ENHANCING THE EVAPORATION RATE AT THE AIR-WATER INTERFACE WITH USE OF CONDUCTIVE NANOPARTICLES AND SUPERHYDROPHOBIC COATED GAUZE FOR IMPROVED DESALINATION PROCESS

A Thesis by

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Bachelor of Engineering, KLS Gogte Institute of Technology, 2014

Submitted to the Department of Mechanical Engineering
and the faculty of the Graduate School of
Wichita State University
in partial fulfillment of
the requirements for the degree of
Master of Science

December 2017

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science with a major in Mechanical Engineering.

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DEDICATION

To my family, my teachers and all my dear friends

ACKNOWLEDGEMENTS

I give my heartfelt thanks to my advisor, Dr. Ramazan Asmatulu, for providing me an opportunity to work as a research assistant under him. I deeply appreciate his brilliant ideas as well as guidance and support during my research. I am thankful to Dr. Abu Asaduzzaman and Dr. Shuang Gu for serving as committee members for my thesis defense, and the entire faculty of the Department of Mechanical Engineering at Wichita State University for being helpful. I am also grateful to Dr. Eylem Asmatulu and Aybala Usta for assisting me in my research.

Finally, I am very thankful to my parents Prakash Patil and Rekha Patil, my sisters Sheetal Patil and Ashwini Patil, my family, and friends for their support and inspiration, which helped me to complete this research work successfully.

ABSTRACT

Most living organisms require fresh water to survive, and our planet is composed of 70% of water. Unfortunately, most of it is salt water and not fresh water, and very soon the fresh water will be depleted. The solution to this problem is desalination using the evaporation method. Evaporation is a natural phenomenon and plays a significant role in nature. Most of the evaporation process involves a total temperature increase of an entire body of water. However, recent research in nanotechnology can help in selective heating of the air-water interface. The nanofluid that forms the colloidal mixture of nanoparticles is dispersed in a fluid medium that possesses thermophysical properties and plays a significant role in heat transfer.

In this research, nanofluids were prepared by dispersing carbon black (CB) and graphene nanoparticles in tap water, salt water, and deionized (DI) water. The concentration of nanoparticles in a water varying, where a 0.1% concentration of nanoparticles in a fluid gave better results than nanoparticle concentrations of 0.05% or 0.5%. Furthermore, the combination of nanoparticles with fluid increases its evaporation rate by 11.20% for tap water, 14.22% for salt water, and 9.07% for DI water. However, when nanoparticles were combined with a rubber black base, the evaporation rate increased to 17.98% for tap water, 18.78% for salt water, and 16.05% for DI water. In all tests, the addition of carbon black showed better results compared to other nanoparticles.

In the next stage of this research, nanoparticles, i.e., carbon black, graphene, and carbon nanotubes (CNTs), were coated on a cotton gauze along with a superhydrophobic liquid, which makes the coated gauze float on water and locally heat the surface. The combination of superhydrophobic gauze coated with carbon black nanoparticles along with the rubber black base showed that the evaporation was 14.09% for tap water, 13.16% for salt water, and 12.41% for DI water.

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LIST OF ABBREVIATIONS

C	Celsius
CB	Carbon Black
CNT	Carbon Nanotubes
DI	Deionized Water
HVLP	High Volume Low Pressure
IR	Infrared
LED	Light Emitting Diode
NaCl	Sodium Chloride
SEM	Scanning Electron Microscopy
TEM	Transmission Electronic Microscopy

CHAPTER 1

INTRODUCTION

The primary focus of this research is to enhance the rate of evaporation at the air-water interface using cotton gauze, nanoparticles, and superhydrophobic properties. The nanoparticles used in this study are carbon black (CB), graphene, and carbon nanotubes (CNTs). Analysis of the rate of evaporation along with the rise in temperature was carried out using a different concentration of nanoparticles under the same environmental conditions.

1.1. Background

The process of using sunlight to vaporize water and then recondense it has been known since the fourth century B.C. when the famous Greek philosopher Aristotle described that salt could be separated from seawater with the help of sunlight to create water vapor [1]. Evaporation is the process of turning liquid into water vapor. Water evaporation is one of the critical natural processes and strongly influences the survival of natural organisms. The evaporation of sweat from the human body helps in regulating body temperature. The evaporation of water from plants, known as transpiration, is an important process whereby a negative pressure gradient is created and thus helps in drawing water and minerals from the roots to the plant body [2, 3].

In many industries, the evaporation of water also plays a significant role in the generation of steam, heat transfer, and desalination. Usually, water evaporation takes place at the air-water interface. Most industries have adopted the method of heating the temperature of water in a bulk quantity to achieve its higher evaporation rate. But this involves a high power consumption and high cost [4]. The process of selectively heating the air-water interface helps to solve this problem. The localized increase in temperature is a more efficient and economical process of evaporation than bulk heating. This process demonstrates a new process of efficient water evaporation. As is known, solar energy is one of the abundantly available sources of energy in nature. In many areas, clean water is not readily available, so solar energy is used to purify the available water, which may be salty or dirty. Almost 98% of the available water supply in the world is from brackish water or sea water; therefore, desalination can be the most important alternative source of obtaining clean water [5]. Solar energy can be used to evaporate water, leaving behind contaminants and salt, and reforming a clean and purified liquid in a separate container. This energy can efficiently economically be utilized to evaporate water by using various methods [6, 7].

Evaporation is considered to be one of the alternative processes in wastewater treatment applications. This process is an efficient method for concentrating and removing heavy metals, salts, and various hazardous materials from water. The process of evaporation can also be used to recover useful by-products from the water or concentrate the wastewater before additional treatment and final dumping [8]. Many modern technologies can be used to obtain a better water evaporation rate. One of these that has flourished over the past few decades is nanotechnology, which employs nanomaterials, due to its exceptional properties as compared to other materials. Nanomaterials consist of nanoparticles with nanoscale dimensions between 1 to 100 nm. These nanomaterials exhibit noble characteristics and show significant changes in physical, chemical, and biological properties because of their following unique properties [9]:

- Large surface area: due to their smaller size, they can occupy a large area.
- Unexpected optical properties: due to their smaller size, they are confined and can produce a quantum effect.
- Ability to form suspensions: the interaction of the surface with solvents is high enough to overcome the density difference between them.

- Hardness property: when clay nanoparticles are incorporated into polymer matrices, they increase the reinforcement, which leads to stronger plastics.
- High diffusion property: they are quickly at elevated temperatures over a shorter period of time than are larger particles.
- Classified according to their morphology, uniformity, dimensionality, agglomeration, and composition [10].

Nanoparticles are inorganic ultrafine particles that can be mixed with a base fluid such as water to obtain a nanofluid. Due to the nanoparticles, the thermal conductivity of the base fluid increases and the surface tension decreases, which in turn helps to increase the rate of evaporation of the base fluid [11, 12].

1.2. Motivation

Most of the earth's surface is covered with water, but almost all of it—glaciers, polar ice caps, sea water—is useless for the purpose of human hydration. Less than 1% of the planet's life-sustaining water is found in rivers, streams, lakes, and underground aquifers. And most of the available drinking water must be pretreated to eradicate harmful toxins and microbes. Access to clean drinking water is limited to many of the world's population. According to reports from water projects, water scarcity affects 1 out of 9 people, and most illness in underdeveloped countries is due to water and sanitary conditions. Water stress has become a global challenge and is becoming more significant all over the world. The quality of water in the U.S. is the highest in the world, but there is still considerable incidence of contamination, which in turn affects people's health. On the other hand, those countries with limited resources and developing countries like India and China, must find a solution to obtaining fresh water. Everyone in the world is affected by this problem, and someone needs to improve this issue with new technology [1].

