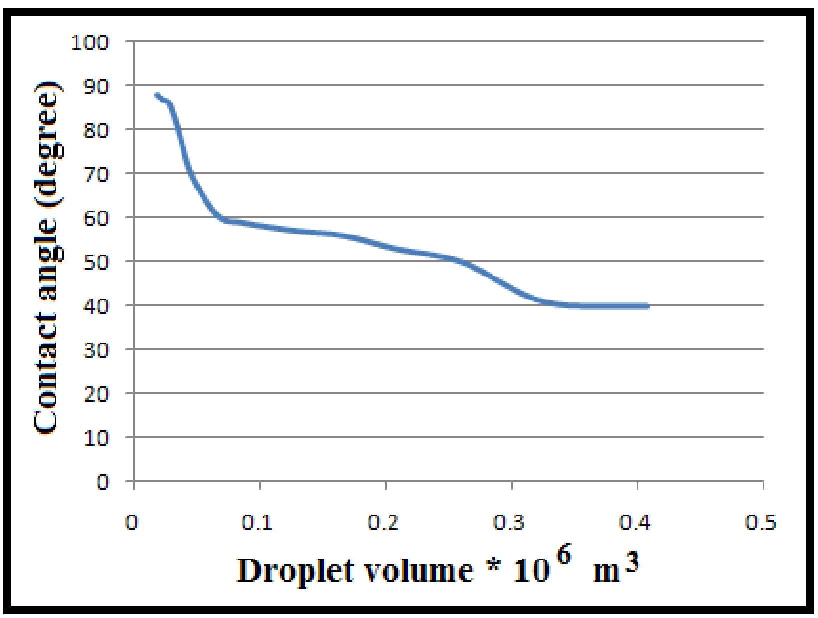

Figure (13): The variation of contact angles with that of droplet volume for Copper.

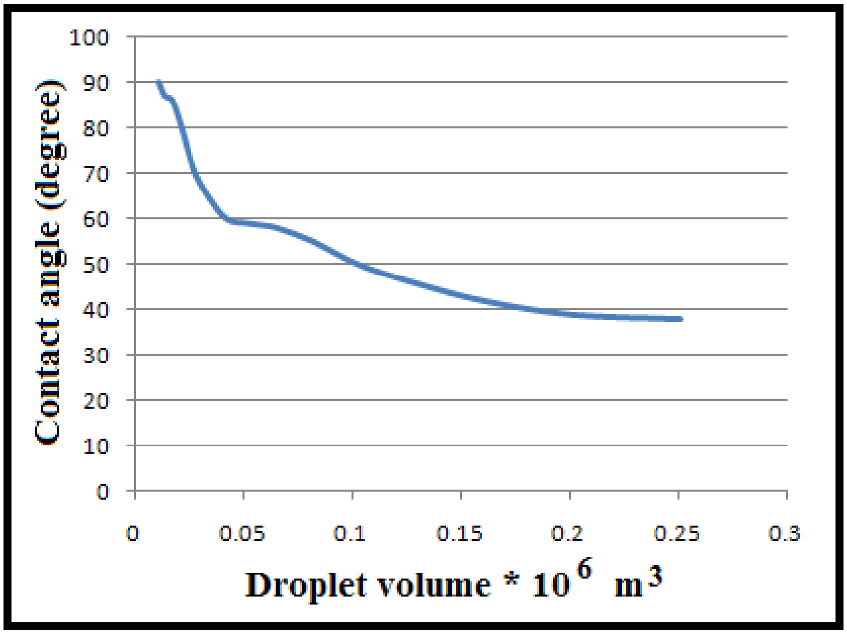

Figure (14): The variation of contact angles with that of droplet volume for Iron.

The behavior of the droplets from very small sizes till the largest droplet shows that the contact angle values are increased as the droplet volume decreased. The values of the contact angle will continuously approach 90^o, which means that the shape of the very small droplets can be assumed as a hemisphere. This behavior is sustained by the experimental data of [10], where the results of contact angles of water at Copper is reaching 90^0 for very small droplet then it decreases as the droplets grow. When the droplet size approaches the largest size (after which the droplet may consider as a puddle) the contact angle values reach its steady value as measured for a puddle. It is important to say that all the previous measurements are done at 90 C^0.

