WETTABILITY CHARACTERISTICS OF SIMPLE AND COLLOIDAL DROPS AT VARIOUS SUBSTRATES

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Dedicated To

My Beloved Parents

FACULTY OF ENGINEERING AND TECHNOLOGY
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DECLARATION OF ORIGINALITY
AND
COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work, by the Undersigned candidate, as part of his ***Master of Engineering*** *studies.*

All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

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CERTIFICATE OF RECOMMENDATION

We hereby recommend that this thesis under our supervision by **Rahul Kumar**, entitled, “**Wettability characteristics of simple and colloidal drops at various substrates”** be accepted in partial fulfillment of the requirements for awarding the degree of Master of Engineering in Automobile Engineering under Department of Mechanical Engineering of Jadavpur University.

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CERTICATE OF APPROVAL

The foregoing thesis entitled "**Wettability characteristics of simple and colloidal drops at various substrates"** is hereby approved as a creditable study of an engineering subject carried out and presented in a manner satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is notified to be understood that by this approval, the undersigned do not necessarily endorse or approved any statement made, opinion expressed and conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

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Abstract

Liquid behaviour on substrates is determined by dropping liquid on the substrate's surface. A parameter affected by both, fluid and substrate, is the contact angle of a liquid drop applied to the substrate surface. It is defined as the angle between the drop's outline tangent at the three-phase contact point, and the substrate. On absorbing substrates an equilibrium between drop and surface is not reached, thus a dynamic contact angle is measured. Contact angle is used for capturing the wetting characteristics of liquids on surfaces, a low contact angle corresponds to strong wetting. Liquids come in contact with solid surfaces in a variety of applications, including everyday situations like painting a wall or using medicine. In industry, wettability is important for example when manufacturing electronics or when planning how to extract oil from the oil reservoir. In all these applications, knowing the contact angle value gives a strong indication on the performance of the product or a successfulness of the process. When a drop of water is placed on a solid, it will spread on the surface based on the inter molecular interactions between the solid and the liquid. Water contact angle will immediately give an indication of the wet ability of the solid. If the measured contact angle is above 90 degrees, the solid is said to have poor wetting and is termed hydrophobic. If the contact angle is below 90 degrees, a term hydrophilic is used. As extreme cases, the water can either spread completely or form a sphere on top of the solid, in these cases terms complete wetting and super hydrophobic surfaces are used, respectively. In the present work, mainly focus on variation of contact angle when different fluid drops vertically on different substrates. The work is experimental analysis as well as software analysis of fluid droplets. It shows in case of glass substrate fluid spreading capacity more in comparison to other substrate like brass, mild steel and cast iron. Fluid on glass substrate have higher contact angle as comparison to other substrate. Propanol2 has tendency to rapid spreading when fall on glass as comparison to other substrate like brass, mild steel and cast iron. It is difficult to find contact angle when propanol2 falls on substrate with normal mobile camera due to its volatile ability.

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Chapter 1

INTRODUCTION

1.1 General Background

Liquid behaviour on substrates is determined by dropping liquid on the substrate's surface. A parameter affected by both, fluid and substrate, is the contact angle of a liquid drop applied to the substrate surface. It is defined as the angle between the drop's outline tangent at the three-phase contact point, and the substrate. On absorbing substrates an equilibrium between drop and surface is not reached, thus a dynamic contact angle is measured. Contact angle is used for capturing the wetting characteristics of liquids on surfaces, a low contact angle corresponds to strong wetting. Liquids come in contact with solid surfaces in a variety of applications, including everyday situations like painting a wall or using medicine. In industry, wet ability is important for example when manufacturing electronics or when planning how to extract oil from the oil reservoir. In all these applications, knowing the contact angle value gives a strong indication on the performance of the product or a successfulness of the process. When a drop of water is placed on a solid, it will spread on the surface based on the intermolecular interactions between the solid and the liquid. Water contact angle will immediately give an indication of the wet ability of the solid. If the measured contact angle is above 90 degrees, the solid is said to have poor wetting and is termed hydrophobic. If the contact angle is below 90 degrees, a term hydrophilic is used. As extreme cases, the water can either spread completely or form a sphere on top of the solid, in these cases terms complete wetting and super hydrophobic surfaces are used, respectively.

1.2 Liquid Surface Tension

The cohesive forces between liquid molecules are responsible for the phenomenon known as surface tension. The molecules at the surface do not have other like molecules on all sides of them and consequently they cohere more strongly to those directly associated with them on the surface. This forms a surface "film" which makes it more difficult to move an object through the surface than to move it when it is completely submersed.

1.3 Liquid Surface Energy

Surface energy quantifies the disruption of intermolecular bonds that occurs when a surface is created. It is also called as surface free energy or inter facial free energy. In simple language, surface energy can be defined as the work per unit area done by the force that creates the new surface. If contact angle is low then surface free energy is high and when contact angle is high surface free energy is low.

1.4 Surface Roughness

There is a large influence of surface roughness on the contact angle. For static contact angle measurements also a surface roughness influence on contact angle. According to Wenzel high surface roughness amplifies both, wetting and liquid repellence. Roughness increases wetting if $\Theta < 90^{\circ}$, and it increases liquid repellence if $\Theta > 90^{\circ}$, Θ being the contact angle on a smooth surface of the same material.

1.5 Materials

To perform this experiment materials like wooden block,90 degree clamping stand, 48 mega pixel mobile camera, burette,10 ml syringe, needle, beaker, copper oxide nanoparticle, aluminium oxide nanoparticle, glass, cast iron, mild steel, brass, tap water, distilled water, propanol2 and table light stand used.

1.6 Software

Image J is a Java base image processing program developed at the National Institutes of Health and the Laboratory for Optical and Computational Instrumentation (LOCI, University of Wisconsin). Image J software is used for liquid drop analysis and calculate the contact angle of fluid on substrates.

1.7 Nano-fluid

A nano-fluid is a fluid in which nano meter-sized particles, suspended in the base fluid, form a colloidal solution of nanoparticles in a base fluid. The nanoparticles used in nano-fluids are typically made of metals, oxides, carbides, or carbon nanotubes, while the base fluids include water, ethylene glycol, and oil.

In my experiment i used aluminium oxide and copper oxide nanoparticle dissolve in tap water and propanol2 in ratio 1:10.Make nano-fluid by dissolving nanoparticle in base fluid by proper mixing to use for calculating contact angle on different substrate below:

1.8 Experiment Overview

To perform this experiment procedure follows as:

(a) Took a flat rectangular table on which experiment is taking place.

(b) Kept small square wooden block on flat rectangular table vertically.

(c) Stand with clamping to hold syringe or burette vertically to substrate kept on small square wooden block.

(d) Small square wooden block must be parallel 180 degree to clamping stand.

(e) Always take care of drop must be fall vertically to substrates.

(f) After falling drop on substrate picture should be taken of that droplet with macro lens from side view with camera must be at 90 degree to that droplet.

(g) After getting picture of fluid drop, analysis drops manually and with the help of software to calculate contact angle.

1.9 State of the art of the present work

In this report the work mainly focus on variation of contact angle when different fluid drops vertically on different substrates. The work is experimental analysis as well as software analysis of fluid droplets. It shows in case of glass substrate fluid spreading capacity more in comparison to other substrate like brass, mild steel and cast iron. Fluid on glass substrate have higher contact angle as comparison to other substrate. Propanol2 has tendency to rapid spreading when fall on glass as comparison to other substrate like brass, mild steel and cast iron. It is difficult to find contact angle when propanol2 falls on substrate with normal mobile camera due to its volatile ability.

Chapter 2

Literature Survey

2.1 Literature Review

Colloidal assembly has a significant impact on the final functioning, special features, and prospective applications. The impact of the substrate's wettability on the colloidal assembly is used in numerous applications. The fundamental colloidal crystal assembly principle, the fundamental impact of substrate wettability on colloidal assembly on substrates with different degrees of wettability such as superhydrophilic, hydrophilic, hydrophobic, superhydrophobic, and substrates with a hydrophilic-hydrophobic pattern are one of the thrust area of research.

A lot of interesting natural phenomena and important industrial uses, including capillarity, microfluidics, nanotechnology, moving contact lines, and coating technology, use contact angles to measure how wet a solid surface is by a liquid. Basically, it is recommended to measure the static and dynamic contact angles at the contact line on the microscale **(Sui *et al.* 2014) [1].** By placing a sessile droplet on an inclined plate, **Extrand and Kumagai (1296) [2]** were able to concurrently measure the advancing and retreating contact angles, which allowed them to study the contact angle hysteresis on a variety of polymer surfaces.

A telescope-goniometer is required for various contact angle measurements in addition to watching a sessile droplet on a solid sample. The solid sample is submerged in the testing liquid while using the captive bubble method, which creates an air bubble **(Zhang and Hallström 1990) [3].**

It is also possible to measure directly the contact angle created by an air bubble in a liquid. The tilting plate method creates a meniscus on both sides of the plate by using a solid plate with one end submerged in the liquid **(Bezuglyi et al. 2001) [4]**.

The contact angle is the angle between the plate and the horizontal at which the plate gradually slopes until the meniscus on one side of the plate becomes horizontal.

It is commonly acknowledged that a telescope-goniometer can directly measure drop contact angles with an accuracy of about 2° **(Yuan and Lee, 2013) [5].**

Another well-liked approach for determining contact angle is the Wilhelmy balancing method **(Tretinnikov and Ikada, 1994) [6].** A solid sample is manipulated to immerse into or emerge from the wetting liquid. The task of measuring an angle is reduced to the measurements of the weight and length, which can be performed with high accuracy and without subjectivity. The method is also suitable to measure dynamic contact angle and hysteresis, because the three-phase line can be in wholesale motion assuring achievement of maximal advancing and minimum receding contact angles **(Krishnan et al., 2005) [7].**

The wetting liquid is used to manipulate a solid sample into or out of it. The task of measuring an angle is reduced to weight and length measurements, which can be carried out precisely and objectively. The three-phase line can be in complete motion, guaranteeing the achievement of maximum advancing and minimum retreating contact angles, making the method suited for measuring dynamic contact angle and hysteresis **[7].**

For their experiment, **Njobuenwu et al. (2006) [8]** studied the spreading of liquid drops over solid substrate for both complete and imperfect wetting. Glycerin, hexadecane, and silicone oil made up the liquid droplets. Glass, polystyrene, and poly-methyl methacrylate are the solid substrates (PMMA). The contact angle that forms between the liquid drop and solid surface was used to quantify wetting. To reduce gravitational effects, measurements were conducted with tiny drops of constant volume. An image analysis system got the contact radius as a function of time and used it to determine the contact area. The contact angle was then calculated using the contact area. The estimated contact angles and the measured value are in good agreement.

On rough, absorbent substrates, which were known to lose contact angle with further drop imbibition, **Krainer and Hirn (2012) [9]** conducted an experiment. They showed that the percentage of the drop volume that penetrated the substrate effectively reflected the effects of three absorption-related parameters (absorption rate, drop size, and residence duration) on the measured contact angle. They examined numerous drop sizes (30pl to 4l) on substrates with widely varying liquid absorption rates. Additionally, the impact of evaporation and the influence of liquid surface tension were assessed. One can recognise the regimes of (1) surface roughness filling and (2) bulk penetration by analysing the evolution of drop volume and contact angle over time. For every percentage point of drop volume that penetrated the substrate, the contact angle fell between 0.5° and 1.2°, regardless of drop size, absorption rate, or drop residence duration. As a result, the relative amount of absorbed drop volume accurately estimated the impact of liquid penetration on the measured contact angle by combining the effects of drop size, contact time, and substrate absorption rate. For the vast majority of water-based liquids, evaporation has little impact. As a result, contact angle measurements on absorbing substrates were compared for the same proportion of absorbed drop volume, for example, when 30% of the drop volume had been absorbed.

The measurement of the liquid/solid contact angle experiment conducted by **Behroozi (2018) [10]** gives important knowledge on the wetting characteristics of fluids. The functional relationship between an extended drop's maximum height and its contact angle was first established in 1870 by German physicist George Hermann Quincke (1834–1924). The direct measurement of contact angle, which in fact has a number of experimental errors, was replaced with Quincke's relation.

Quetzeri-Santiago (2015) [11] used a polynomial or a linear fitting to the droplet profile around the triple-phase point to measure the contact angle of a liquid. Previous studies concentrated on quasi-static or sessile droplets, or in situations where inertia does not significantly affect the dynamics of contact angle. Here, they looked at how droplet form, fitting polynomial order, and fitting domain affected the measurement of the contact angle at different phases after droplet impact where the contact line was moving. Their findings, which are reported in terms of optical resolution and droplet size, demonstrate that a quadratic fitting yields the most reliable outcomes for a variety of different droplet forms. In circumstances where the droplet approximated a spherical cap, their findings demonstrated that contact angle values were less susceptible to the fitting conditions. They used a variety of substrates in their experiments, as well as impact events with liquid droplets of varying sizes and viscosities. Additionally, validating earlier studies, their findings demonstrated that the Weber number and the quickly rising contact angle parameterized the maximum spreading diameter.

On the basis of the so-called Wilhelmy plate approach, **Volpe (2018) [12]** conducted an experiment on the contact angle measurement with the force tensiometer. When a solid sample was brought into contact with the test liquid, a force tensiometer assessed the mass that was affected to the balance. When the liquid's surface tension and the sample's perimeter were determined, the contact angle could be calculated. When the sample was retrieved from the liquid, the retreating angle was measured as well as the advancing angle as it was submerged. The sample had to be rectangular or in the shape of a rod because the sample's perimeter had to be determined. Over the entire region dipped into the test liquid, the contact angle was averaged. This implies that the sample's surface needs to be consistent on all sides, including the edges. The Wilhelmy plate was then unsuitable for determining the contact angle of sample surfaces that had only received one side of a surface treatment.

2.2 Scope of the Present Work.

Based on the literature survey, it was observed that different approaches may be used to determine contact angle when liquid drops on various substrates. In the present work, a simple technique adopted to study droplets on various substrate using simple liquid and colloidal nano-fluids. The experimental contact angle data to see the effect of the variation of contact angle of different liquid and nano-fluids and comparison among them are studied.

Chapter 3

Experimental Method

3.1 Materials

(a) Wooden Block

A cubical wooden box of size 20cm*20cm*20cm is used to perform the experiment in proper way. Main use of this wooden block as a base for keeping substrates on this and for more accuracy distance between substrate and dropping device must be less so, wooden box is used as a base to maintain less distance between solid substrate and dropper.

(b) Syringe and Needle

Needle is used in this experiment for dropping fluid from a certain height at less diameter to see the effect on contact angle. 10 ml syringe is used as a dropper in this experiment because of its less cost and easy to handle for performing experiment.

Fig.3.1 Needle and Syringe

(d) Burette and Clamping Stand

Clamping stand is used to hold dropper at 90 degree vertically to solid substrate which is kept at certain distance on wooden base. 25 ml burette is used as one of the dropper in this experiment for dropping liquid or fluid droplets on solid substrate.

Fig.3.2 Clamping stand and Burette

(f) Macro lens mobile camera

Macro lens camera mobile poco x3 pro is used to click all the picture of droplets in this experiment to calculate contact angle. Macro lens is the most suitable for clicking image of droplets for clearances view.

(g) Liquid

Tap water, Distilled water, Propanol2 are used as liquid for drop analysis on solid substrate for measuring contact angle.

(h) Nano-fluid

Al2O3-Tap water, Al2O3-Propanol2, CuO-Propanol2, CuO-Tap water are these nano-fluid used in ratio 1:10 for drop analysis to measure contact angle of fluid.

(i) Mild steel & Cast iron

Fig.3.3 Cast Iron and Mild Steel

Solid mild steel of dimension 76mm*64mm*7mm is used as one of the substrate on which drop analysis is done for calculating contact angle. Solid cast iron of dimension 76mm*64mm*7mm is used as one of the substrate on which drop analysis is done for calculating contact angle.

(j) Glass & Brass

Fig.3.4 Glass and Bras

Solid glass of dimension 88mm*64mm*12mm is used as one of the substrate on which drop analysis is done for calculating contact angle. Solid brass of dimension 76mm*64mm*8mm is used as one of the substrate on which drop analysis is done for calculating contact angle.

3.2 Nanoparticles

(a) Aluminium Oxide & Copper Oxide

Fig.3.5 Al2O3 nanoparticle and CuO nanoparticle

Aluminium oxide nanoparticle of purity- 99.9%, average particles size: 20-50nm, bulk density: 0.5g/cm3, physical form: powder, morphology: near spherical, colour: white is used in this experiment to mix with liquid and then drop analysis of that mixture is taking place.

Copper oxide nanoparticle of purity- 99.9%, average particles size: 30-70nm, bulk density: 0.66g/cm3, physical form: powder, morphology: spherical, colour: brownish white is used in this experiment to mix with liquid and then drop analysis of that mixture is taking place.