1.3. Research Objective

The primary purpose of this study is to enhance the rate of water evaporation with the help of nanotechnology. The first objective here is to obtain experimental data relative to the evaporation of tap water, salt water, and deionized (DI) water. The second objective is to prepare nanofluids with different concentrations of nanoparticles and observe the evaporation behavior of tap water, salt water, and DI water. Then the nanoparticles that give the maximum amount of evaporation are used to fabricate floatable gauze with the help of superhydrophobic properties and perform evaporation tests on the tap water, salt water, and DI water. The final step is comparing the results to determine which nanoparticles provide the best evaporation rate along with the best rise in temperature.

CHAPTER 2

LITERATURE REVIEW

2.1. Evaporation

During the process of evaporation, liquid changes to a gaseous state at the free surface by transferring energy below its boiling point. Evaporation is known as a cooling process in which the latent of vaporization should be provided by the water body. The rate of evaporation of water depends on the following:

- Vapor pressure at the air-water interface.
- Incident solar radiation.
- Wind speed at the air-water interface.
- Atmospheric pressure.
- Air and water temperature.
- Quality of water.
- Amount of water.

2.1.1. Vapor Pressure

Evaporation depends upon vapor pressure in which the rate of water evaporation is directly proportional to the saturated vapor pressure at the water temperature and the actual vapor pressure in the air. The rate of water evaporation is given by

$$E_L = C\,(e_w - e_a) \qquad (1)$$

where E_L is the rate of evaporation, C is a constant, e_w is the saturation vapor pressure at water temperature in mm of mercury, and e_a is the actual vapor pressure in the air in mm of mercury. Equation (1) is known as Dalton's Law of Evaporation, whereby the evaporation of water takes place until the saturation vapor pressure at water temperature is equal to the actual vapor pressure in the air. If the saturation vapor pressure is greater than the actual vapor pressure, then condensation of the water takes place [13].

2.1.2. Temperature

Temperature plays a significant role in the evaporation of a liquid. The rate of evaporation of a liquid increase with the increase in its temperature. However, there is also an increase in the rate of evaporation when there is an increase in air temperature that encounters the water surface [14].

2.1.3. Wind Velocity

When the evaporation of water takes place, the evaporated water vapor occupies the zone of evaporation, thereby causing partial blocking. Wind helps to remove this blockage by removing the evaporated water from the evaporation zone, thereby enhancing the evaporation. The rate of evaporation is enhanced with the increase in wind velocity up to a limit; thereafter, if the velocity of the wind increases, it does not have any effect on the rate of evaporation [15].

2.1.4. Atmospheric Pressure

Atmospheric pressure also controls the rate of evaporation, whereby if the atmospheric pressure decreases, then the rate of evaporation increases. This type of evaporation is usually seen at high altitudes where the atmospheric pressure is less than other regions.

2.1.5. Soluble Salts

Dissolved salts in water reduce the rate of evaporation, due to the vapor pressure of the water, which is less than that of the undissolved salts in tap water or pure water. The amount of percentage reduction of the evaporation rate approximately resembles the percentage increase in the specific gravity. From previous studies, the rate of evaporation of sea water is 2–3% less than that of ordinary fresh water [16]. The reason for less evaporation is due to the presence of salts, which causes the dissolved salt molecules to bind the water molecules tightly together and not allowing their natural release.

2.1.6. Heat Storage in Water Bodies

The heat-storing capacity of water depends on the depth of the water body. Deep bodies of water save a greater amount of heat than shallow bodies of water. For instance, a deep-water body such as a lake stores heat radiation energy during the summer and releases it in the winter. This results in more evaporation in winter and less evaporation in summer. A shallow lake ultimately behaves in the opposite way when exposed to a comparable situation. The heat storage in water bodies helps in changing the seasonal evaporation rate due to which the annual evaporation rate remains unaltered [17].

2.2. Evaporation Model

This evaporation model explains how the detachment of atoms takes place at the surface of water when an inside outgoing particle reaches its surface. The rate of evaporation depends on the configuration of molecules and intermolecular force at the air water surface, which resists the molecules to break away from the water surface. For instance, the evaporation of escaping molecules that try to come out of the outermost layer must overcome only the bonding energy from neighboring molecules. The rate of evaporation can be enhanced by suspended nanoparticles on the surface of the water, which comes in contact with the incident radiation. It can be considered that nanoparticles on the water's surface are covered by a layer of water molecules, and this layer of particles is being absorbed on the surface of the nanoparticles. Whenever the radiation is incident on the surface, the nanoparticles absorb the energy and transmit it to the water molecules. This causes the water molecules to have enough kinetic energy to overcome the adsorption energy and, hence, causes the water molecules to evaporate. Figure 1 shows the model of evaporation [18].

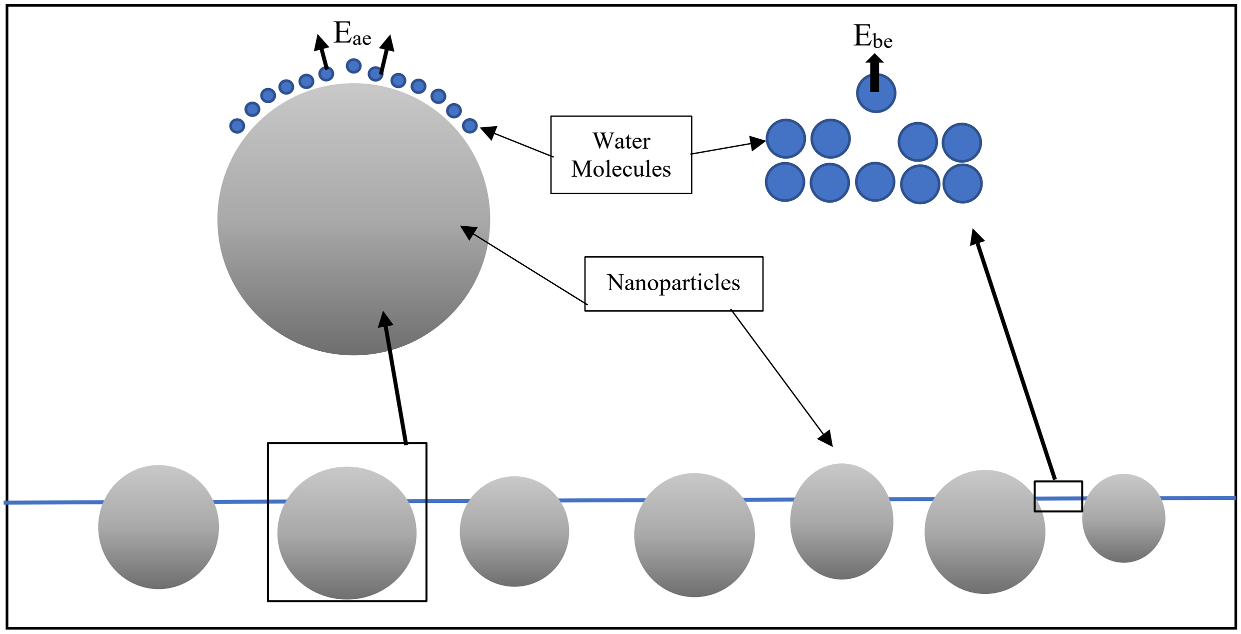


Figure 1. Model of evaporation

2.3. Desalination

Desalination is the process of removing salts and minerals from saline water. Generally, it is used to remove the salts from the target substance. The process of desalination is used to produce fresh water that is appropriate for human consumption.

2.3.1. Desalination Mechanism

The process of separating the salt and water takes place when the salt water to be desalinated undergoes a change in phase into vapor. The phase transition of a liquid to vapor is widely used for the desalination process [5]. Nanoparticles can also play an important role in the process of desalination. When nanoparticles are mixed with salt water and then subjected to irradiation, they start absorbing heat, which is then transmitted to the water. As the temperature of water increases slowly, the phase transition of water takes place from the liquid state, separating the salt from the water.

2.3.2. Desalination Advantage

The process of desalination is a proven and effective method of removing salt from saline water. The process of desalination is highly understood due to scientific-backed data. Saline water in oceans provides a massive source for this process. The desalination process is an independent process and does not depend on naturally changing factors. This helps in creating awareness of preserving current freshwater supplies.