Another measurement is done for the values of the puddle thickness which can be shown in figures (15, 16, 17, 18, and 19)

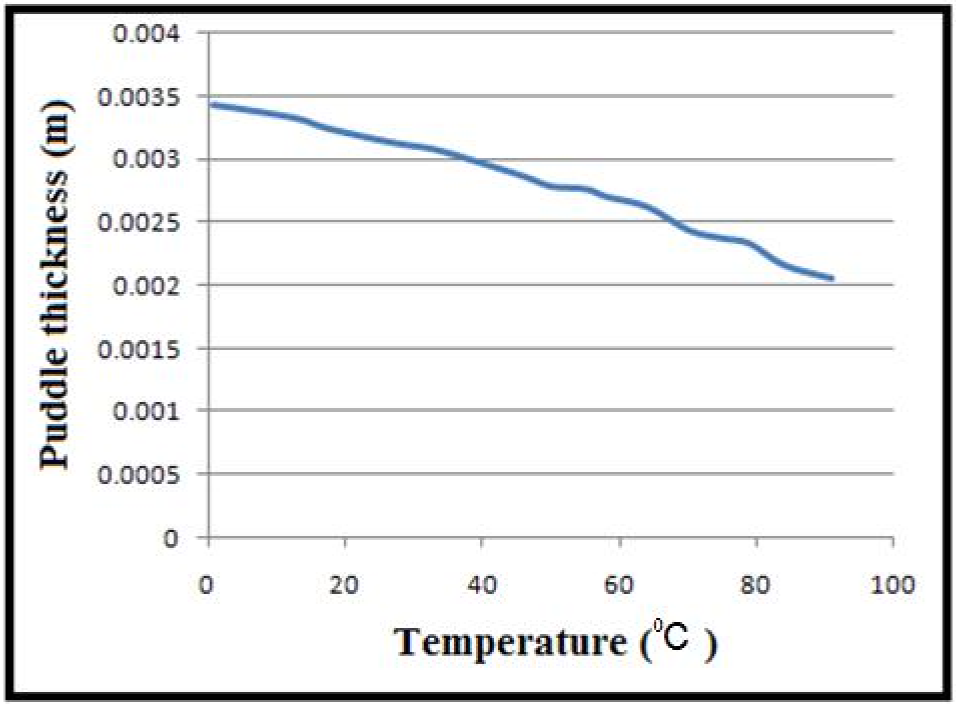

Figure (15): Puddle thickness versus temperature variation on Brass.

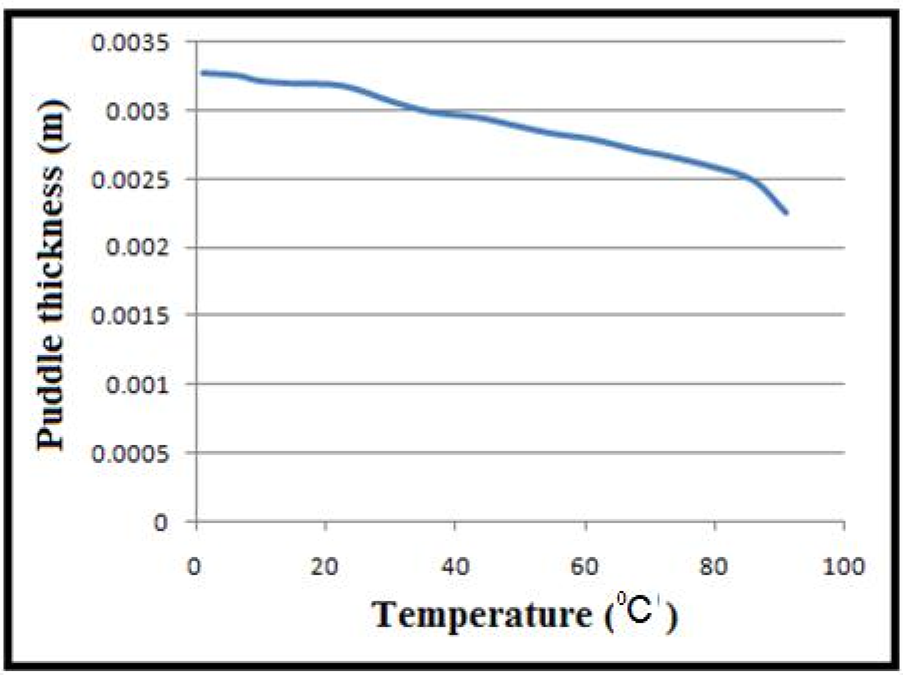

Figure (16): Puddle thickness versus temperature variation on Aluminum.