3.3 Experiment Procedure

(a) Use a flat rectangular clean table on which experiment is taking place.

(b) Keep small cubical wooden box on flat rectangular table vertically.

(c) Stand with clamping to hold syringe or burette vertically to substrate kept on cubical wooden box.

(d) Always take care of distance between tip of the dropper and substrate in range of 8 to 10 cm for more accuracy.

(e) Small cubical wooden box must be parallel 180 degree to clamping stand.

(f) Always take care of drop must be fall vertically to substrates.

(g) After falling drop on substrate picture should be taken of that droplet with macro lens from side view with camera must be at 90 degree to that droplet.

(h) After getting picture of liquid or fluid drop, drop analysis should be done manually and with the help of software to calculate contact angle.

(i) For manually we use protector to calculate contact angle of droplets.

(j) For software we use Image J software for drop analysis and calculate contact angle.

(k) Compare contact angle obtained manually with software obtained value and plot the graph.

Fig.3.6 Experimental Setup

Chapter 4

Experimental Results and Discussions

To calculate the contact angle of all the droplets of liquid (tap water, distilled water, propanol2) or fluid (Al2O3-tap water, Al2O3-propanol2, CuO-propanol2, CuO-tap water) falling on substrate (mild steel, cast iron, glass, brass) have been done by two method in this experiment:- The measurement of contact angle of all the experimental figure of droplets are done with the help of protector and Image J software in this experiment.

4.1 Mild steel substrate with syringe with needle dropper

(a) Tap Water

Droplet of tap water from syringe with needle dropper falls vertically on mild steel substrate as shown below in figure and gives contact angle value 91.4 degree calculated by Image J drop analysis software and 96 degree contact angle found by protector method.

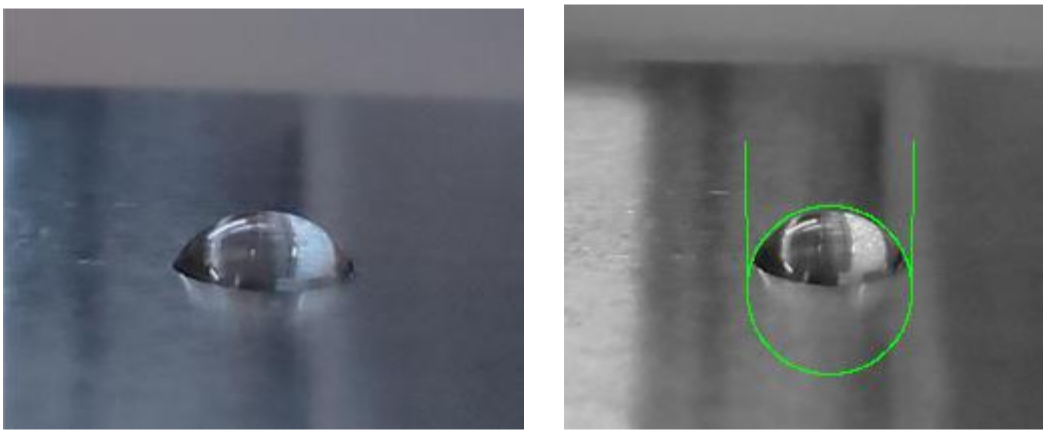

Fig.4.1 Tap water droplet from syringe with needle dropper on mild steel substrate and its Contact angle drop analysis from image J software.

(b) Distilled Water

Droplet of distilled water from syringe with needle dropper falls vertically on mild steel substrate as shown below in figure and gives contact angle value 94.5 degree calculated by Image J drop analysis software and 95 degree contact angle found by protector method.

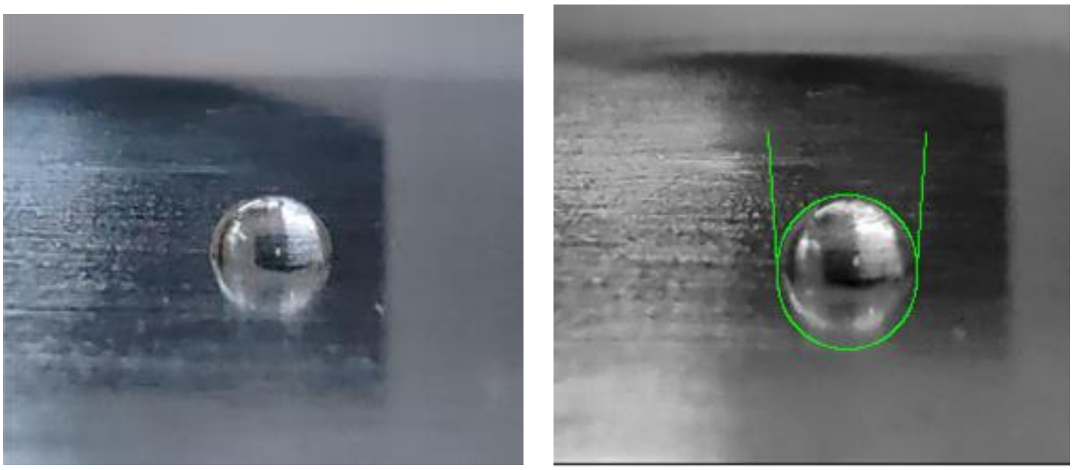

Fig.4.2 Distilled water droplet from syringe with needle dropper on mild steel substrate and its contact angle drop analysis from image J software.

(c) Propanol2

Droplet of liquid propanol2 from syringe with needle dropper falls vertically on mild steel substrate as shown below in figure and gives contact angle value 93 degree calculated by Image J drop analysis software and 88 degree contact angle found by protector method.

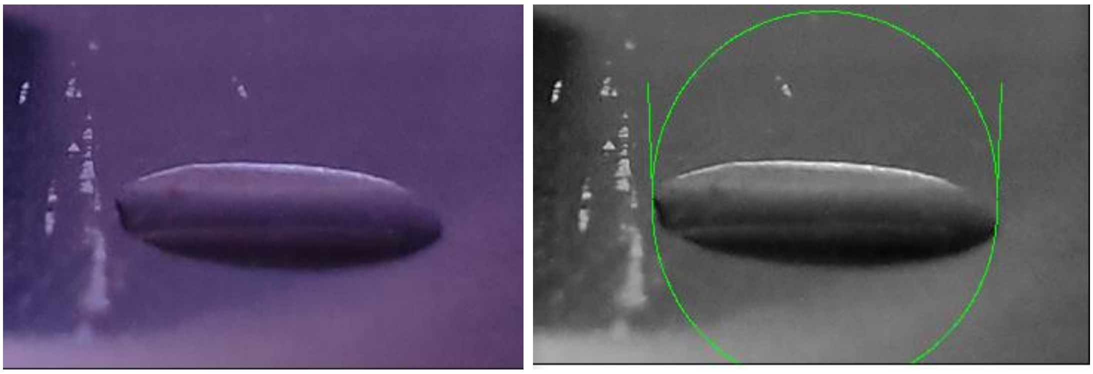

Fig.4.3 Propanol2 droplet from syringe with needle dropper on mild steel substrate and its contact angle drop analysis from image J software.

4.2 Mild steel substrate with syringe dropper

(a) Tap Water

Droplet of tap water from syringe dropper falls vertically on mild steel substrate as shown below in figure and gives contact angle value 99.6 degree calculated by Image J drop analysis software and 94 degree contact angle found by protector method.

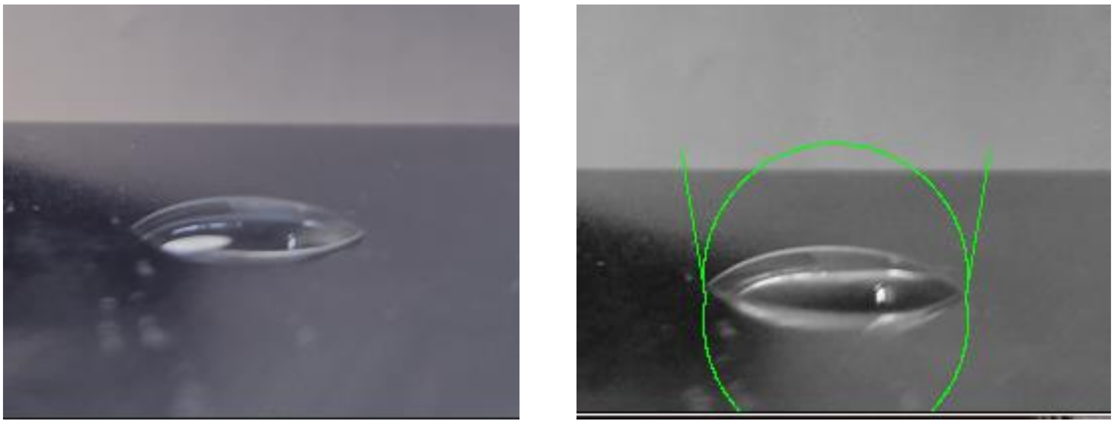

Fig.4.4 Tap water droplet from syringe dropper on mild steel substrate and its contact angle drop analysis from image J software.

(c) Propanol2

Droplet of liquid propanol2 from syringe dropper falls vertically on mild steel substrate as shown below is spreading too fast so, contact angle is difficult to find.

Fig.4.5. Propanol2 droplet from syringe dropper on mild steel substrate.

4.3 Mild steel substrate with burette dropper

(a) Tap Water

Droplet of tap water from burette dropper falls vertically on mild steel substrate as shown below in figure and gives contact angle value 93 degree calculated by Image J drop analysis software and 95 degree contact angle found by protector method.

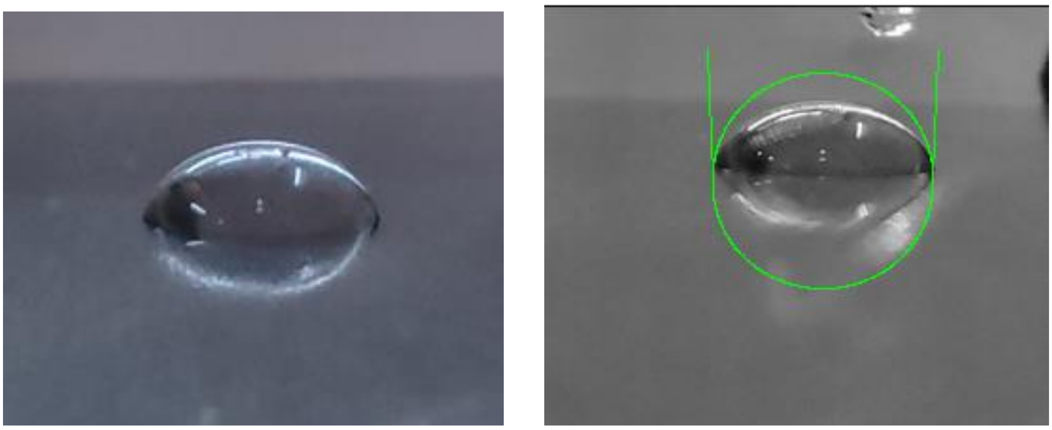

Fig.4.6 Tap water droplet from burette dropper on mild steel substrate and its contact angle drop analysis from image J software.

(b) Distilled Water

Droplet of distilled water from burette dropper falls vertically on mild steel substrate as shown below in figure and gives contact angle value 91.8 degree calculated by Image J drop analysis software and 94 degree contact angle found by protector method.

Fig.4.7 Distilled water droplet from burette dropper on mild steel substrate and its contact angle drop analysis from image J software.

(c) Propanol2

Droplet of liquid propanol2 from burette dropper falls vertically on mild steel substrate as shown below in figure and gives contact angle value 100.240 degree calculated by Image J drop analysis software and 99 degree contact angle found by protector method.

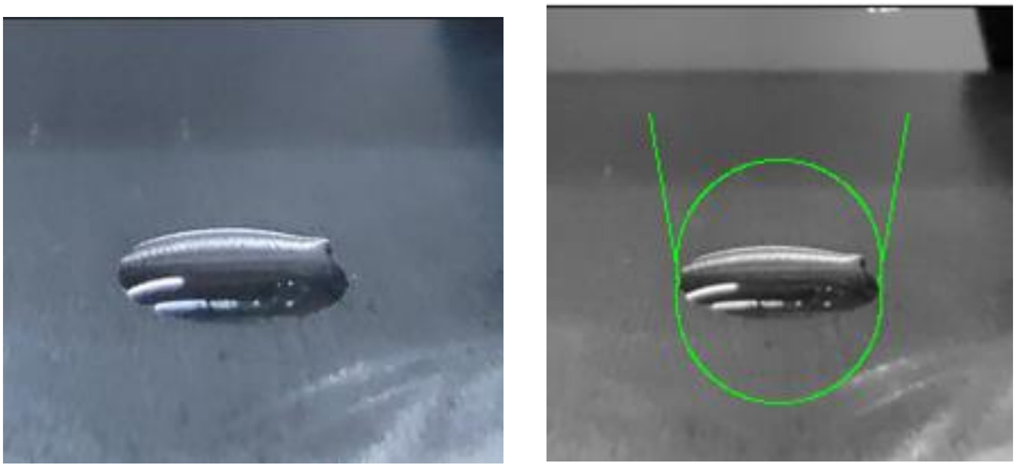

Fig.4.8. Propanol2 droplet from burette dropper on mild steel substrate and its contact angle drop analysis from image J software.

4.4 Cast iron substrate with syringe with needle dropper

(a) Tap Water

Droplet of tap water from syringe with needle dropper falls vertically on cast iron substrate as shown below in figure and gives contact angle value 91.5 degree calculated by Image J drop analysis software and 91.5 degree contact angle found by protector method.

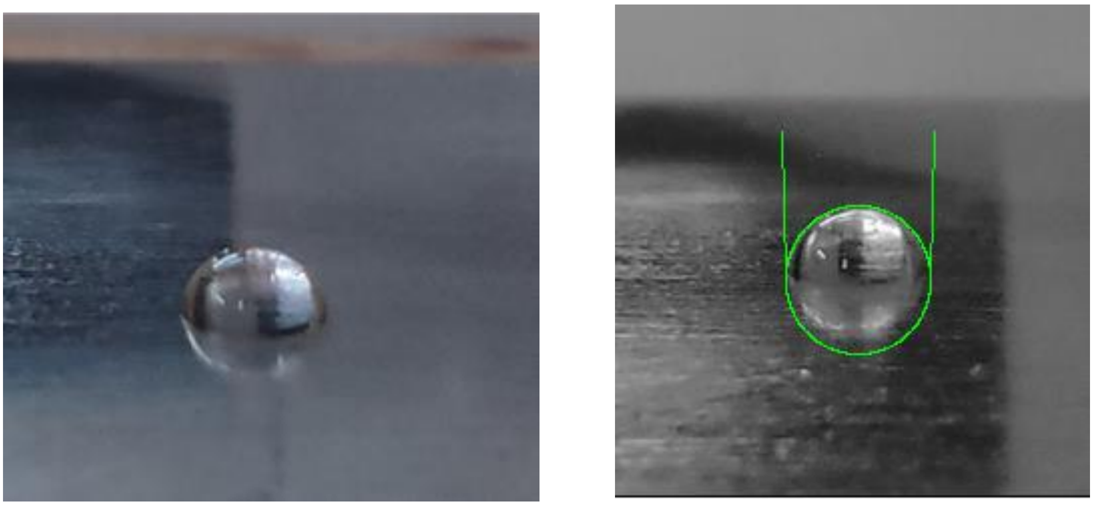

Fig.4.9. Tap water droplet from syringe with needle dropper on cast iron substrate and its contact angle drop analysis from image J software.

(b) Distilled Water

Droplet of distilled water from syringe with needle dropper falls vertically on cast iron substrate as shown below in figure and gives contact angle value 91 degree calculated by Image J drop analysis software and 92.75 degree contact angle found by protector method.

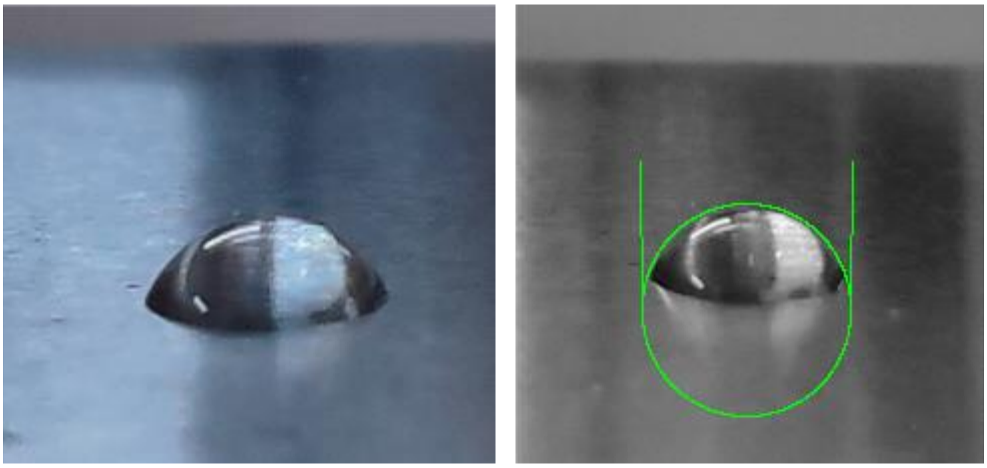

Fig.4.10. Distilled water droplet on cast iron substrate and its contact angle drop analysis from image J software.