2.3.3. Desalination Problems

The process of desalination is a costly process. Although the operating cost of a desalination plant is reasonable, the actual cost of the desalination plant building is expensive. The energy required to produce water from desalination is considerable. Desalination also contributes to greenhouse gas emissions, which causes harm to the environment. The process can also produce contaminated water by introducing biological and chemical contaminants into the water supply. In the end, the resulting brine from saline water can cause an adverse effect on living organisms.

2.4. Classification of Surfaces

Surfaces can be classified as hydrophilic, hydrophobic, or superhydrophobic.

2.4.1. Hydrophilic Surfaces

Hydrophilic surfaces are water-loving surfaces, whereby the molecule or other molecular entity gets attracted to or tends to be dissolved in the water. On these surfaces, water tries to maximize contact with the surface due to the contact angle between the water and surface, which decreases and its always less than 90^0. Figure 2 shows a hydrophilic surface interaction with water.

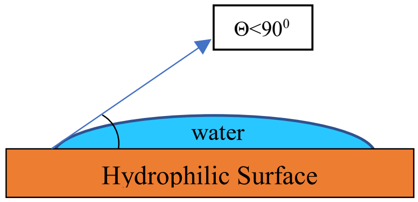


Figure 2. Hydrophilic surface with water droplet, having contact angle less than 90^0

2.4.2. Hydrophobic Surfaces

Hydrophobic surfaces are known as water-fearing surfaces in which the physical property of the molecule is seemingly being repelled from the mass of water. On these surfaces, the water tries to minimize contact with the surface, whereby the contact angle between the water and the surface increases and is greater than 90^0. Figure 3 shows a hydrophobic surface interaction with water.

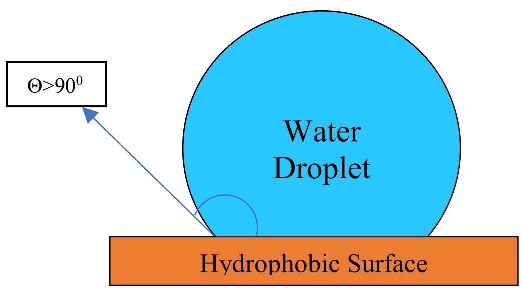


Figure 3. Hydrophobic surface with water droplet, having contact angle more than 90^0

2.4.3. Superhydrophobic Surfaces

Superhydrophobic surfaces are those surfaces that are extremely difficult to wet; these surfaces have nano-scale roughness. The contact angle of the water dropped on these surfaces exceeds 150^0 and the roll-off angle when tilted is less than 10^0. When these surfaces come in contact with water, the water is highly repelled. The main reason behind this repulsion is due to the nano-scale roughness which crest lower water substantial contact area and results in a higher contact angle. When the water comes in contact with the superhydrophobic surface, it gets preached on the hydrophobic posts containing trapped air, as shown in Figures 4 and 5.

Superhydrophobicity plays an important role in the wettability of surfaces because of the low water contact angle, which reduces the capillary pressure [19].

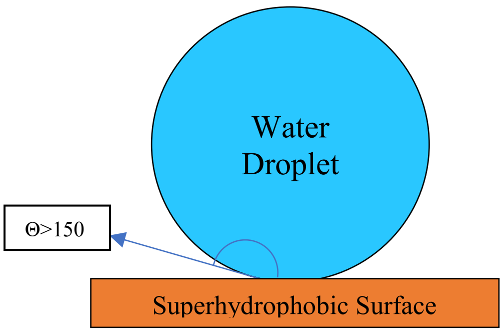


Figure 5. Superhydrophobic surface with water droplet, having contact angle more than 150^0

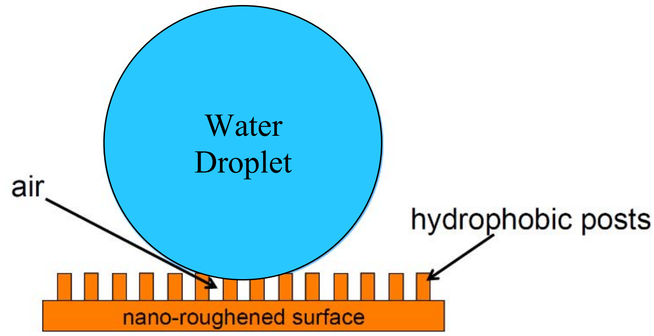


Figure 4. Water droplet repelled by the hydrophobic post containing trapped air

2.4.4. Evaporation Efficiency

As the development of nanotechnology increases, the capability of changing the evaporation rate of water as the base fluid also increases with the addition of nanoparticles [20]. Due to the existence of nanoparticles in the base fluid, it exhibits different thermophysical properties, such as surface tension, thermal conductivity, and viscosity, from that of the base fluid without nanoparticles [21]. The addition of nanoparticles increases the collision and interaction among the particles and the base fluid [22] and also affects the evaporation rate. In order to obtain the evaporation rate of the nanofluids and analyze the data, evaporation efficiency (η) of the nanofluid must be considered, which is defined as

$$\eta = \frac{|E_{DW} - E_{NF}|}{E_{DW}} \tag{2}$$

where E_{DW} is the evaporation from DI water, and E_{NF} is the evaporation from nano fluids

Both the evaporation are done under the same conditions. If the addition of nanoparticles shows a reduction in evaporation, then it appears as η_{ERE} , and if the addition of nanoparticles enhances the evaporation rate, then it appears as η_{EEE} [23].

2.5. Preparation of Nanofluids

For preparing the nanofluid, the incorporated nanoparticles are in the form of a nano-sized dry powder, which is dispersed in the base fluid to obtain the nanofluid. Before the nanoparticles are dispersed into the base fluid, the nano-sized powder should be weighed. The mass fraction of nanoparticles can be defined as

$$wt\% = \frac{m_{NP}}{m_{NP}+m_{BF}} \text{ x } 100 \qquad (3)$$

where m_{NP} is the mass of the nanoparticle, and m_{BF} is the mass of the base fluid. Because the mass fraction of nanoparticles is very small, they are usually expressed in percent values [23, 24].

2.6. Surface Tension of Nanofluids

Nanofluids are a colloidal mixture of nanosized particles and base fluid in which the thermophysical properties play a significant role in transferring heat. The surface tension of the liquid surface is the result of the attraction of particles on the surface layer by the bulk liquid, which always tends to minimize the surface area. Surface tension is the per unit length or surface energy per unit area which dominates the transportation of fluid.

According to experimental studies, surface tension is influenced by the concentration and size of nanoparticles. The surface tension of the nanofluid increases with the increase in concentration and size of the nanoparticles [25]. Studies also show that the surface tension could decrease for some nanoparticle concentrations. However, the nanoparticle concentration cannot determine the boundaries for reducing or increasing the surface tension [26].

2.6.1. Thermodynamics at Air Bubble-Water-Hydrophobic Surface Interface

Hydrophobic surfaces that have functional groups can interact with air and water by means of electrostatic, van der Waals, hydrophobic, columbic, ionic, or dipolar interactions. Based on this, an air bubble attachment on the surface of water is shown in Figures 6 and 7, which indicates an air bubble (3) in a liquid (water) phase (2) before and after interacting with a hydrophobic surface (1).

In this model, once the hydrophobicity chemicals (surfactants or polymers) are added to the system, air bubbles will attach to the particle surface. The contact area of the air bubble increases on the surface based on the surface hydrophobicity [27, 28].