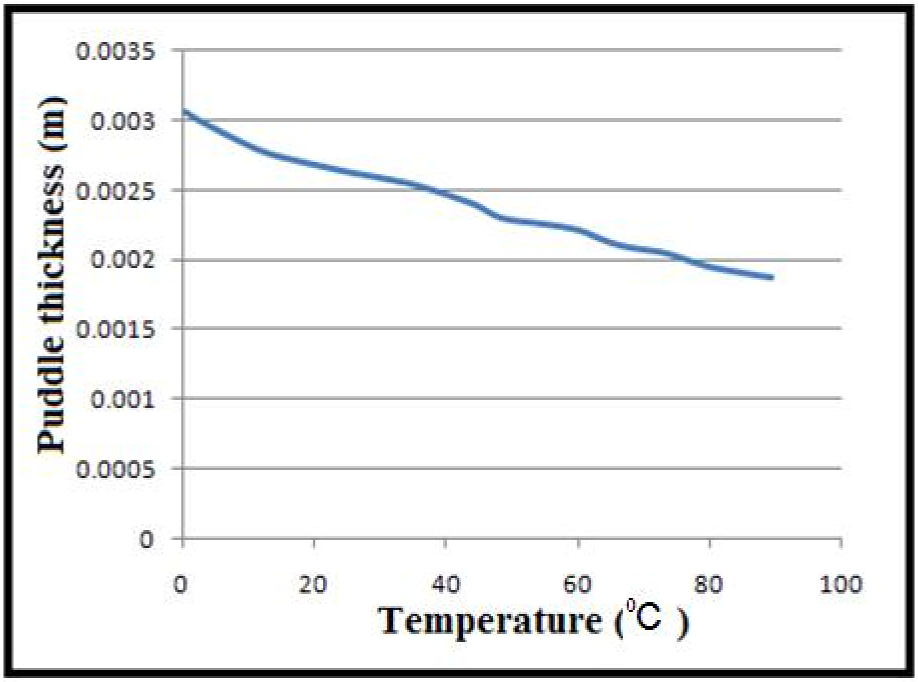

Figure (17): Puddle thickness versus temperaturevariation on Copper.

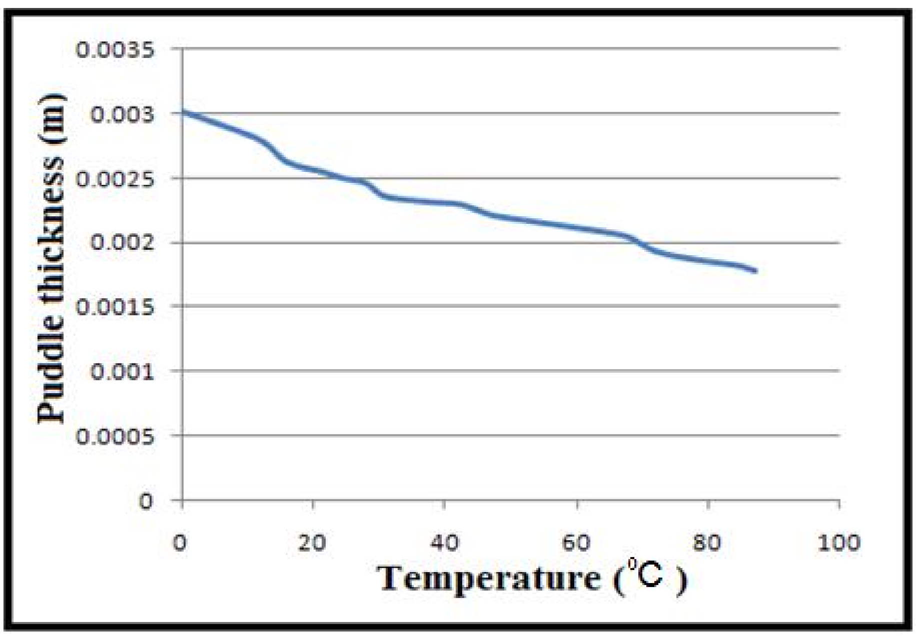

Figure (18): Puddle thickness versus temperature variation on Iron.