(c) Propanol2

Droplet of liquid propanol2 from syringe with needle dropper falls vertically on cast iron substrate as shown below in figure and gives contact angle value 92 degree calculated by Image J drop analysis software and 93.5 degree contact angle found by protector method.

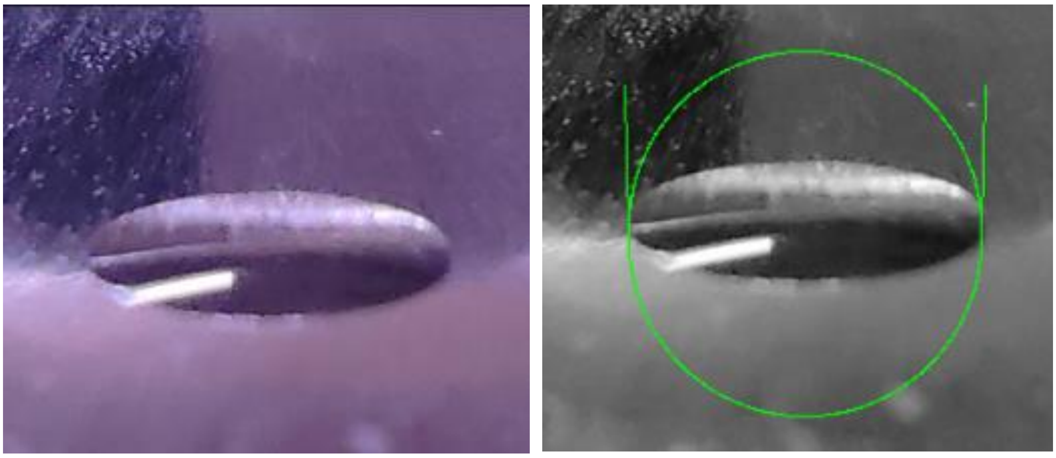

Fig.4.11 Propanol2 droplet from syringe with needle dropper on cast iron substrate and its contact angle drop analysis from image J software.

4.5 Cast iron substrate with syringe dropper

(a) Tap Water

Droplet of tap water from syringe dropper falls vertically on cast iron substrate as shown below in figure and gives contact angle value 100 degree calculated by Image J drop analysis software and 94.5 degree contact angle found by protector method.

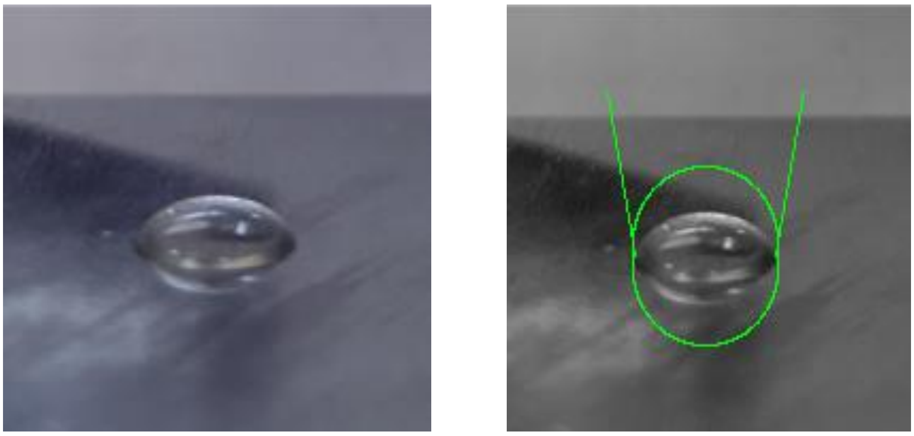

Fig.4.12 Tap water droplet from syringe dropper on cast iron substrate and its contact angle drop analysis from image J software.

(c) Propanol2

Droplet of liquid propanol2 from syringe dropper falls vertically on cast iron substrate as shown below in figure and gives contact angle value 90.5 degree calculated by Image J drop analysis software and 92 degree contact angle found by protector method.

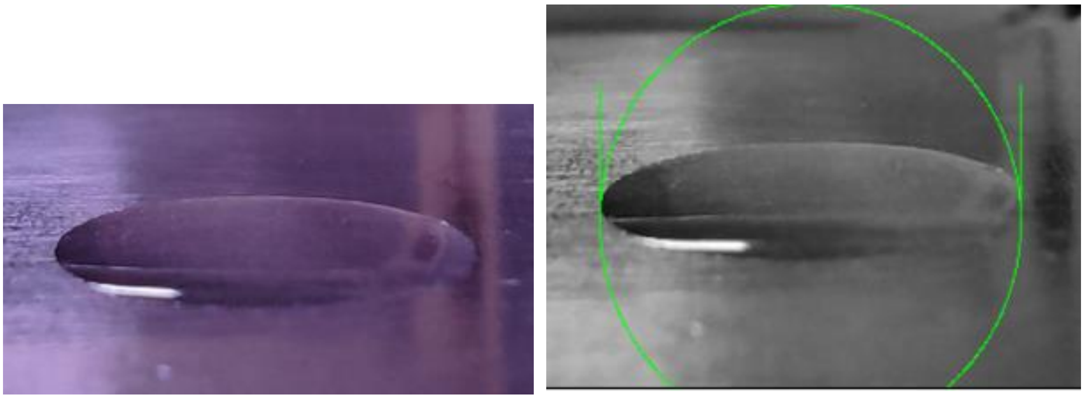

Fig.4.13 Propanol2 droplet from syringe dropper on cast iron substrate and its Contact angle drop analysis from image J software.

4.6 Cast iron substrate with burette dropper

(a) Tap Water

Droplet of tap water from burette dropper falls vertically on cast iron substrate as shown below in figure and gives contact angle value 93 degree calculated by Image J drop analysis software and 93 degree contact angle found by protector method.

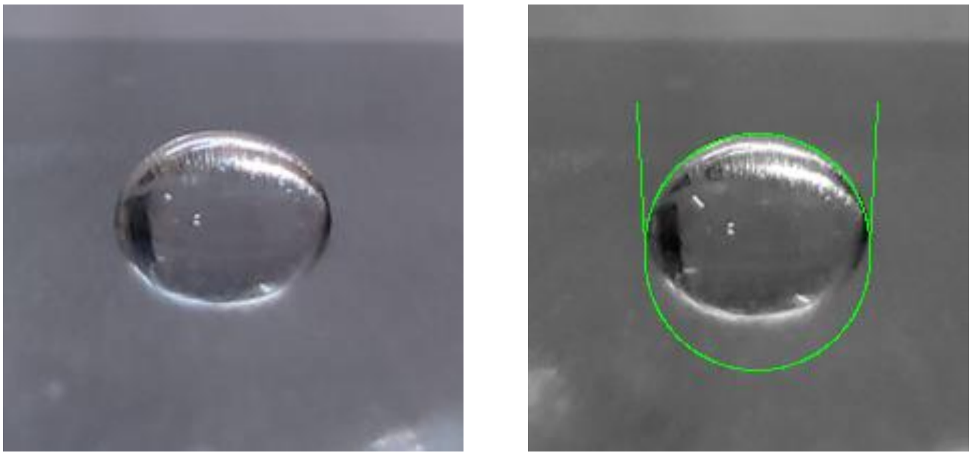

Fig.4.14 Tap water droplet from burette dropper on cast iron substrate and its contact angle drop analysis from image J software.

(b) Distilled Water

Droplet of distilled water from burette dropper falls vertically on cast iron substrate as shown below in figure and gives contact angle value 92 degree calculated by Image J drop analysis software and 94 degree contact angle found by protector method.

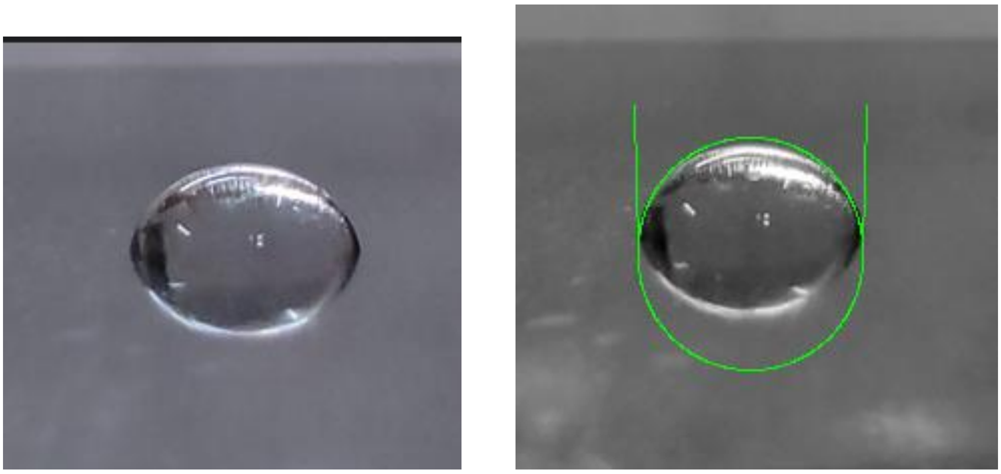

Fig.4.15 Distilled water droplet from burette dropper on cast iron substrate and its contact angle drop analysis from image J software.

(c) Propanol2

Droplet of liquid propanol2 from burette dropper falls vertically on cast iron substrate as shown below in figure and gives contact angle value 95.645 degree calculated by Image J drop analysis software and 99 degree contact angle found by protector method.

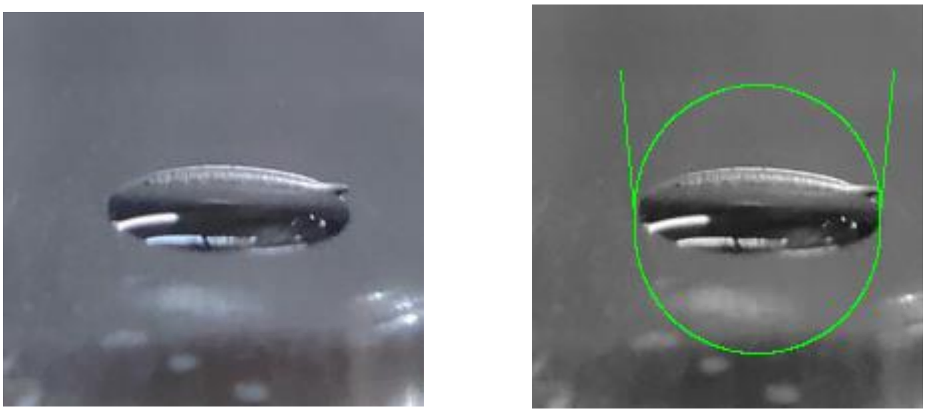

Fig.4.16 Propanol2 droplet from burette dropper on cast iron Substrate and its contact angle drop analysis from image J software.

4.7 Glass substrate with syringe with needle dropper

(a) Tap Water

Droplet of tap water from syringe with needle dropper falls vertically on glass substrate as shown below in figure and gives contact angle value 88 degree calculated by Image J drop analysis software and 92 degree contact angle found by protector method.

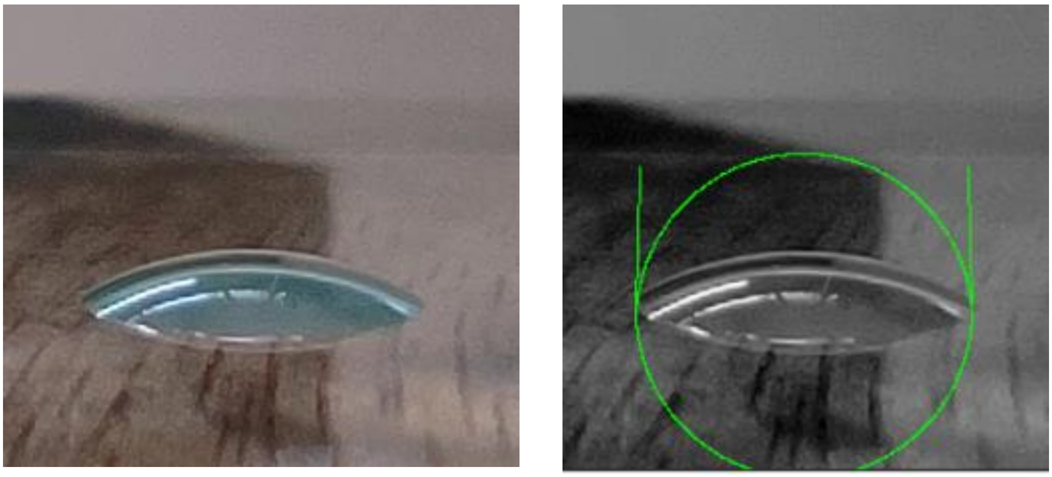

Fig.4.17 Tap water droplet on glass substrate and its contact angle drop analysis by image J software.

(b) Distilled Water

Droplet of distilled water from syringe with needle dropper falls vertically on glass substrate as shown below in figure and gives contact angle value 98 degree calculated by Image J drop analysis software and 99.5 degree contact angle found by protector method.

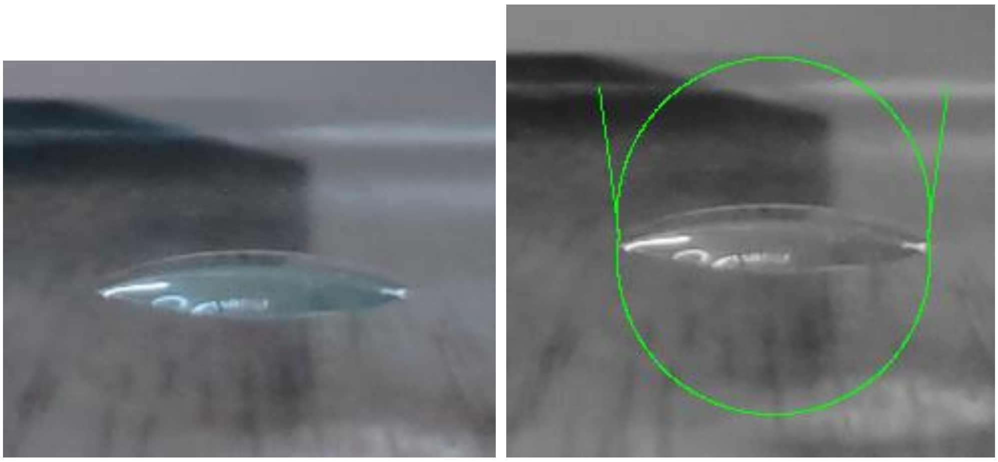

Fig.4.18 Distilled water droplet from syringe with needle dropper on glass substrate and its contact angle drop analysis by image J software.

(c) Propanol2

Droplet of liquid propanol2 from syringe with needle dropper falls vertically on glass substrate as shown below in figure and gives contact angle value 93.7 degree calculated by Image J drop analysis software and 90 degree contact angle found by protector method.

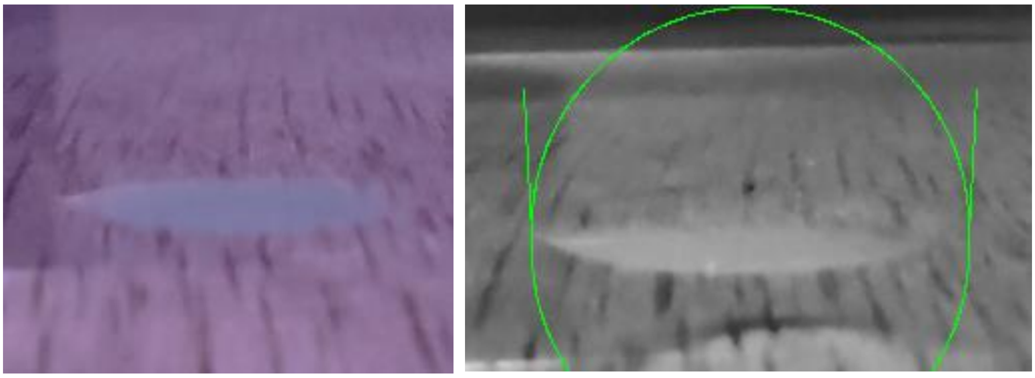

Fig.4.19 Propanol2 droplet from syringe with needle dropper on glass substrate and its contact angle drop analysis by image J software.

4.8 Glass substrate with syringe dropper

(a) Tap Water

Droplet of tap water from syringe dropper falls vertically on glass substrate as shown below in figure and gives contact angle value 100 degree calculated by Image J drop analysis software and 105 degree contact angle found by protector method.