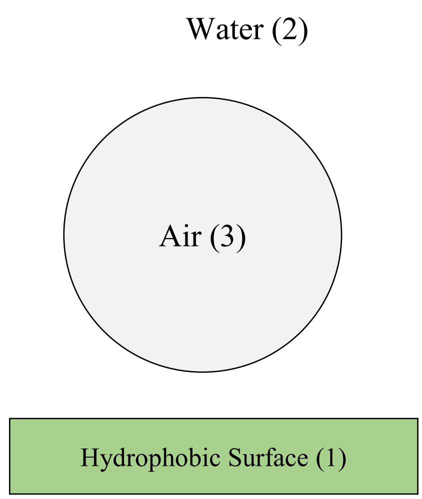


Figure 6. Air bubble-water interface before interaction

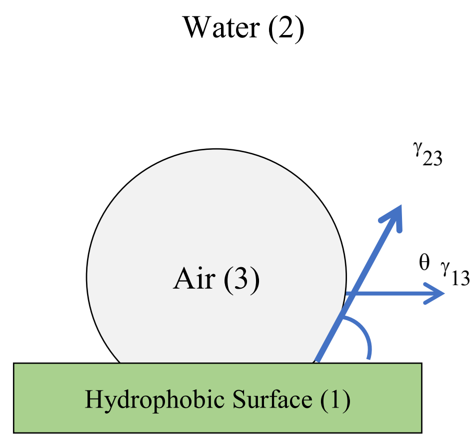


Figure 7. Air bubble-water interface after interaction

The free energy change (dG/dA) for a spontaneous flotation is as follows: γ_{13} is the surface free energy at the solid-air interface, γ_{23} is surface free energy at the water-air interface, γ_{12} is surface free energy at the solid-water interface, and ***A*** is an area of contact at the solid-air interface. Also, θ is the contact angle between solid-liquid-air interface.

The equilibrium of three interfacial energies can be given by Young`s equation as

$$\frac{dG}{dA} = \gamma_{13} - (\gamma_{23} + \gamma_{12}) < 0 \tag{4}$$

It is known that the more negative the ΔG values, the greater the probability of flotation of particles occurring at a given time, which can be achieved using hydrophobic chemicals. The interfacial energy at surfaces 1 and 3 is

$$\gamma_{13} = \gamma_{23}\cos\theta + \gamma_{12} \tag{5}$$

Substituting equation (5) into equation (4) yields

$$\frac{dG_{dis}}{dA} = \gamma_{23}(\cos\theta - 1) < 0 \tag{6}$$

This equation suggests that the air bubble and surface attachment is spontaneous if the free energy change ΔG is less than 0 or the contact angle is greater than 0°.

Work done on air bubble surface attachment (Wa) shows that attachment on surfaces can be minimized by adding hydrophobized chemicals [29]:

$$Wa = -\gamma 23\ (\cos\theta - 1) < 0 \tag{7}$$

2.7. Contact Angle

The contact angle is then defined as the angle formed at the surface of the liquid. The liquid-solid contact angle occurs when there is a surface between the solid and the liquid. This contact angle can be resolved by the solid and liquid properties, and the repulsion and contact forces can also be obtained by the three-phase interface properties, namely solids, liquids, and gases. The three-phase interface properties can be explained well by the adhesion and cohesion forces. The concept of wettability of the surface can be used to determine the contact angle of the liquid on the solid surface and can be obtained with the help of two equations: Young's equation and the Wenzel and Cassie-Baxter models. The concept of wettability, which gives the contact angle between the surface and liquid, is valuable information and shows the level of wetting at the interface. Wettability can be determined based on the contact angle: a small contact angle of more than 90^0 forms a high wettability surface, whereas a contact angle of 90^0 leads to a low wettability surface. If the contact angle is equal to 0^0, then the surface is considered as a thoroughly wetted surface [30]. Figure 8 shows the different contact angles that determine the wettability of a surface. Tables 1 and 2 shows the characterization and behavioral properties of surfaces.

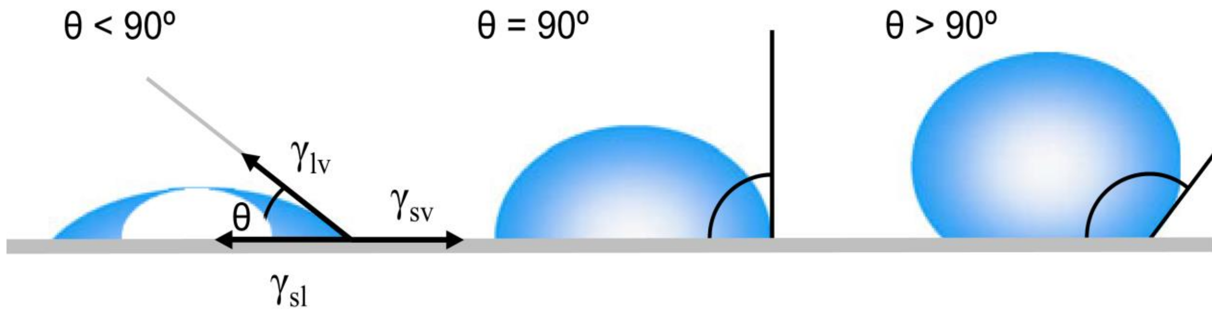


Figure 8. Different contact angle determining surface wettability [26]

TABLE 1. CHARACTERIZATION OF SURFACE WITH RESPECT TO CONTACT ANGLE

Nature	Surface Energy	Condition	Effect
Hydrophilic	Increases	$\theta < 90°$	Water droplets spread
Hydrophobic	Decreases	$\theta c > 90°$	Water droplets bead up on surface
Superhydrophobic	Decreases	$\theta c > 150°$	Water droplets highly beaded and repelled

TABLE 2. BEHAVIOR AND PROPERTIES OF SURFACES

Property	Hydrophilic Surface	Hydrophobic Surface
Contact Angle	Lower	Higher
Adhesiveness	More	Less
Wettability	More	Less
Solid Surface Free Energy	Higher	Lower

2.7.1. Wilhelmy Plate Method

The Wilhelmy plate method is one of the conventional techniques to calculate the contact angle between a surface and a liquid. This process involves immersing a plate into liquid and then removing it out by measuring the force on the plate. This means that calculating the contact angle is more complicated than the sessile drop method, because this approach requires a large volume of liquid, does not give heterogeneity, needs manufacturing an active specimen surface of different measurements with two identical surfaces, it requires a force scale. During this process, the capillary increase on the Wilhelmy plate captures the contact angle by calculating the meniscus height, which is formed when the plate is slightly immersed into the liquid. The wetting force f is

$$f = \gamma^{lv} p \cos\theta \tag{8}$$

where γ^{lv} is the surface tension of the liquid, p is the perimeter of contact line, and θ is the contact angle. The total force change F is defined as

$$F = \gamma^{lv} p \cos\theta - V\Delta\rho g \tag{9}$$

where V is the volume of displaced liquid, Δρ is the difference in density of the liquid and air, and g is the acceleration due to gravity [30].

Figure 9 shows the submersion cycle for the Wilhelmy balance measurement: (1) the sample approaching the liquid, contact angle 0^0; (2) the sample in contact with the liquid, contact angle more than 90^0; (3) the sample further immersed in the liquid causing an increase in buoyancy and a decrease in force on the balance, with advancing contact angle; and (4) the sample pulled out of the liquid, and force is measured for receding contact angle.