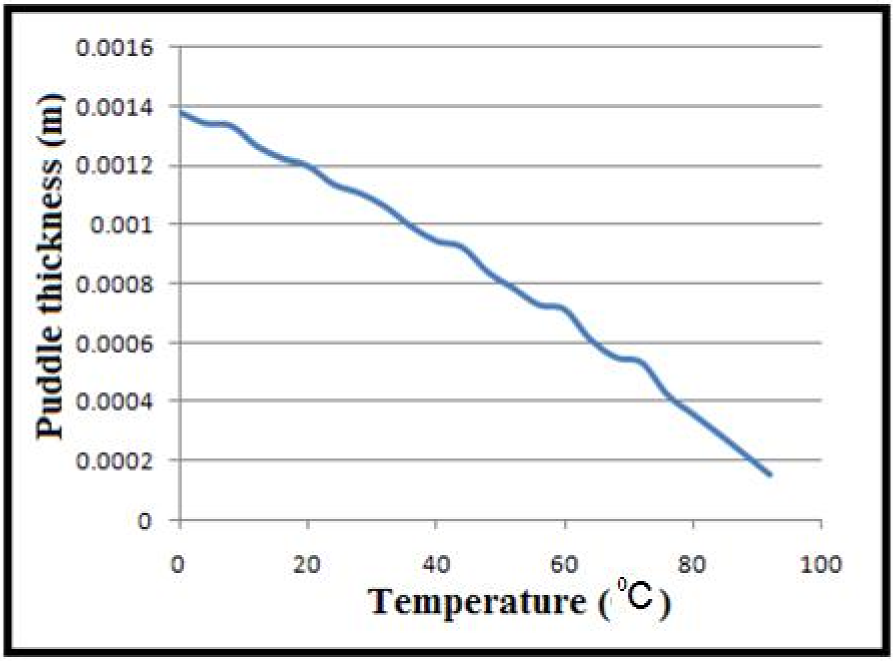

Figure (19): Puddle thickness versus temperature variation on Glass.

It can be said that it is logical for the values of the puddle thickness to decrease as the temperature increase. This is due to the dependency of the puddle thickness on the values of the surface tension. The values also show that the minimum puddle thickness may be obtained at the glass case, which may give the hint to use glass as the substrate in the measurement of the waves developing at the surface of the condensate film since the thickness of the puddle in the glass case is closer to the real case.

Conclusions:

The static contact angle of water droplets, and the thickness of a puddle (big droplet), are a function of temperature, where the temperature of the water increase, the values of the contact angle and the puddle thickness decreased, which will cause the water droplet to spread in order to sustain the volume of the puddle. The sessile droplet method is a reliable method to measure the contact angle values,

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قياس زاوية التلامس الاستاتيكية وسمك قطرة الماء الاكبر مع تغير درجة حرارة الماء

ماجد حميد مجيد

مساعد رئيس معهد الاساس الفني

الخلاصة:

طريقة القطرة الثابتة استخدمت في هذا البحث لقياس زاوية التلامس و سمك القطرات الكبيرة (المياه الضحلة) و كذلك لقياس زاوية التلامس للقطرات المتنامية بالحجم عمليا. تمت القراءات عند مدى درجات حرارة 0-90 درجة سيليزية و لخمس أنواع مختلفة من السطوح (نحاس- حديد –ألمنيوم– زجاج – براص) بينت النتائج ان ازدياد درجة حرارة الماء المستخدم في التجارب يؤدي إلى تناقص في مقدار زاوية التلامس و كذلك نقصان في سمك المياه الضحلة. و قد وجد أيضا ان القطرات الصغيرة تولد زاوية تلامس مقاربة لـ 90 درجة و تبدأ بعد ذلك زاوية التلامس بالتغير إلىأن تصل إلى مقدار ثابت عند زيادة حجم القطرات. تم بناء معادلات تجريبيةوفق النتائج المستحصلة من التجارب لربط زاوية التلامس و سمك المياه الضحلة مع درجات الحرارة.