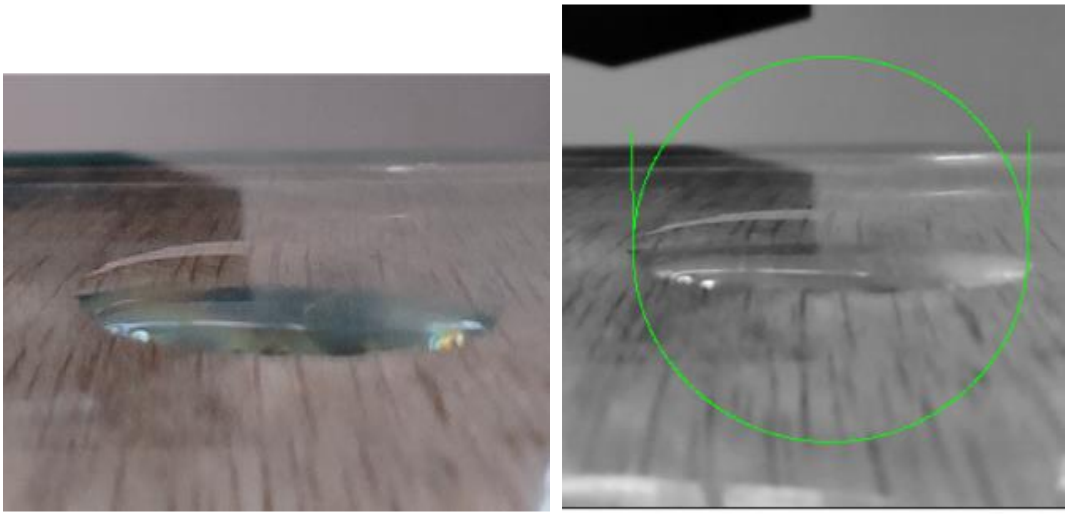

Fig.4.20 Tap water droplet from syringe dropper on glass substrate and its contact angle drop analysis from image J software.

(b) Propanol2

Droplet of liquid propanol2 from syringe dropper falls vertically on glass substrate as shown below in figure and gives contact angle value 91.926 degree calculated by Image J drop analysis software and 91 degree contact angle found by protector method.

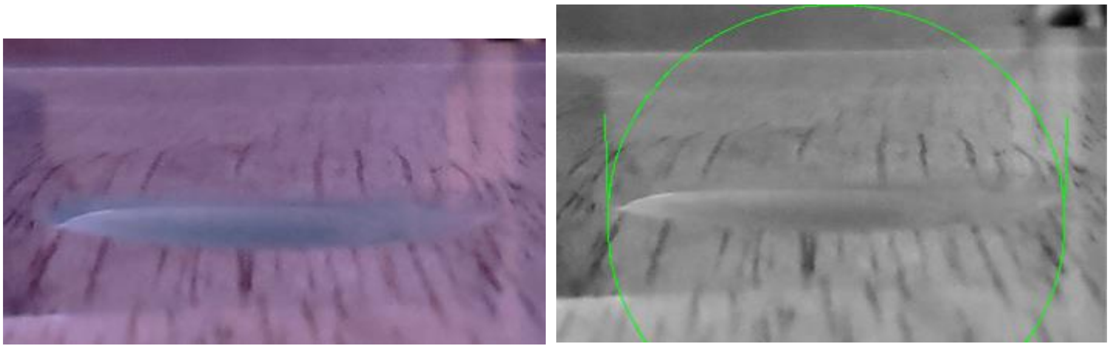

Fig.4.21 Propanol2 droplet from syringe dropper on glass substrate and its contact angle drop analysis from image J software.

4.9 Glass substrate with burette dropper

(a) Tap Water

Droplet of tap water from burette dropper falls vertically on glass substrate as shown below in figure and gives contact angle value 106.6 degree calculated by Image J drop analysis software and 103 degree contact angle found by protector method.

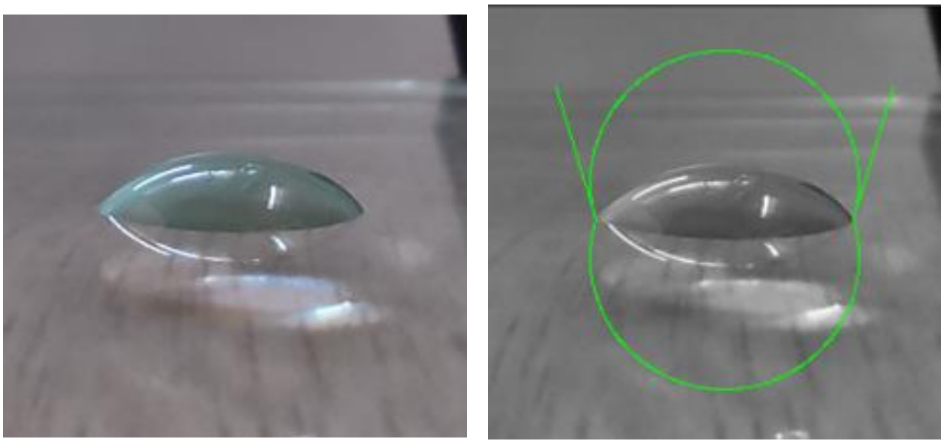

Fig.4.22 Tap water droplet from burette dropper on glass substrate and its contact angle drop analysis image J software.

(b) Distilled Water

Droplet of distilled water from burette dropper falls vertically on glass substrate as shown below in figure and gives contact angle value 92 degree calculated by Image J drop analysis software and 97.5 degree contact angle found by protector method.

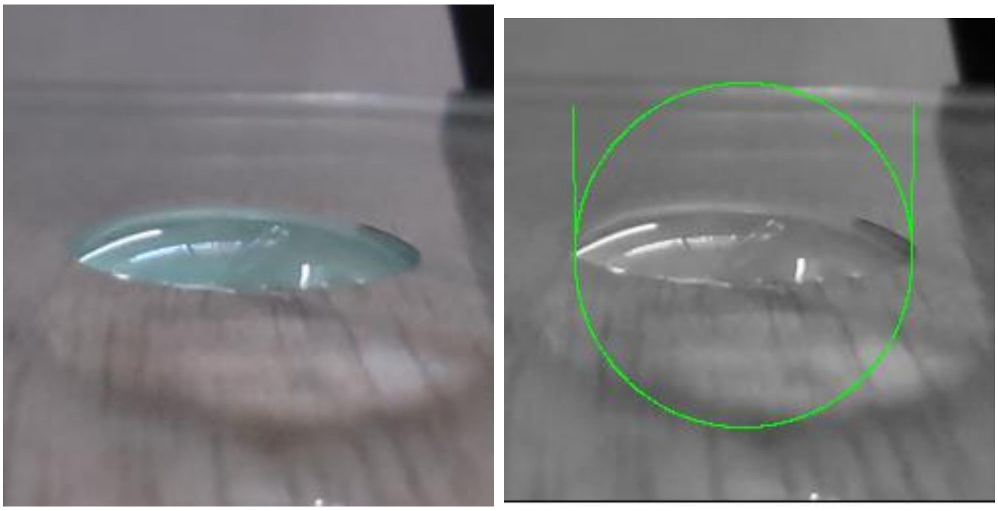

Fig.4.23 Distilled water droplet from burette dropper on glass substrate and its contact angle drop analysis from image J software.

(c) Propanol2

Droplet of liquid propanol2 from burette dropper falls vertically on glass substrate as shown below in figure and spreading so fast on glass that's why contact angle value difficult to find.

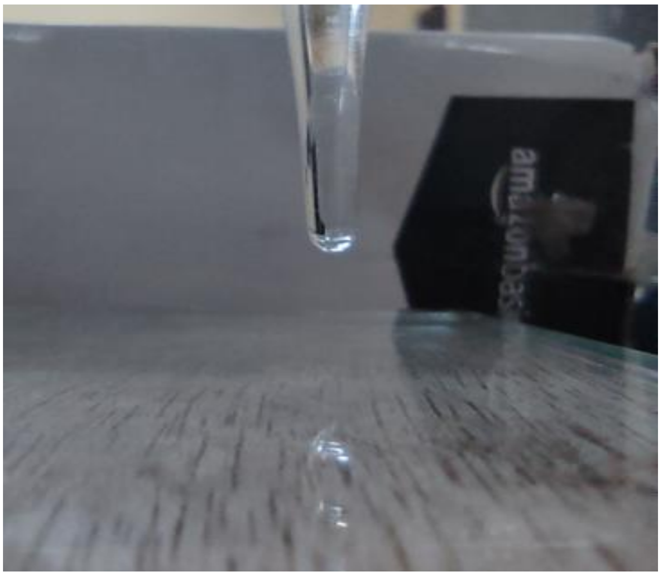

Fig.4.24 Propanol2 droplet from burette dropper on glass substrate.

4.10 Brass substrate with syringe with needle dropper

(a) Tap Water

Droplet of tap water from syringe with needle dropper falls vertically on brass substrate as shown below in figure and gives contact angle value 94.2 degree calculated by Image J drop analysis software and 94 degree contact angle found by protector method.

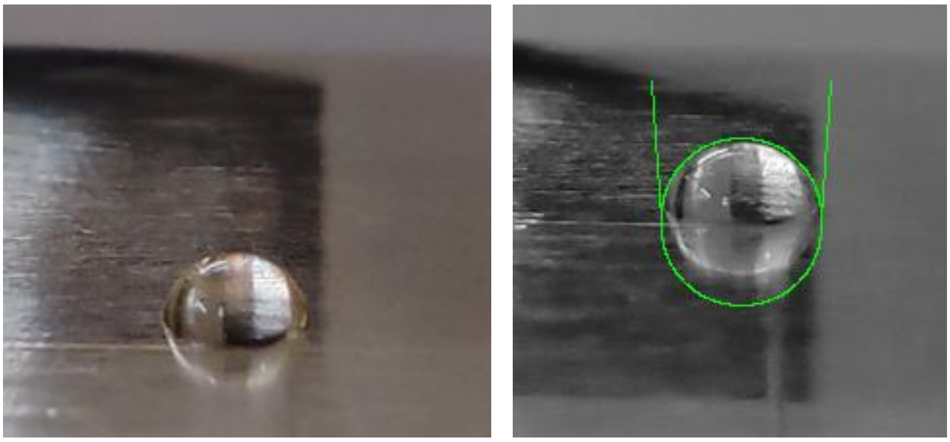

Fig.4.25 Tap water droplet from syringe with needle dropper on brass substrate and its contact angle drop analysis by image J software.

(b) Distilled Water

Droplet of distilled water from syringe with needle dropper falls vertically on brass substrate as shown below in figure and gives contact angle value 94 degree calculated by Image J drop analysis software and 92 degree contact angle found by protector method.

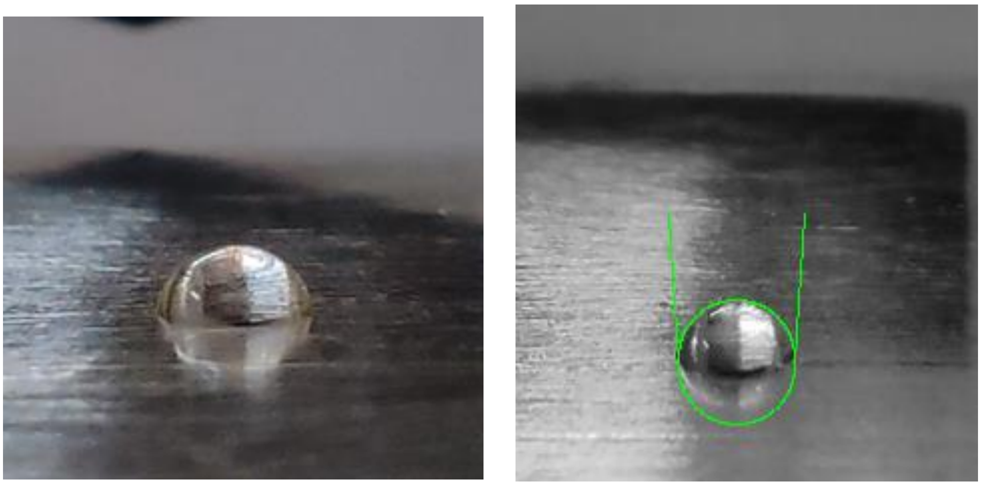

Fig.4.26 Distilled water droplet from syringe with needle dropper on brass substrate and its contact angle drop analysis by image J software.

(c) Propanol2

Droplet of liquid propanol2 from syringe with needle dropper falls vertically on brass substrate as shown below in figure and gives contact angle value 91.15 degree calculated by Image J drop analysis software and 90 degree contact angle found by protector method.

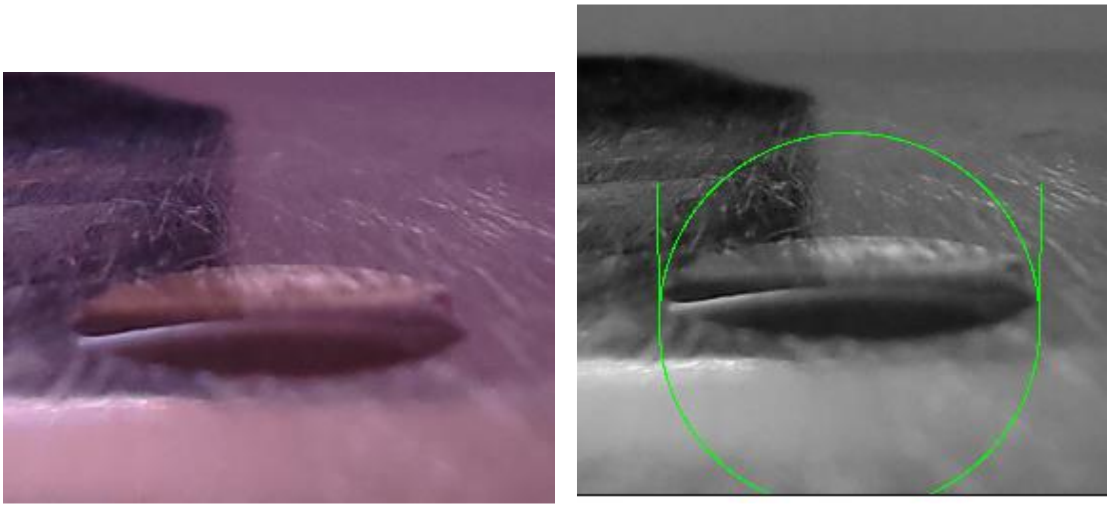

Fig.4.27 Propanol2 droplet from syringe with needle dropper on brass substrate and its contact angle drop analysis by image J software.

4.11 Brass substrate with syringe dropper

(a) Tap Water

Droplet of tap water from syringe dropper falls vertically on brass substrate as shown below in figure and gives contact angle value 93.185 degree calculated by Image J drop analysis software and 92.33 degree contact angle found by protector method.

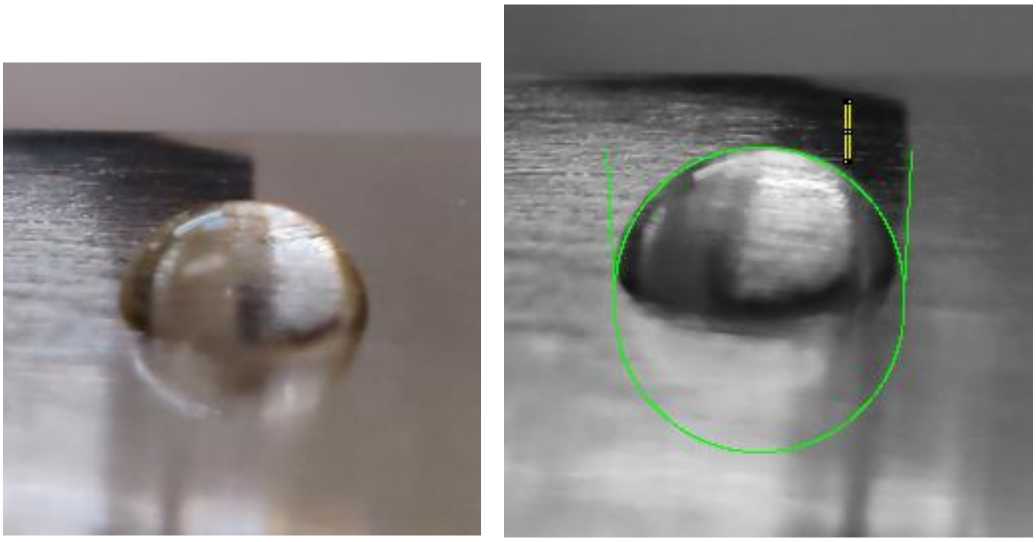

Fig.4.28 Tap water droplet from syringe dropper on brass substrate and its contact angle drop analysis by image J software.

(b) Propanol2

Droplet of liquid propanol2 from syringe dropper falls vertically on brass substrate as shown below in figure and gives contact angle value 88 degree calculated by Image J drop analysis software and 92 degree contact angle found by protector method.