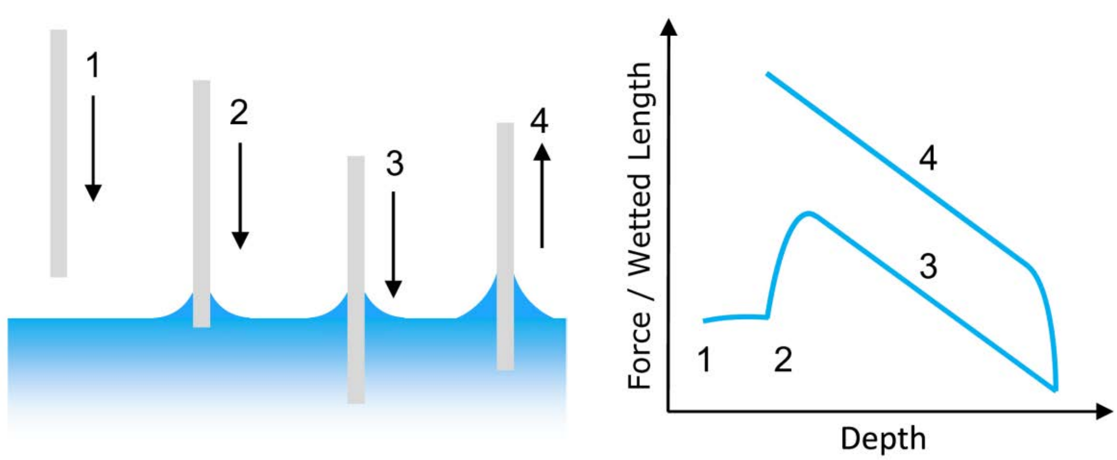


Figure 9. Wilhelmy plate method [26]

2.7.2. Young's Equation

The method employing Young's equation is used to measure the two-dimensional contact angle between the liquid drop and the solid with help of the vertex at the three-stage line. This equation shows the collaboration between the adhesion and cohesion. The wettability of the surface with Young's equation is given by

$$\gamma^{sv} - \gamma^{sl} = \gamma^{lv}\cos\theta \tag{10}$$

where γ^{sv} is the interface of the solid and vapor phases, γ^{sl} is the interface of the solid and liquid phases, γ^{lv} is the interface of the liquid and vapor phases, and θ is the water contact angle.

Young's equation holds true for smooth solid surfaces, but is not good for rough surfaces. This equation is commonly used, but there are some difficulties due to the theories of surface tension. To overcome this, the Young-Dupré equation is used. This equation explains the surface tension of the liquid-gas phase, the reversible work of adhesion of the liquid-solid, and contact angle:

$$WA = \gamma^{lv}(1 - \cos\theta) \tag{11}$$

where WA is the reversible work of adhesion of the liquid to the solid when it is coated with adsorbed film, γ^{lv} is the interface of the liquid and vapor phases, and θ is the water contact angle [30]. Figure 10 shows the angle made at air-water-surface interface.

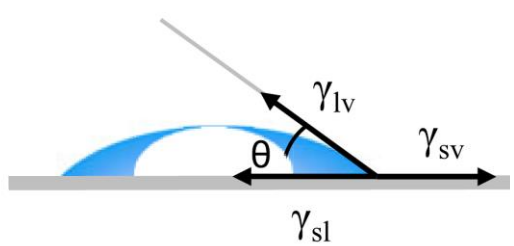


Figure 10. Contact angle at air- water- surface interface [26]

2.7.3. Tilting Plate Method

In the tilting plate technique, a solid plate gripped at one end above the liquid is slowly rotated towards the surface of the liquid until the end of the plate is immersed in the liquid, and the contact angle is measured. This forms a meniscus on both sides of the submerged plate. Once immersed, the plate is then slowly tilted on one side towards the liquid until the meniscus formed becomes horizontal to one side of the tilted plate, as shown in the Figure 11. This procedure forms an angle between the plate and the horizontal, which is the required contact angle. This method gives an angle error of $\pm 5^0$ due to contamination of the liquid [30].

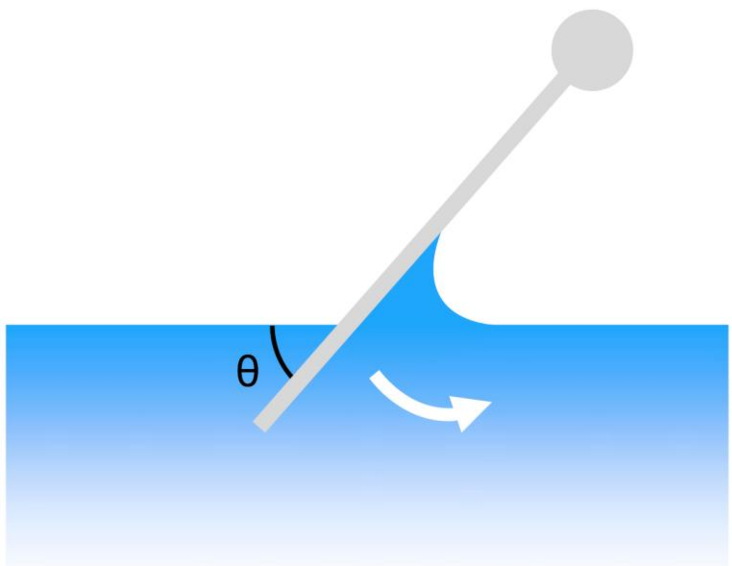


Figure 11. Contact angle calculation using tilting plate method [26]

2.7.4. Contact Angle Measurement

The static contact angle is measured with a drop of liquid formed at the tip of a needle attached to a screw syringe. This needle is connected to a stand to obtain stability during the process. Then, using the Y controller of the stage, the surface is slowly raised until it touches the drop of liquid, which is brought into the view field on the focal point of the microscope. The focus on the drop can be cleared with the help of the x-y translation of the stage, and then the image is captured, which is used to measure the contact angle. If the contact angle is measured when the drop is in motion, then the measuring method is known as a dynamic contact angle measurement.

2.8. Methods of Applying Surface Coating

The most commonly used methods to coat a surface are brushing, spraying, and dipping.

2.8.1. Spraying

The spraying methods for applying a coating achieves a decent quality finish. This approach is used to provide a uniform layer of coating on the material and is known to be the most economical method because it requires less material for the coating application. All spray coating techniques are similar but typically are characterized as two main types of air spray guns: gravity feed and high-volume low-pressure (HVLP).

2.8.2. Brushing

This method is used when spray coating is not possible and is typically used for repairs or for small projects. With brush coating, the material is diluted using a thinner in order to obtain better consistency while applying the coat. This coating technique fails to give a uniform coat due to its over-and-over brushing of coating material during application, but it is more efficient than the dipping method.

2.8.3. Dipping

Dipping is the one of the easiest methods to apply a coating. This approach primarily depends upon the surface tension, gravity, and consistency of the liquid. In most cases, if the substrate is detached, then the sooner a thicker film is achieved. Also, a thicker layer can be reached if the capillarity regime is enforced. The thickness of the layer depends upon the amount of contact time between the specimen and the coating material [31].

CHAPTER 3

EXPERIMENTAL PROCEDURE

3.1. Materials

During this research study, many materials and equipment were selected and used based on their properties and applications. In this study, we have used the material with high thermal conductivity and absorption like graphene and carbon black. The main reason to use the superhydrophobic coating is to make the nanoparticles float on the top of water along the gauze which forms the medium of transfer of heat between the heat radiation and water. All the materials used in this research were used without any further processing, and the instruments used were pre-calibrated before use.

3.1.1. Carbon black

Carbon black is the nano sized fine particles, black colored powder which are substantially composed of carbon. These nanoparticles help us make many of the things which we use in our day today life stronger, brighter and sustainable. Carbon black is produced by the pyrolysis process by partially burning low-value oil resides at a higher temperature under controlled process conditions. Carbon black is primarily used to strengthen rubber tires, as a pigment, plastic, paint applications, ink, UV stabilizer and as an insulating or conducting agent in a variety of specialty rubber. Figure 12 shows the transmission electronic microscopy (TEM) image of the structure of nano sized carbon black particles along with the surface characteristics which shows the functional groups on the surface of the structure [32].

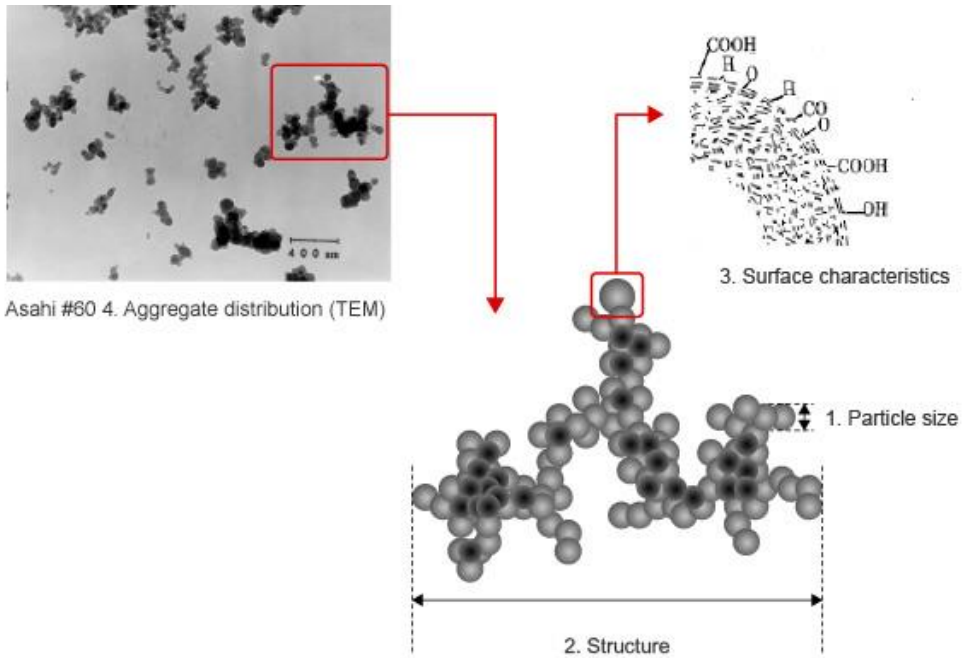


Figure 12. Carbon black nanoparticles [32]

In this research, Carbon black was purchased from Sigma Aldrich. Carbon is used due to its exceptional thermal conductivity and heat absorption property, which helps in transmitting the heat from the radiation to the nanofluid. It also has the excellent property of absorbing ultraviolet light and assist in preventing the ultraviolet degradation. Due to its Nano size, it has more surface area which helps better interaction with the incident radiation.

3.1.2. Graphene

Graphene is a two-dimensional, hexagonal lattice, atomic scale allotrope of carbon, with each atom forming a vertex in a hexagonal lattice. Graphene forms the fundamental structural element of other allotropes like charcoal, carbon nanotubes, fullerenes, and graphite. Graphene is known for its unusual properties due to its strangeness which is 200 times more than that of steel. Graphene is used in this research was purchased from Sigma Aldrich which conduct heat efficiently. N008-N pristine graphene powder is utilized in this study whose thickness varies between 50 – 100 nm and in x-y dimensions of about 5um. This graphene powder contains approximately 97% of carbon and less than 2% of oxygen content. This graphene is mainly used for nanocomposites, heat radiation, conductive adhesive applications, conductive inks and conductive composites [33]. Figure 12 shows the scanning electron microscopy (SEM) image of N008-N pristine graphene powder

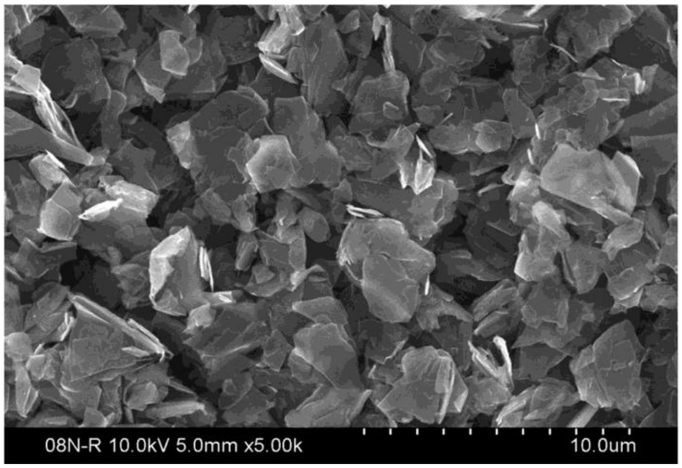


Figure 13. SEM image of N008-N pristine graphene powder [34]

3.1.3. Carbon Nanotubes

Carbon nanotubes were discovered by Lijima during the study of graphite electrodes surface in electric are discharge. CNTs have played a significant role in the field of nanotechnology due to their unique mechanical, electronic and structural properties. These are a tube-shaped material made out of carbon, whose diameter varies in nanometer scale. CNTs are known for its high conductivity and high aspect ratio which forms a network of tubes which makes it solid material. The mechanical properties of CNTs are outstanding with the combination of stiffness, tenacity, and strength. Due to their unique mechanical and electrical properties, they have a broad range of applications in thermal interface materials, nanocomposite material, Nano sensors and logic elements [35]. CNTs comes in single wall, and multi walled with different diameter, length, and purity. In this research study, CNT's were purchased from Sigma Aldrich which were multi walled nanotubes with a diameter ranging from 0-20 nm and length from 1-2 nm and purity of about 95%. Figure 14 shows the single walled and multi walled CNT.

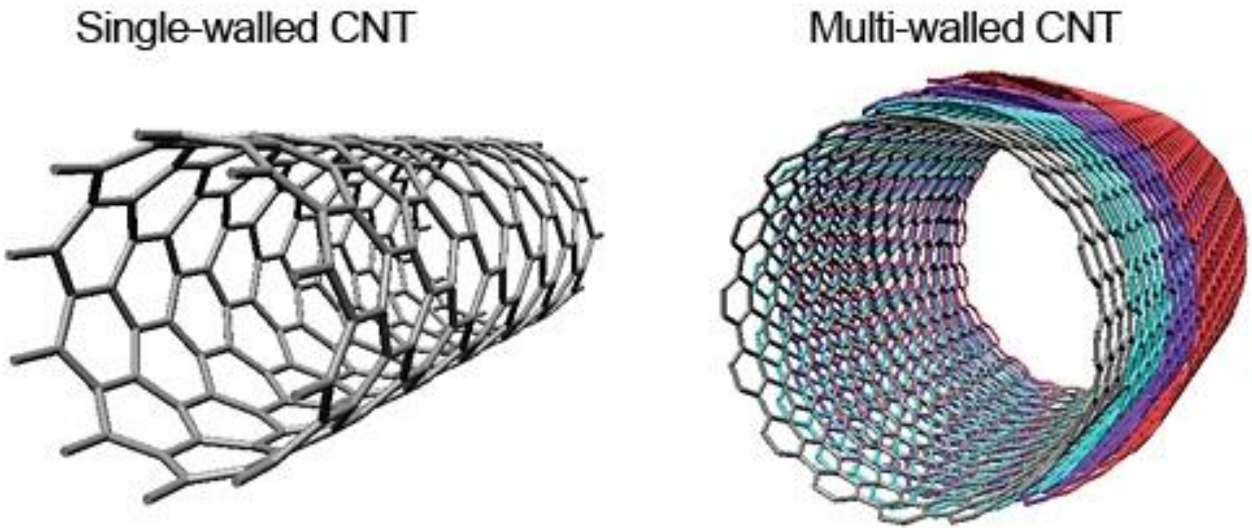


Figure 14. Single-walled and multi-walled CNT [36]

3.1.4. Superhydrophobic Coating (Ultra-Ever Dry)

It is a coating which creates an oleophobic (hydrocarbon) and superhydrophobic (water) nanoscopic layer on the surface which repels most of the water based and some oil based liquids. This coating uses proprietary Omni phobic technology for a coated object and creates a different surface chemistry with textured patterns of high points and peaks geometric shapes. These peaks and high points repel water, some oil, and other liquids. This coating consists of two layers which was purchased from amazon.com

3.1.4.1. Bottom Coat

It is the primary layer which is to apply to the substrate; it is a dissolvable hydrophobic resin and micro particles coatings that hold fast to the substrate surface as also helps in holding the top coat. It contains methyl isobutyl, butyl acetate, ketone and mineral spirit. Figure 15 shows the bottom coat of superhydrophobic coating liquid.