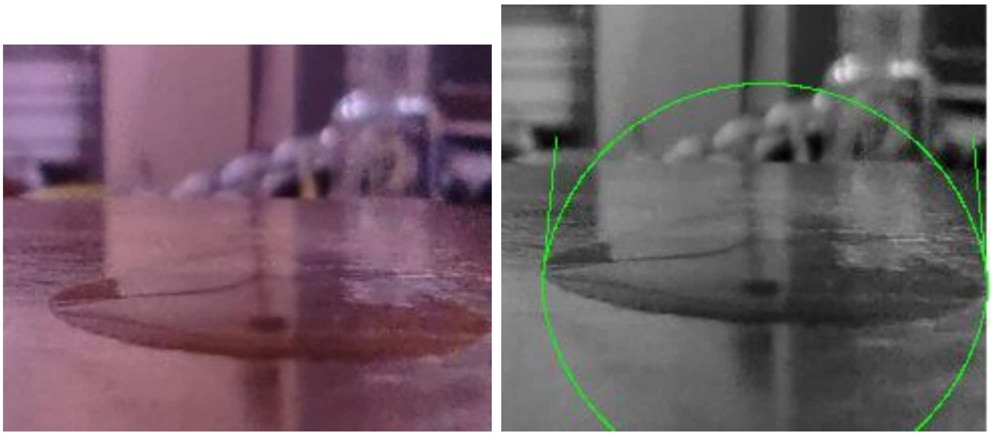

Fig.4.29 Propanol2 droplet from syringe dropper on brass substrate and its contact angle drop analysis by image J software.

4.12 Brass substrate with burette dropper

(a) Tap Water

Droplet of tap water from burette dropper falls vertically on brass substrate as shown below in figure and gives contact angle value 91 degree calculated by Image J drop analysis software and 92.75 degree contact angle found by protector method.

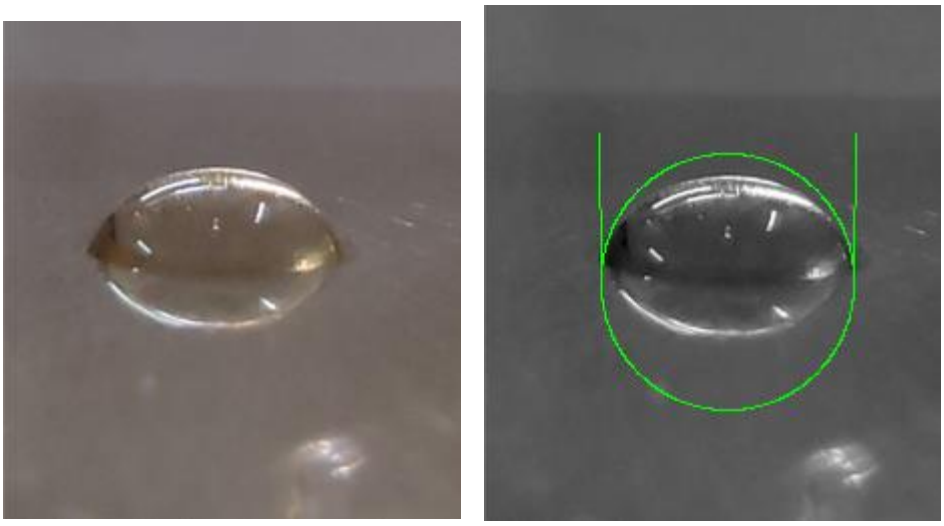

Fig.4.30 Tap water droplet from burette dropper on brass substrate and its contact angle drop analysis image J software.

(b) Distilled Water

Droplet of distilled water from burette dropper falls vertically on brass substrate as shown below in figure and gives contact angle value 91 degree calculated by Image J drop analysis software and 94 degree contact angle found by protector method.

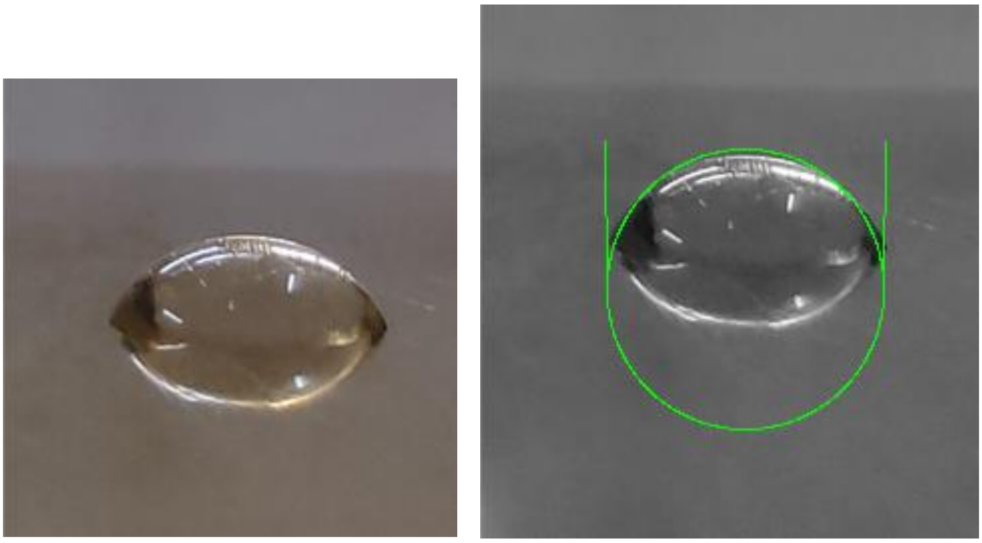

Fig.4.31 Distilled water droplet from burette dropper on brass substrate and its contact angle drop analysis image J software.

(c) Propanol2

Droplet of liquid propanol2 from burette dropper falls vertically on brass substrate as shown below in figure and gives contact angle value 97 degree calculated by Image J drop analysis software and 104 degree contact angle found by protector method.

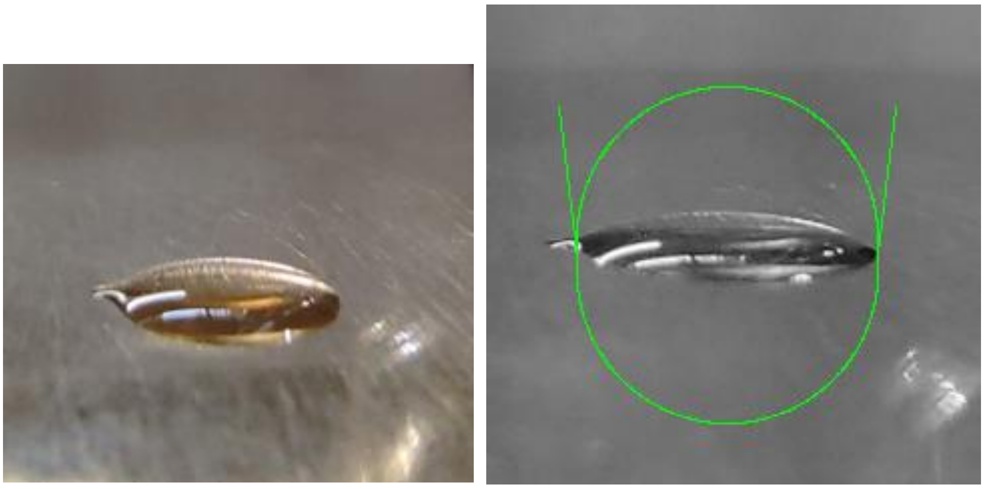

Fig.4.32 Propanol2 droplet from burette dropper on brass substrate and its contact angle drop analysis image J software.

4.13 Nano-fluid

A nano-fluid is a fluid in which nano meter-sized particles, suspended in the base fluid, form a colloidal solution of nanoparticles in a base fluid. The nanoparticles used in nano-fluids are typically made of metals, oxides, carbides, or carbon nanotubes, while the base fluids include water, ethylene glycol, and oil.

In my experiment i used aluminium oxide and copper oxide nanoparticle dissolve in tap water and propanol2 in ratio 1:10.Make nano-fluid by dissolving nanoparticle in base fluid by proper mixing to use for calculating contact angle on different substrate below.

4.13(a) Mild steel

When nano-fluid Al_2O_3-Propanol2 falls on substrate mild steel it gives contact angle value of 89.5 and 89.45 degree by protector method and image J drop analysis software respectively.

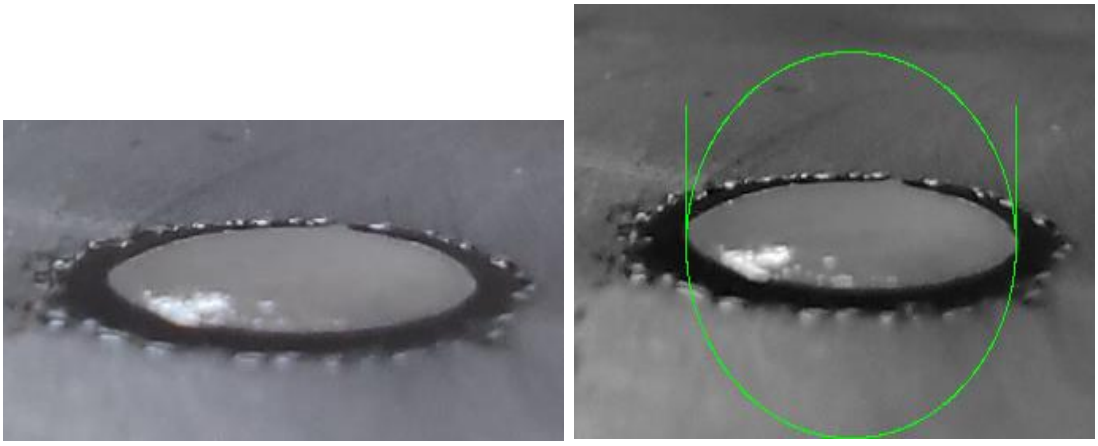

Fig.4.33 Al2O3-Propanol2 droplet on mild steel substrate and its contact angle drop analysis by image J software.

When nano-fluid Al2O3-Tap water falls on substrate mild steel it gives contact angle value of 88 and 91.56 degree by protector method and image J drop analysis software respectively.

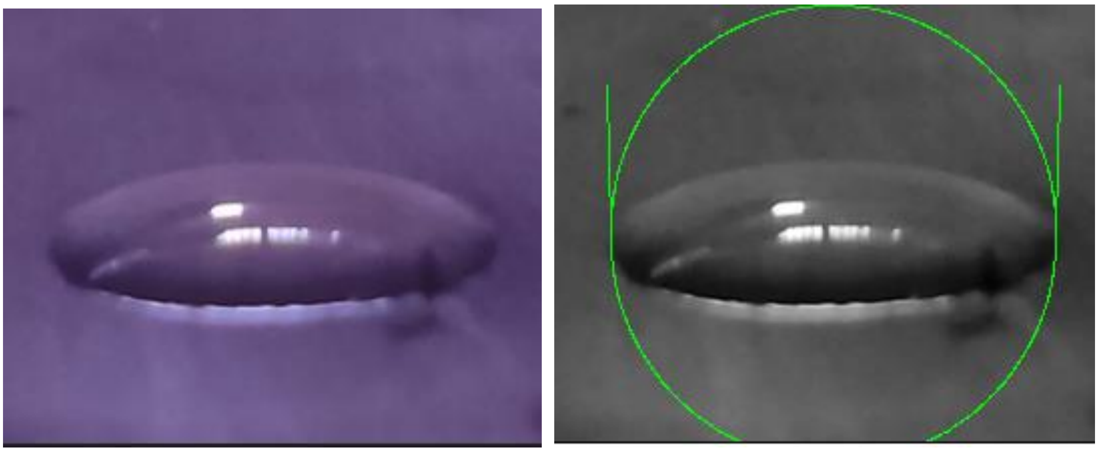

Fig.4.34 Al2O3-Tap water droplet on mild steel substrate and its contact angle drop analysis by image J software.

When nano-fluid CuO-Tap water falls on substrate mild steel it gives contact angle value of 90.5 and 91.64 degree by protector method and image J drop analysis software respectively.

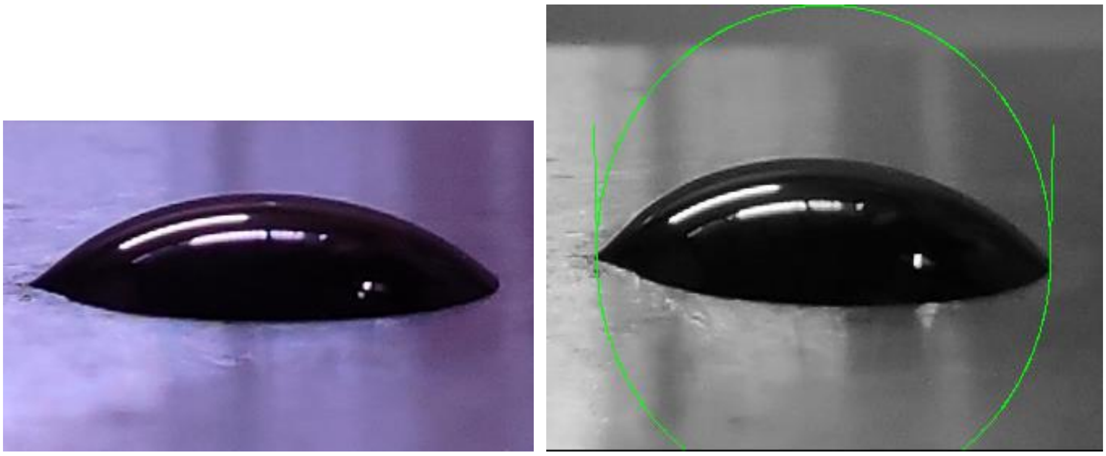

Fig.4.35 CuO-Tap water droplet on mild steel substrate and its contact angle drop analysis by image J software.

4.13(b) Cast Iron

When nano-fluid Al2O3-Propanol2 falls on substrate cast iron it gives contact angle value of 91.75 and 95.645 degree by protector method and image J drop analysis software respectively.

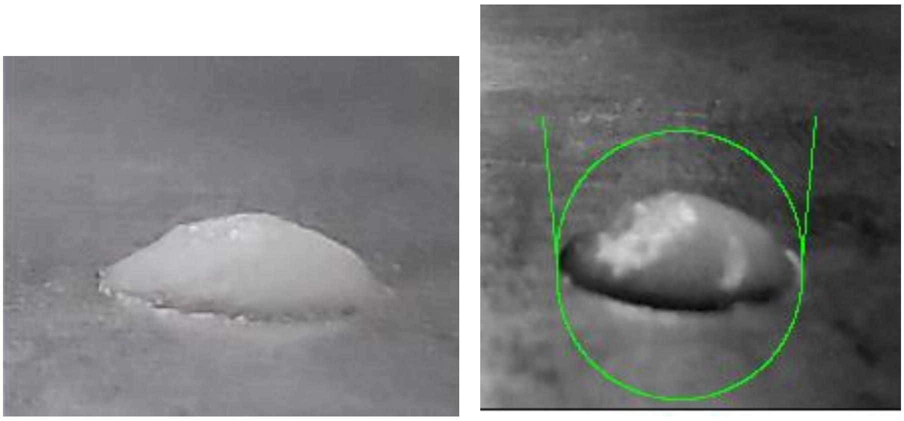

Fig.4.36 Al2O3-Propanol2 droplet on cast iron substrate and its contact angle drop analysis by image J software.

When nano-fluid Al2O3-Tap water falls on substrate cast iron it gives contact angle value of 92 and 91.5 degree by protector method and image J drop analysis software respectively.

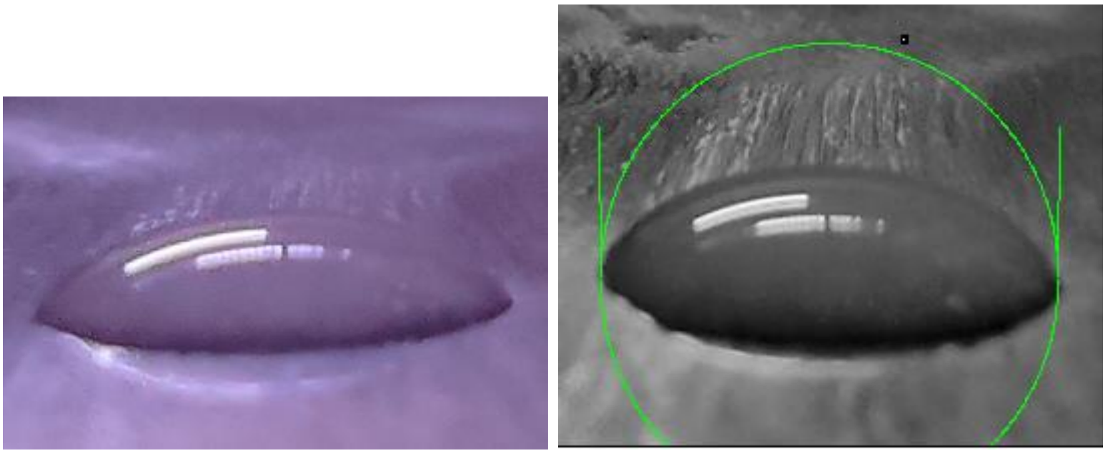

Fig.4.37 Al2O3-Tap water droplet on cast iron substrate and its contact angle drop analysis by image J software.