3.1.4.2. Top Coat

It's a secondary layer which is to be applied over the bottom coat; it is a dissolvable hydrophobic polymer and nanoparticle coating that adheres to the base coat and causes the surface to be superhydrophobic. It mainly contains acetone. Figure 16 shows the bottom coat of superhydrophobic coating liquid.

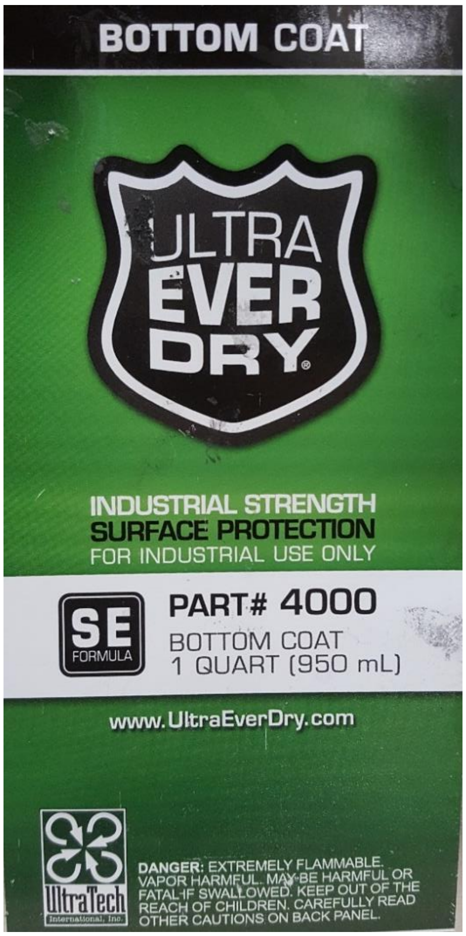


Figure 15. Bottom coat of superhydrophobic coating liquid

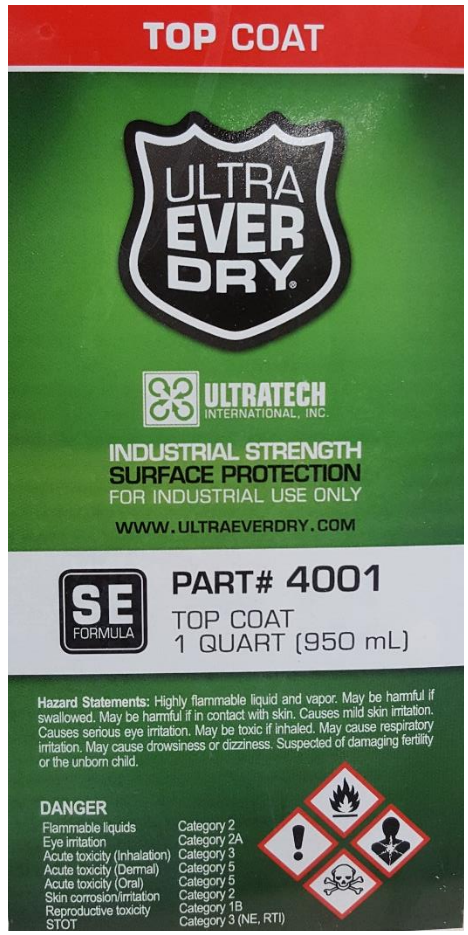


Figure 16. Top coat of superhydrophobic coating liquid

3.1.4.3. Properties of Coating

Table 3 shows the properties of superhydrophobic coating liquid

TABLE 3. PROPERTIES OF SUPERHYDROPHOBIC COATING LIQUID [37]

Colors – Standard	Translucent White (Not Clear)
Recommended Thickness	13 To 25μm
Dry Time	Bottom Coat 30-60 Min (Standard) Top Coat 15-30 Min (Standard)
Surface Application Temp	50-90°F (10 – 32°C)
Working Temp	-30-300°F (-34°C - 149°C)
Flash Point	Bottom Coat 10 °F (-12 °C) Top Coat -4 °F (-20 °C)
Storage Temp	40-115°F (4 – 46°C)
Shelf Life	2 Years @ 77°F (25°C)
Weatherability	12 Months Depending On UV Intensity

- **Anti-Wetting**- The coating keeps objects dry. It repels water and many other liquids.
- **Anti-Corrosion** - It offers corrosion protection since the coating repels water, aqueous acids and bases.
- **Anti-Icing** - The coating keeps the material completely dry, eliminating the formation of ice or, in the instance of frost, making the removal of ice dramatically easier.
- **Anti-Contamination** – The liquids that contain bacteria never actually comes in contact with the coated material.
- **Self-Cleaning** - This coating also repels dirty water and some oils, and when some dust, dirt or other molecules accumulate on the surface, a light spray of water or a blast of air grabs the dust and removes it.

- **Product Life** - Extending – several products fail from moisture, water, oil or simply getting too dirty. But, the coating can extend the life of these products [37].

3.1.5. Spray Gun

The high volume low-pressure spray gun is used in this research which is a gravity feed spray gun with the fluid tip of 1.0 mm. The HVLP spray gun consists of the metal container to hold the paint, pressure gauge and spray gun. This spray gun is refillable and reusable as the metal container can be refilled. The pressure gauge is set at 20 psi to obtain the professional grade uniform coating. The samples can be quickly coated with the spray gun, where the metal container is filled with the liquid and pressure being set to 20 psi in order to carry the paint with the air force. In this process, the spray gun is it to be help at a distance of at least 15cms from the sample to get the uniform layer. The spray gun is activated with the trigger, which is pulled for the air to pass through the gun. The figure 17 shows the high volume low-pressure spray gun used in this process, which was purchased from amazon.com.

Figure 17. Aero-pro high-velocity low-pressure spray gun [38]

3.1.6. Optical Contact Angle Machine - (Goniometer)

It is, an instrument used to measure the advancing and receding contact angle, static contact angle, and sometimes surface tension. The contact angle goniometer was first designed by Dr. Williams Zisman of United States Naval Research Laboratory, Washington D.C. In this research work, the contact angle of the nanofluid was obtained using optical contact angle goniometer which has an optical subsystem to depict liquid, solid surface profile. Static sessile drop technique was used to determine liquid, solid contact angle. This optical contact angle goniometer has a broad range of application in the field of research and development, industrial and educational purpose [39]. The Optical contact angle goniometer contains a high-resolution camera which is controlled using the software Cam 100 to obtain the clear interface of liquid and solid. This software captures the picture of the liquid and solid interface and hence calculates the contact angle at the interface. Figure 18 shows goniometer contact angle machine.