When nano-fluid Cuo-Propanol2 falls on substrate cast iron it gives contact angle value of 91.75 and 88.842 degree by protector method and image J drop analysis software respectively.

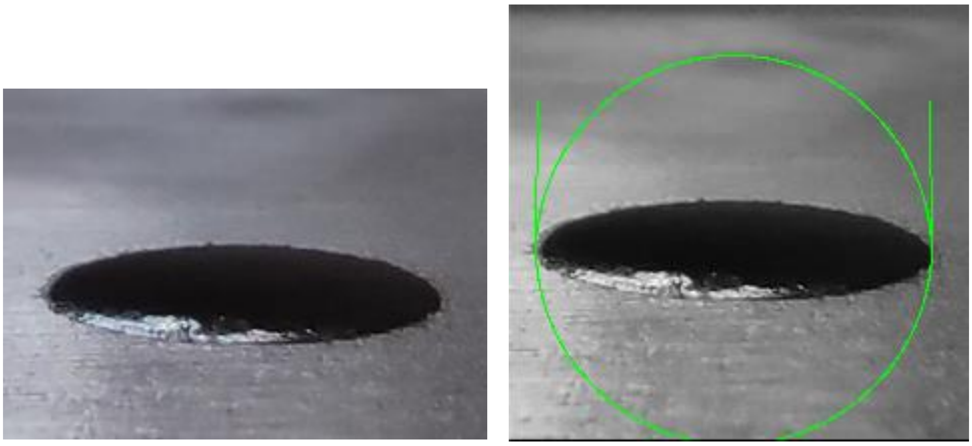

Fig.4.38 CuO-Propanol2 droplet on cast iron substrate and its contact angle drop analysis by image J software.

When nano-fluid CuO-Tap water falls on substrate cast iron it gives contact angle value of 90 and 90.80 degree by protector method and image J drop analysis software respectively.

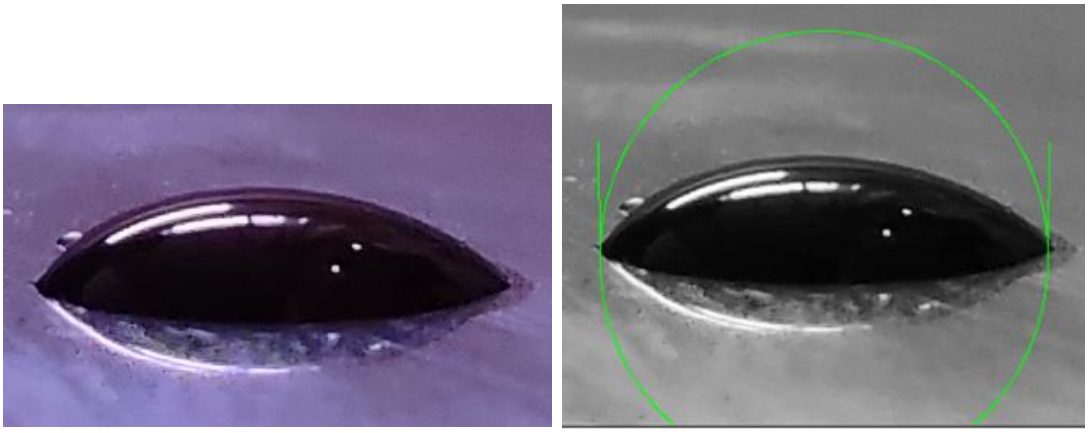

Fig.4.39 CuO-Tap water droplet on cast iron substrate and its contact angle drop analysis by image J software.

4.13(c) Glass

When nano-fluid Al2O3-Propanol2 falls on substrate glass it gives contact angle value of 91.5 and 90.5 degree by protector method and image J drop analysis software respectively.

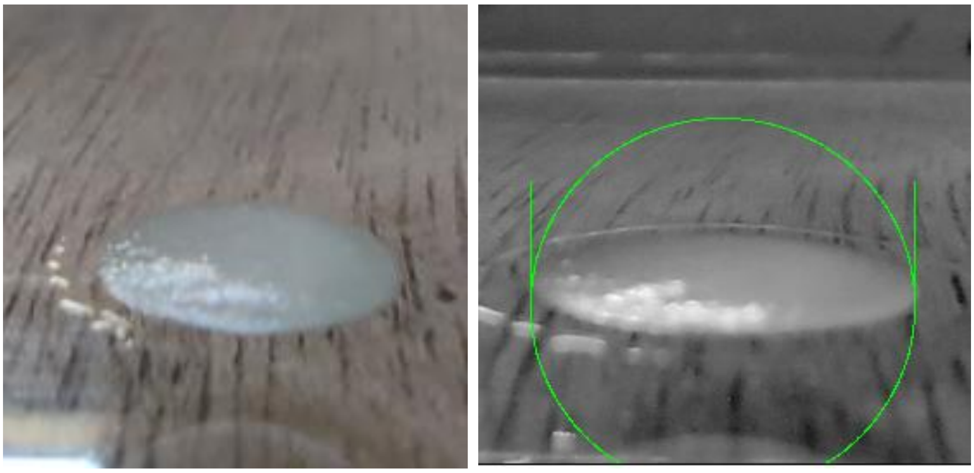

Fig.4.40 Al2O3-Propanol2 droplet on glass substrate and its contact angle drop analysis by image J software.

When nano-fluid Al2O3-Tap water falls on substrate glass it gives contact angle value of 86.5 and 85 degree by protector method and image J drop analysis software respectively.

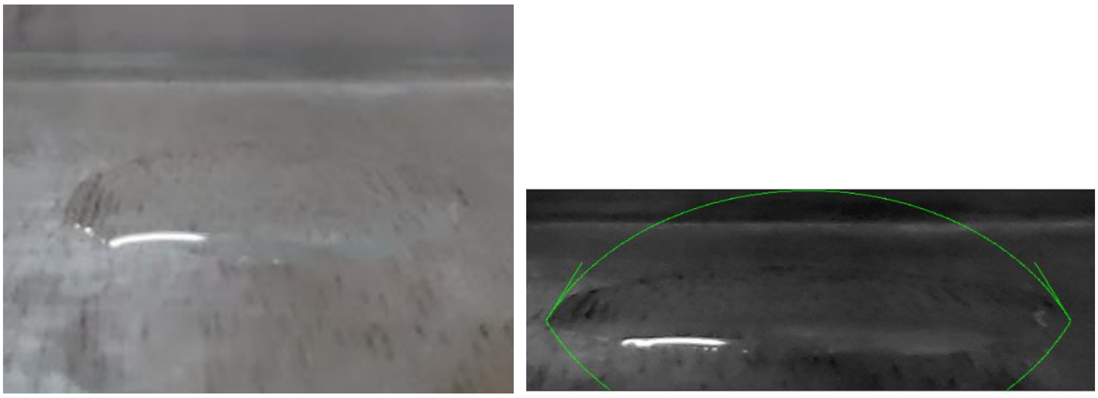

Fig.4.41 Al2O3-Tap water droplet on glass substrate and its contact angle drop analysis by image J software.

When nano-fluid CuO-propanol2 falls on substrate glass it gives contact angle value of 90 and 91.2 degree by protector method and image J drop analysis software respectively.

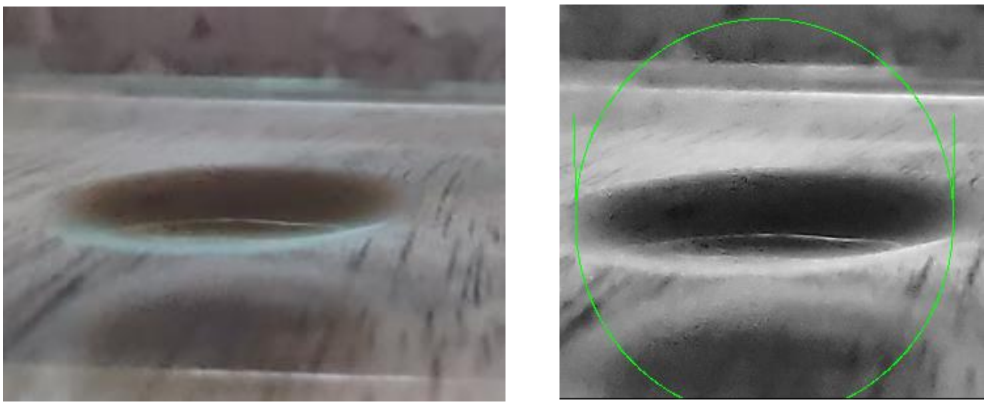

Fig.4.42 CuO-Propanol2 droplet on glass substrate and its contact angle drop analysis by image J software.

When nano-fluid CuO-Tap water falls on substrate glass it gives contact angle value of 91 and 92 degree by protector method and image J drop analysis software respectively.

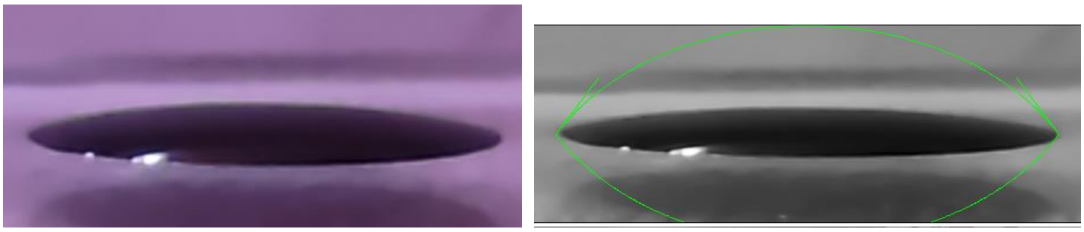

Fig.4.43 CuO-Tap water droplet on glass substrate and its contact angle drop analysis by image J software.

4.13(d) Brass

When nano-fluid Al2O3-Propanol2 falls on substrate brass it gives contact angle value of 91 and 93 degree by protector method and image J drop analysis software respectively.

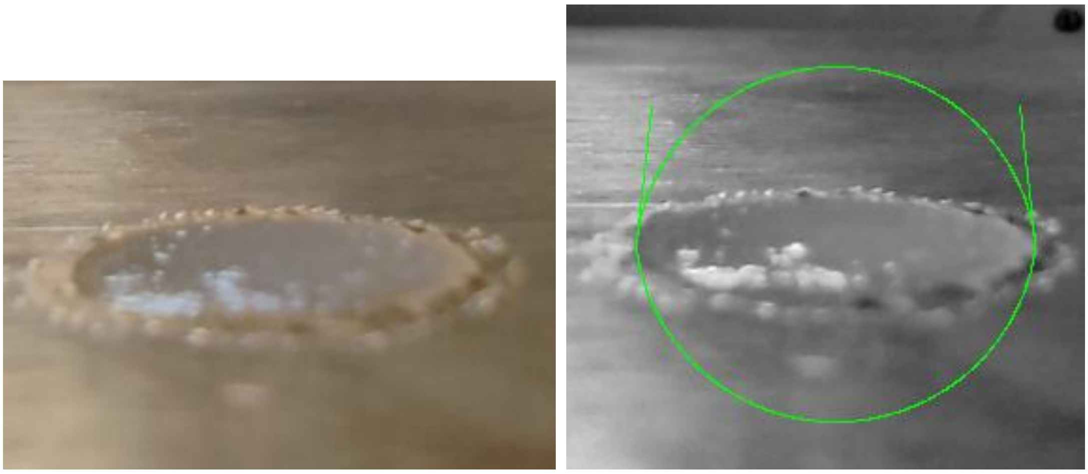

Fig.4.44 Al2O3-Propanol2 droplet on brass substrate and its contact angle drop analysis by image J software.

When nano-fluid Al2O3-Tap water falls on substrate brass it gives contact angle value of 92 and 90.5 degree by protector method and image J drop analysis software respectively.

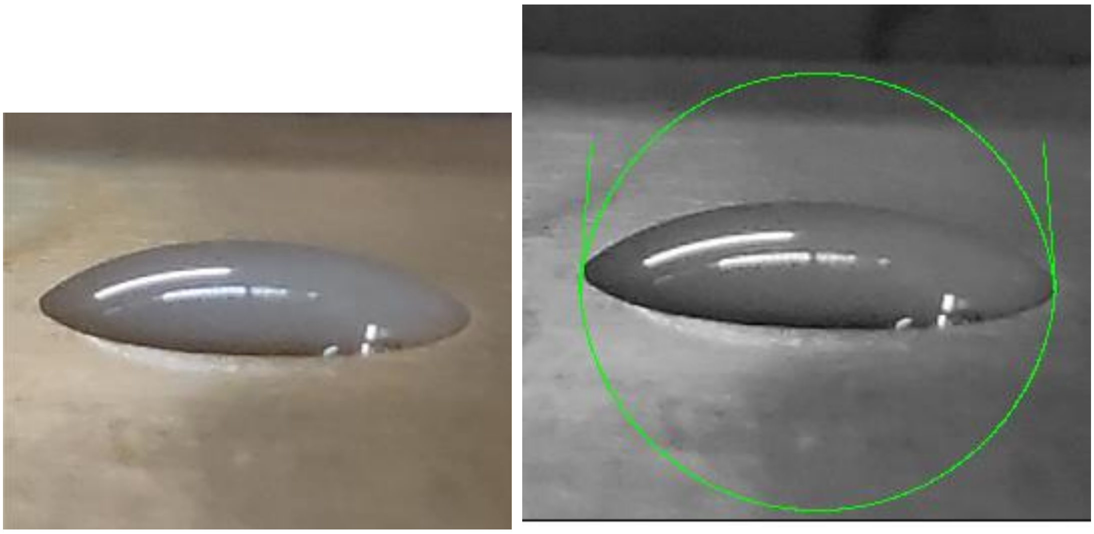

Fig.4.45 Al2O3-Tap water droplet on brass substrate and its contact angle drop analysis by image J software.

When nano-fluid CuO-Propanol2 falls on substrate brass it gives contact angle value of 92 and 93 degree by protector method and image J drop analysis software respectively.

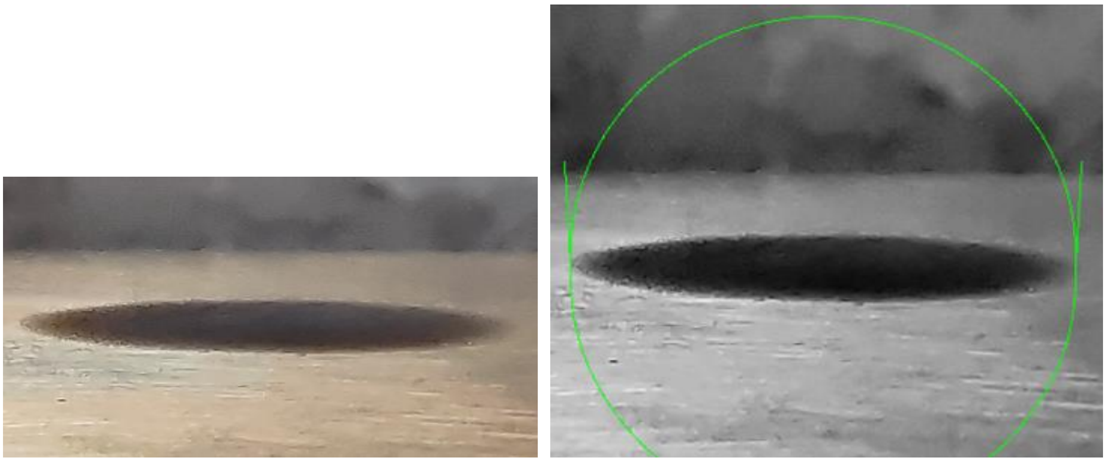

Fig.4.46 CuO-Propanol2 droplet on brass substrate and its contact angle drop analysis by image J software.

When nano-fluid CuO-Tap water falls on substrate brass it gives contact angle value of 93.5 and 90.6 degree by protector method and image J drop analysis software respectively.

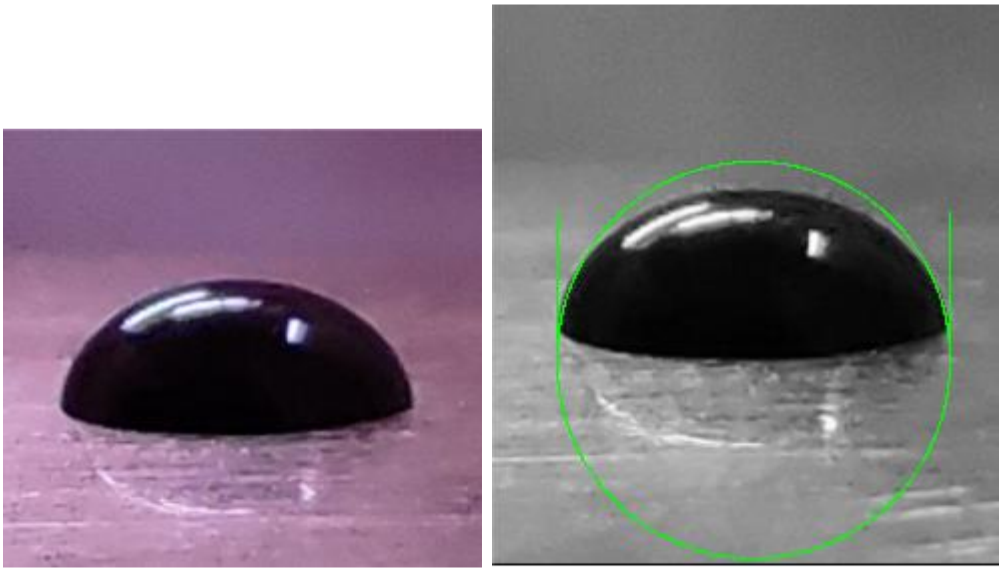

Fig.4.47 CuO-Tap water droplet on brass substrate and its contact angle drop analysis by image J software.

Chapter 5

Comparative Analysis

5.1 Mild Steel Substrate

(a) Manually measured contact angle in degree below:

All the contact angle data shown below in table1 and bar graph of below data in table 1 obtained by protector method when droplets of liquid (tap water, distilled water, propanol2) falls on substrate mild steel by dropper (syringe with needle, syringe, burette) respectively.

Table 5.1: Manually measured contact angle data on mild steel substrate

Dropper	**Tap Water**	**Distilled Water**	**Propanol2**
Syringe with needle	96	95	88
Syringe	94	93	Rapid Spreading
Burette	95	94	99

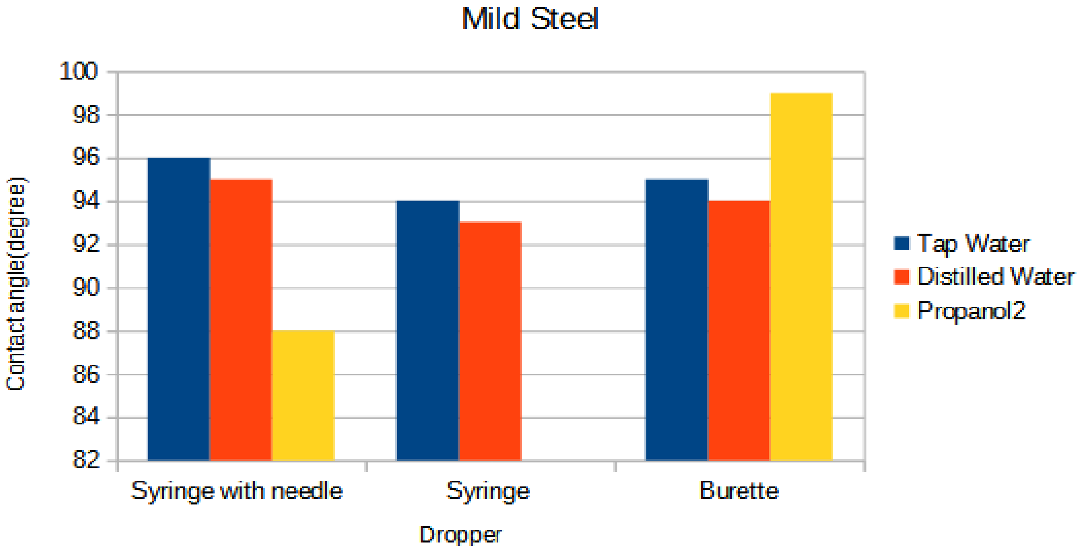

Fig. 5.1: Comparison of contact angle using different fluids

(b)Software measured contact angle in degree below:

All the contact angle data shown below in table2 and bar graph of below data in table 2 obtained by image J drop analysis method when droplets of liquid (tap water, distilled water, propanol2) falls on substrate mild steel by dropper (syringe with needle, syringe, burette) respectively.

Table 5.2: Software measured contact angle data on mild steel substrate

Dropper	**Tap Water**	**Distilled Water**	**Propanol2**
Syringe with needle	91.4	94.5	93
Syringe	99.6	95	Rapid Spreading
Burette	93	91.8	100.240

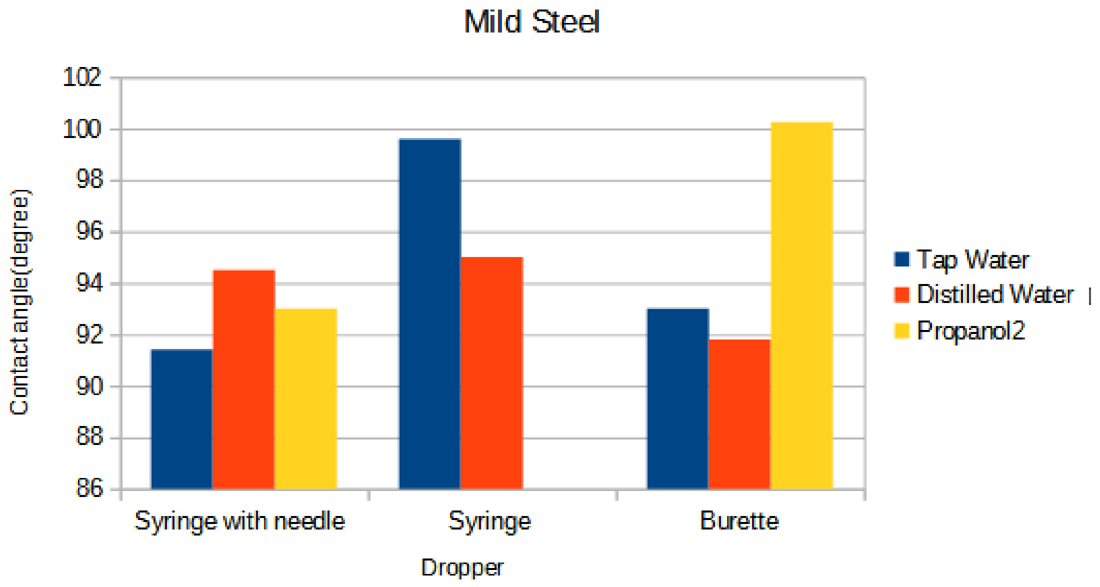

Fig. 5.2: Comparison of contact angle using different fluids

(5.2) Cast Iron substrate

(*a) Manually measured contact angle in degree below:*

All the contact angle data shown below in table1 and bar graph of below data in table 1 obtained by protector method when droplets of liquid (tap water, distilled water, propanol2) falls on substrate cast iron by dropper (syringe with needle, syringe, burette) respectively.

Table 5.3: Manually measured contact angle data on cast iron substrate

Dropper	Tap Water	Distilled Water	Propanol2
Syringe with needle	91.5	92.75	93.5
Syringe	94.5	94	92
Burette	93	94	99

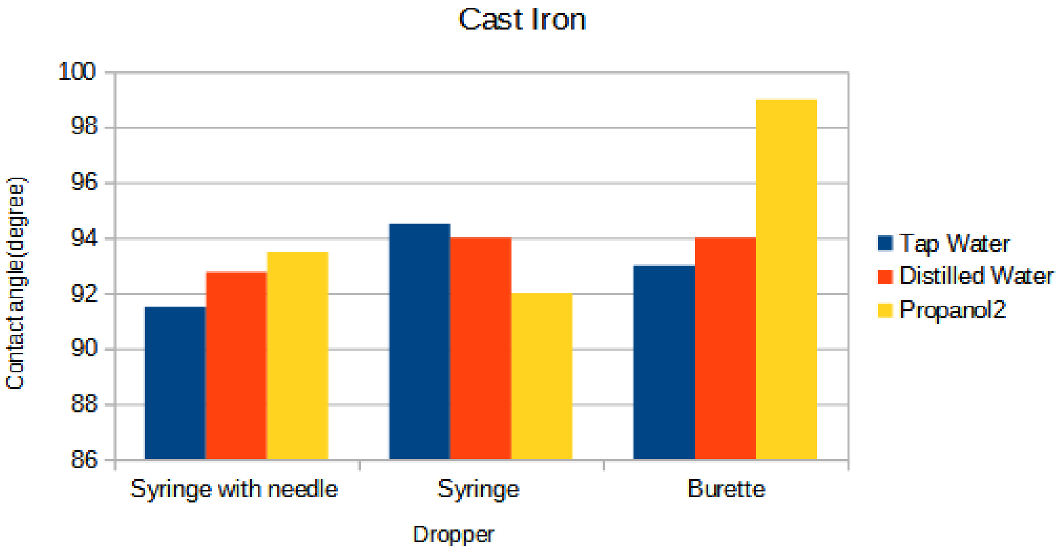

Fig. 5.3: Comparison of contact angle using different fluids

(b) Software measured contact angle in degree below:

All the contact angle data shown below in table2 and bar graph of below data in table 2 obtained by image J drop analysis method when droplets of liquid (tap water, distilled water, propanol2) falls on substrate cast iron by dropper (syringe with needle, syringe, burette) respectively.

Table 5.4: Software measured contact angle data on cast iron substrate

Dropper	**Tap Water**	**Distilled Water**	**Propanol2**
Syringe with needle	91.5	91	92
Syringe	100	97	90.5
Burette	93	92	95.645

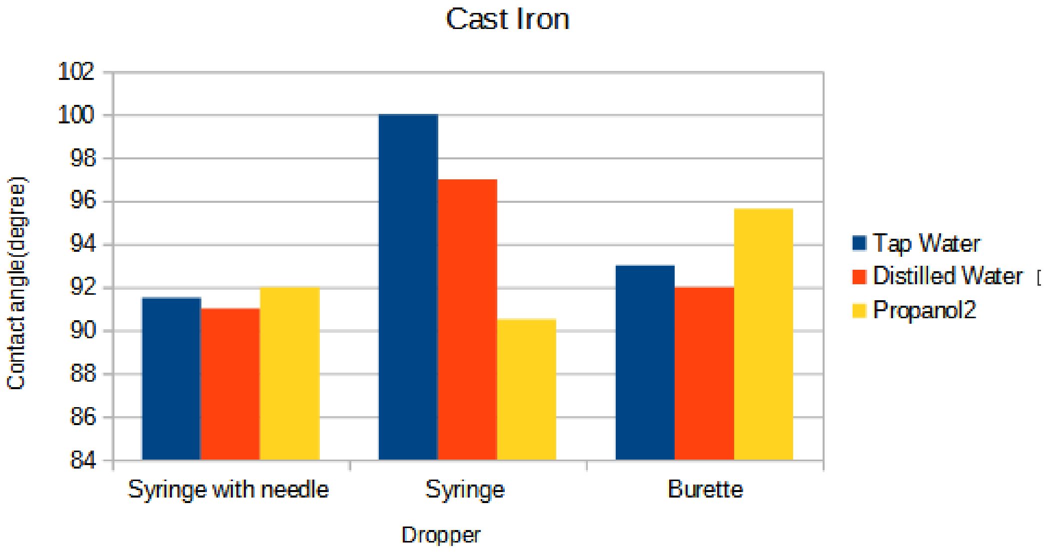

Fig. 5.4: Comparison of contact angle using different fluids

(5.3) Glass substrate

(a) Manually measured contact angle in degree below:

All the contact angle data shown below in table1 and bar graph of below data in table 1 obtained by protector method when droplets of liquid (tap water, distilled water, propanol2) falls on substrate glass by dropper (syringe with needle, syringe, burette)

respectively.

Table 5.5: Manually measured contact angle data on glass substrate

Dropper	**Tap Water**	**Distilled Water**	**Propanol2**
Syringe with needle	92	99.5	90
Syringe	105	103	91
Burette	103	97.5	Rapid Spreading

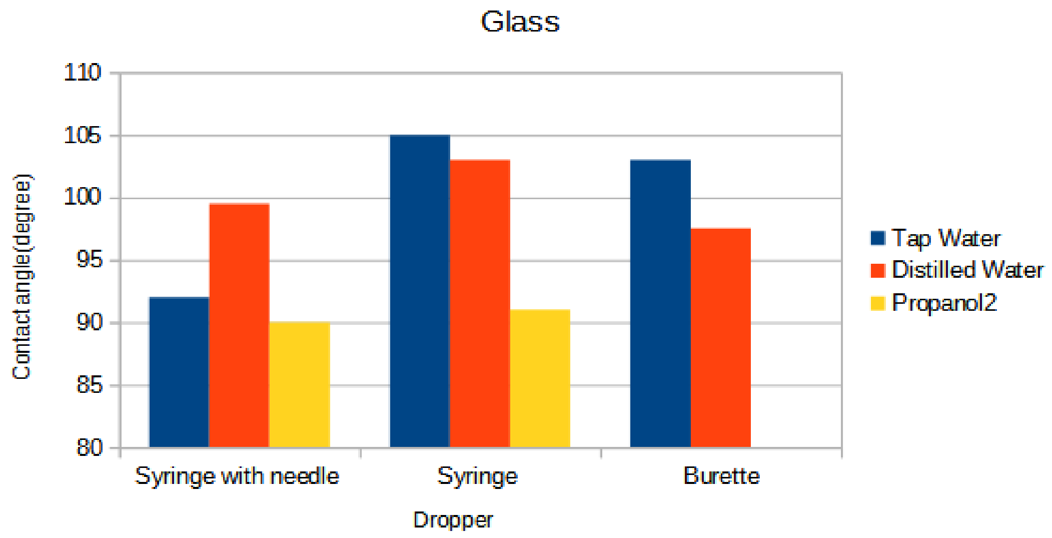

Fig. 5.5: Comparison of contact angle using different fluids

(b) Software measured contact angle in degree below:

All the contact angle data shown below in table2 and bar graph of below data in table 2 obtained by image J drop analysis method when droplets of liquid (tap water, distilled water, propanol2) falls on substrate glass by dropper (syringe with needle, syringe, burette) respectively.

Table 5.6: Software measured contact angle data on glass substrate

Dropper	**Tap Water**	**Distilled Water**	**Propanol2**
Syringe with needle	88	98	93.7
Syringe	100	102	91.926
Burette	106.6	92	Rapid Spreading

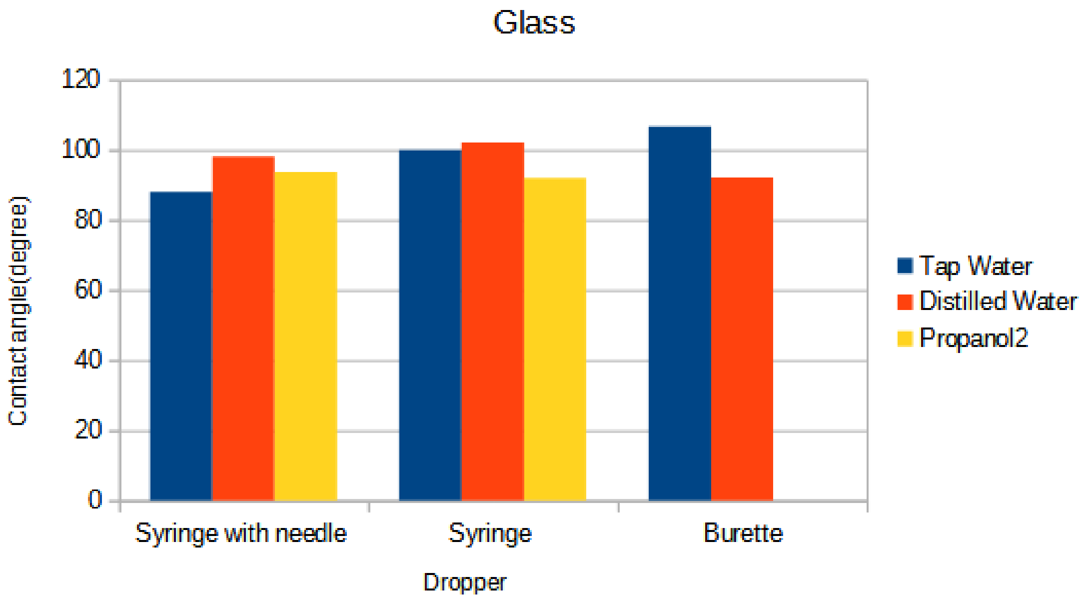

Fig. 5.6: Comparison of contact angle using different fluids

(5.4) Brass substrate

(a) Manually measured contact angle in degree below:

All the contact angle data shown below in table1 and bar graph of below data in table 1 obtained by protector method when droplets of liquid (tap water, distilled water, propanol2) falls on substrate brass by dropper (syringe with needle, syringe, burette) respectively.

Table 5.7: Manually measured contact angle data on brass substrate

Dropper	Tap Water	Distilled Water	Propanol2
Syringe with needle	94	92	90
Syringe	92.33	91	92
Burette	92.75	94	104

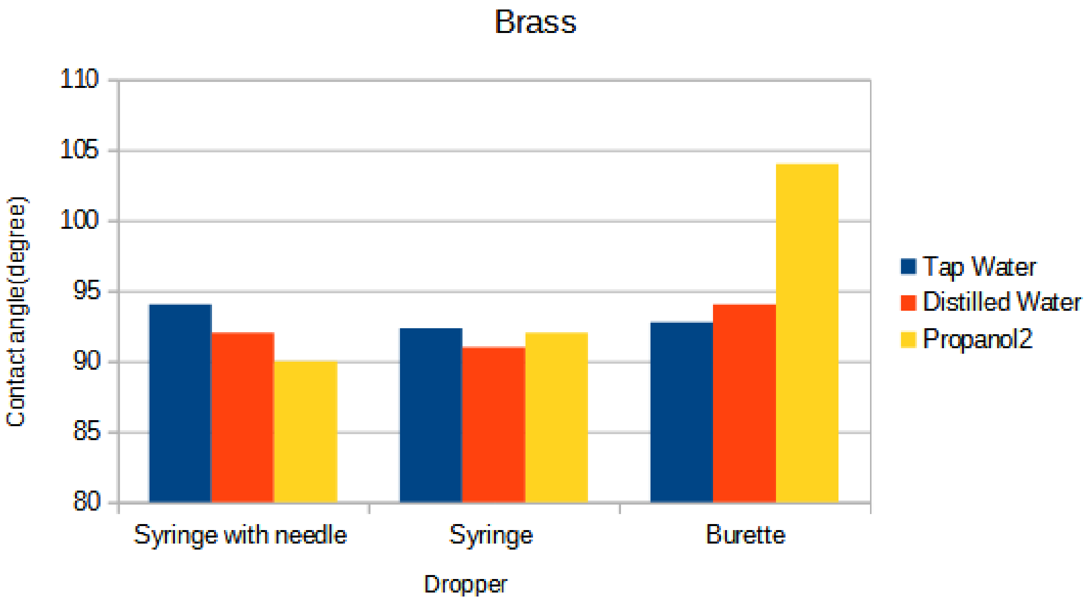

Fig. 5.7: Comparison of contact angle using different fluids

(b) Software measured contact angle in degree below:

All the contact angle data shown below in table2 and bar graph of below data in table 2 obtained by image J drop analysis method when droplets of liquid (tap water, distilled water, propanol2) falls on substrate brass by dropper (syringe with needle, syringe, burette) respectively.

Table 5.8: Software measured contact angle data on brass substrate

Dropper	**Tap Water**	**Distilled Water**	**Propanol2**
Syringe with needle	94.2	94	91.15
Syringe	93.185	91.5	88
Burette	91	91	97

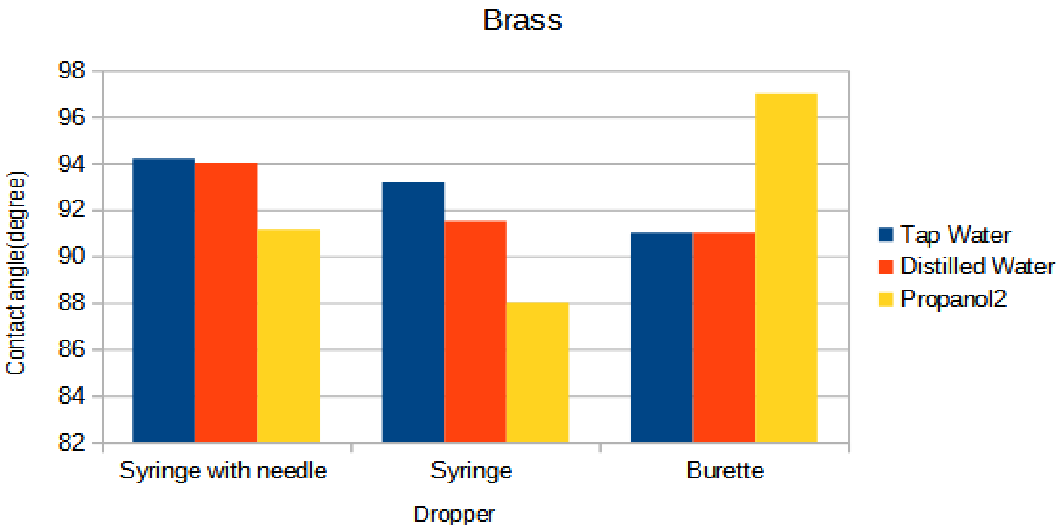

Fig. 5.8: Comparison of contact angle using different fluids

(5.5) Nano-fluid

A nano-fluid is a fluid in which nano meter-sized particles, suspended in the base fluid, form a colloidal solution of nanoparticles in a base fluid. The nanoparticles used in nano-fluids are typically made of metals, oxides, carbides, or carbon nanotubes, while the base fluids include water, ethylene glycol, and oil. In my experiment i used aluminium oxide and copper oxide nanoparticle dissolve in tap water and propanol2 in ratio 1:10.Make nano-fluid by dissolving nanoparticle in base fluid by proper mixing to use for calculating contact angle on different substrate below:

(a) Mild Steel

When nano-fluid (Al_2O_3-Propanol2, Al_2O_3-Tap water, CuO-Propanol2, CuO-Tap water) falls vertically on substrate mild steel then contact angle measured by protector method and image J drop analysis method are shown below in table and bar graph of below data in table are also drawn below.

Table 5.9: Manually and software measured contact angle data on mild steel substrate

Nano-fluid	**Manually measured value**	**Software measured value**
Al_2O_3-Propanol2	89.5	89.45
Al_2O_3-Tap water	88	91.56
CuO-Propanol2	Rapid Spreading	Rapid Spreading
CuO-Tap water	90.5	91.64

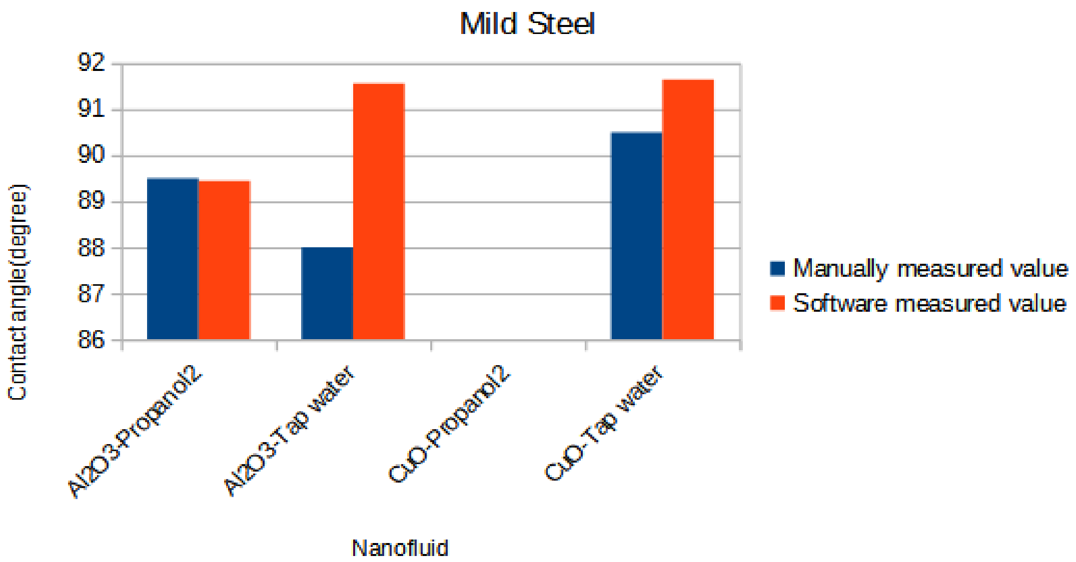

Fig. 5.9: Comparison of contact angle using different nanofluids

(b) Cast Iron

When nano-fluid (Al2O3-Propanol2, Al2O3-Tap water, CuO-Propanol2, CuO-Tap water) falls vertically on substrate cast iron then contact angle measured by protector method and image J drop analysis method are shown below in table and bar graph of below data in table are also drawn below.

Table 5.10: Manually and software measured contact angle data on cast iron substrate

Nano-fluid	**Manually measured value**	**Software measured value**
Al2O3-Propanol2	91.75	95.645
Al2O3-Tap water	92	91.5
CuO-Propanol2	91.75	88.842
CuO-Tap water	90	90.80

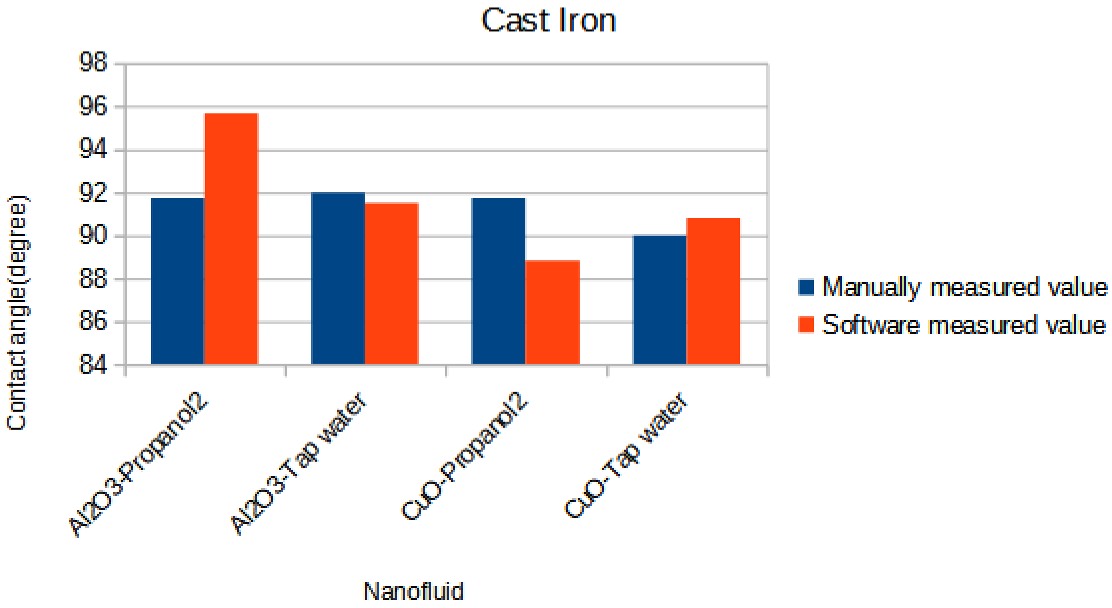

Fig. 5.10: Comparison of contact angle using different nanofluids

(c) Glass

When nano-fluid (Al2O3-Propanol2, Al2O3-Tap water, CuO-Propanol2, CuO-Tap water) falls vertically on substrate glass then contact angle measured by protector method and image J drop analysis method are shown below in table and bar graph of below data in table are also drawn below.

Table 5.11: Manually and software measured contact angle data on glass substrate

Nano-fluid	**Manually measured value**	**Software measured value**
Al2O3-Propanol2	91.5	90.5
Al2O3-Tap water	86.5	85
CuO-Propanol2	90	91.2
CuO-Tap water	91	92

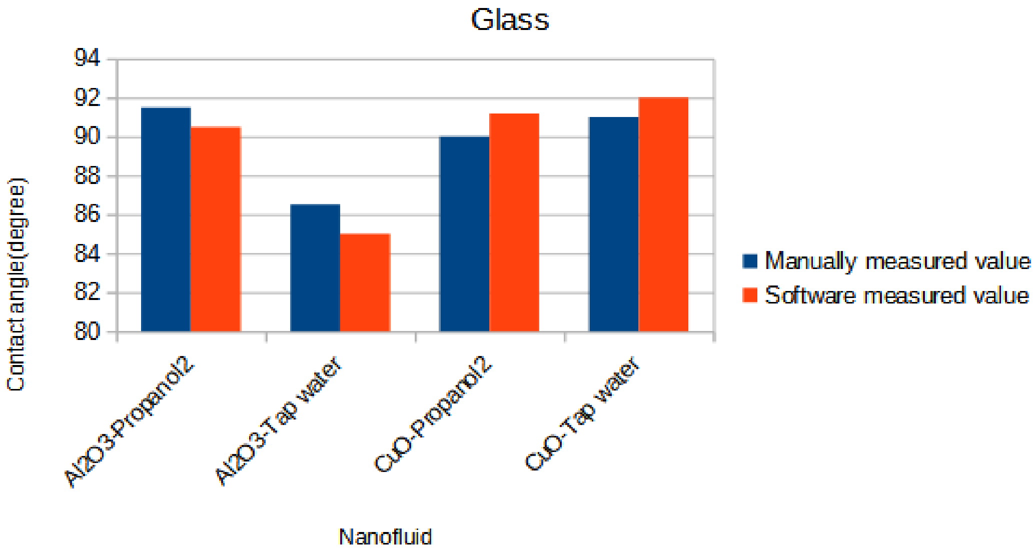

Fig. 5.11: Comparison of contact angle using different nanofluids

(d)Brass

When nano-fluid (Al2O3-Propanol2, Al2O3-Tap water, CuO-Propanol2, CuO-Tap water) falls vertically on substrate brass then contact angle measured by protector method and image J drop analysis method are shown below in table and bar graph of below data in table are also drawn below.

Table 5.12: Manually and software measured contact angle data on brass substrate

Nano-fluid	**Manually measured value**	**Software measured value**
Al2O3-Propanol2	91	93
Al2O3-Tap water	92	90.5
CuO-Propanol2	92	93
CuO-Tap water	93.5	90.6

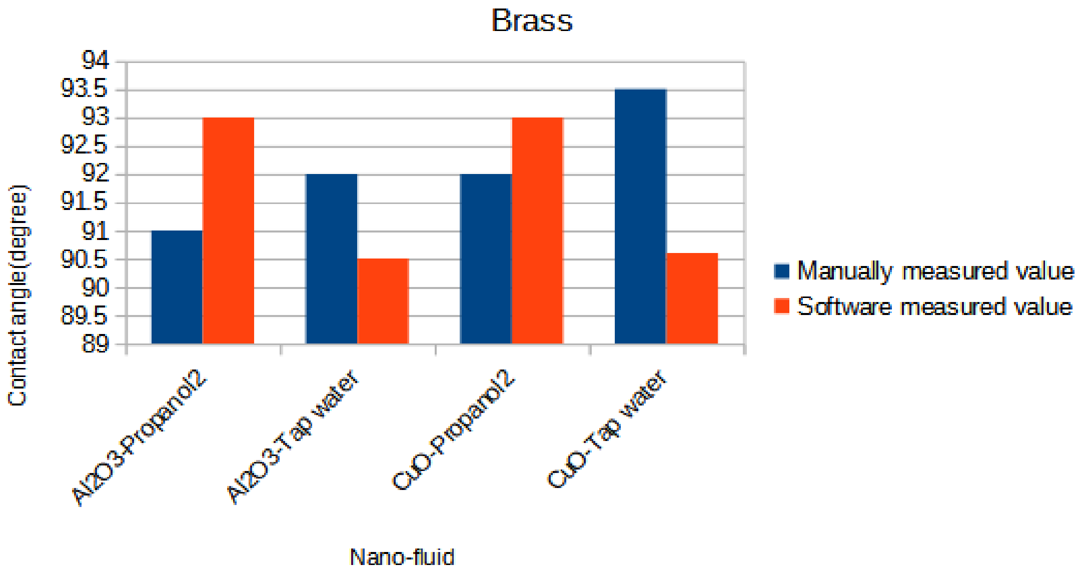

Fig. 5.12: Comparison of contact angle using different nanofluids

Chapter 6

Conclusion and Future Scope

In the present work, detailed experimental investigations have done to analyze wettability characteristics of the simple and colloidal drops at different substrate. The following conclusions are made:

- Contact area is more when tap water, distilled water falls on glass substrate as compared to mild steel, cast iron and brass substrate.
- Propanol2 has tendency to volatile so, when propanol2 liquid falls on solid substrate like mild steel, cast iron, glass and brass it started to spread on surface and after some seconds its disappear.
- Drop size of liquid droplet is more when same concentration of liquid droplets fall on glass substrate compared to other substrate like mild steel, brass, cast iron.
- In most of the case, contact angle is little bit more when distilled water falls on solid substrate compared to tap water falls on solid substrate.
- Generally, nano-fluid of nanoparticle like Al_2O_3, CuO and solvent propanol2 gives higher contact area and contact angle on solid substrate compared to other nano-fluid.

6.1 Future Scope

- Modeling of droplets formation using colloidal drops and its experimental validation may conduct on the above study is in future scope.

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