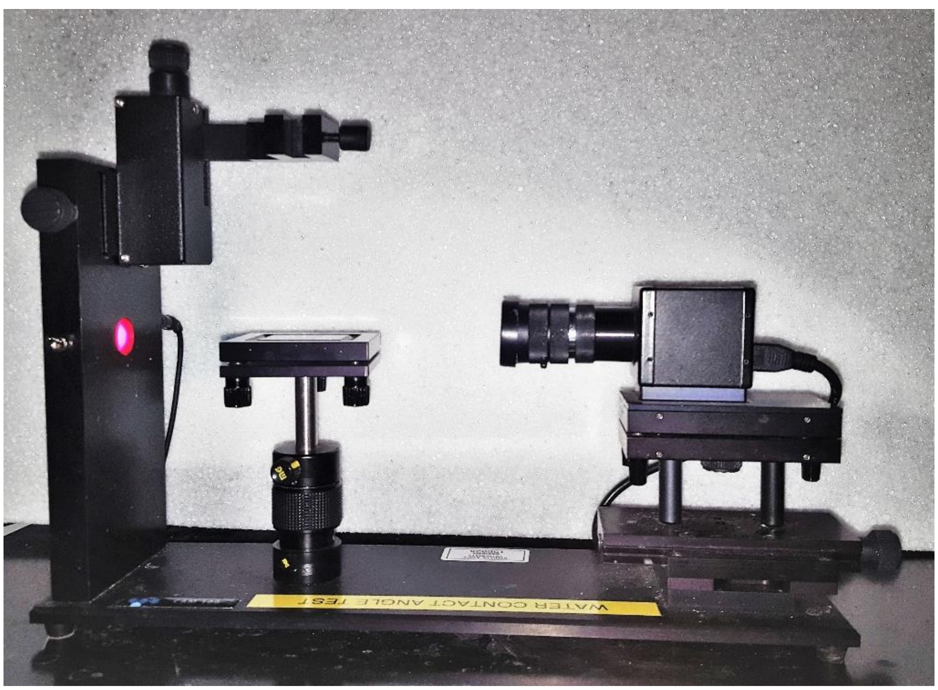


Figure 18. Contact angle machine – goniometer

3.1.7. Optical Microscope

The Zeiss Axio Imager is an upright optical research microscope which has the capability of observing and recording. This microscope has different magnification setting which can give the magnification from 5X to 100X with finest details of the sample. These microscopes are primarily used in the organic sector to determine the tissues and material structure. In this research, the optical microscope is used to determine the deposition of nanoparticles and superhydrophobic on the surface of the cotton gauze. This microscope shows the clear image of the nanoparticle and the superhydrophobic coating attached to the gauze. Figure 19 and 20, shows the front and side view of optical microscope.

Figure 19. Side view of optical microscope

Figure 20. Front view of optical microscope

3.1.8. Industrial Oven for Curing

This oven has the capacity of curing up to 200^0 Celsius; it has a built-in digital temperature scale which can be varied according to the requirement. The inbuilt timer also allows as to set the time for curing. This oven is insulated thoroughly to ensure uniform temperature within the oven. In this research, the oven is used to cure the nanoparticles and superhydrophobic coated cotton gauze of eliminating the moisture and water content from the sample. This process also helps in enhancing the coating process. Figure 21 show the industrial oven.

Figure 21. Industrial oven

3.1.9. Infrared Heat Light

Infrared heat lamps are the electric bulb which emits infrared radiation along with heat. These infrared lights are widely used as the heat light in radiant heating processes. The infrared heat bulb utilized in this study is clear BR40 which is the medium based bulb of 125 watts, purchased from Home Depot. This heat bulb is used to the incident the heat rays on the surface of the water. The primary purpose of using the heat light is to generate the heat required for evaporation of water. The filament temperature of this bulb goes up to 200^0C, which gives the right amount of heat necessary for this research study. Figure 22 shows the 125-watt infrared heat light.

Figure 22. Infrared heat light 125 watt

3.1.10. Infrared Thermometer

The Infrared thermometer is a device which measures the temperature of the portion of thermal radiation, which is radiated by the body being measured. These devices are used to measure the temperature of the body from a distance. The main working principle of this device is the infrared energy, the amount of infrared energy emitted is known from which the temperature of the body can be determined. This device consists of a lens to focus infrared thermal radiation on the detector; this converts radiant power to an electrical signal, which is then displayed in units of temperature. A laser pointer which is used to point the place where the temperature is to be measured. These thermometers are also known as the thermal radiation thermometers. Figure 23 shows the side view and front view of infrared thermometer. This device was purchased from amazon.com.

Figure 23. Infrared thermometer side view (left), front view (right)

3.1.11. Homogenizer

Homogenizer is a laboratory device or an industrial equipment used for mixing or homogenizing various types of materials, like plants, soil, liquids, tissues and many others. This device looks similar to the blender which applies the shear force to obtain the proper mixing of the materials. This device is being the first step of many sample preparation and is being widely used in the homogenization of the various types of mixtures. Figure 24 shows the homogenizer.

Figure 24. Homogenizer

3.2. Methods

3.2.1. Evaporation Test for Tap Water, Salt Water, and DI Water

This evaporation test was conducted with three types of water, i.e. tap water, salt water and DI water at 20^0C room temperature, 15% humidity, with no atmospheric pressure and wind velocity.

- In the first test, 250g regular tap water with the temperature of 18.5^0C was taken in a Pyrex beaker of dimension 190mm X 100mm, No.3140. The beaker along with the water was placed on the weighing scale to measure the amount of water evaporating with respect to time. The whole setup of beaker and weighing scale is kept under the infrared heat lamp. The light is then switched ON, and then the reading on the weighing scale was recorded, along with temperature rise for every 5 minutes for 2 hours. An infrared thermometer is used to check the temperature of the water.
- In this test, the regular tap water was mixed with 3.5% of Sodium Chloride (NaCl) to make the salt water. Here 241.25g of regular tap water with a temperature of 18.5^0C was mixed with 8.75g of NaCl in a Pyrex beaker of dimension 190mm X 100mm, No.3140 and mixed well with the help of homogenizer. Once the NaCl is dissolved in water the mixture is kept on weighing scale and then the whole setup placed under the Infrared heat lamp. The light is then switched ON, and then the reading on the weighing scale was recorded, along with temperature rise for every 5 minutes for 2 hours. An infrared thermometer is used to check the temperature of the water.
- In the third test, 250g DI water with the temperature of 18.5^0C was taken in a Pyrex beaker of dimension 190mm X 100mm, No.3140. The beaker along with the water was placed on the weighing scale to measure the amount of water evaporating with respect to time. The

whole setup of beaker and weighing scale is kept under the infrared heat lamp. The light is then switched ON, and then the reading on the weighing scale was recorded, along with temperature rise for every 5 minutes for 2 hours. An infrared thermometer is used to check the temperature of the water. Figure 25, shows the experimental setup of infrared light focused on the water

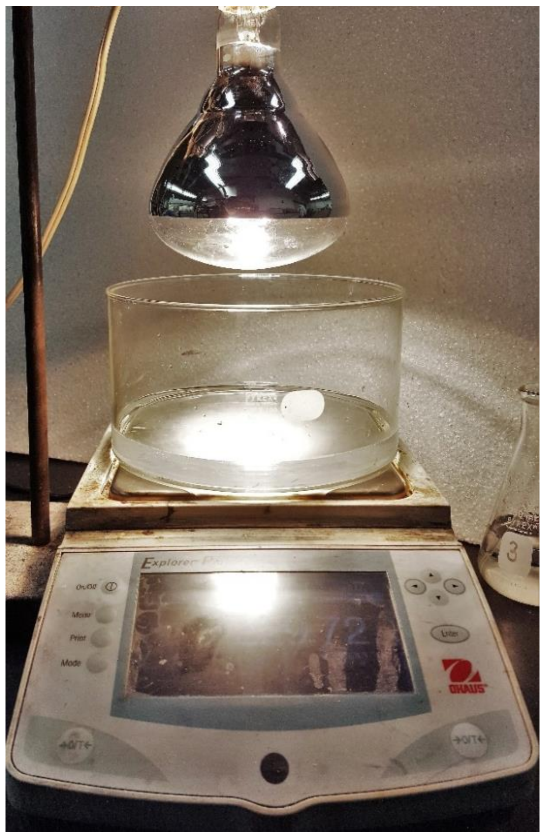


Figure 25. Experimental setup for evaporation of tap water, salt water, and di water

3.2.2. Preparation of Nanofluids using Carbon Black and Graphene

Nanofluids are prepared by mixing nanoparticles into the base fluid. In this study, the nanoparticles used are carbon black, and graphene and the base fluid used are water, DI water, and salt water.

- In this preparation, the required concentration of carbon black nanoparticles is mixed with the base fluids like water, DI water, and salt water to obtain the carbon black based nanofluid.
- For graphene, the required concentration of graphene nanoparticles is mixed with the base fluids like water, DI water, and salt water to obtain the graphene based nanofluid.

In the preparation of nanofluid, the required concentration of nanoparticles is weighed and mixed with the based fluid. The nanoparticles do not easily mix up with the base fluid. In order to obtain the uniform suspension of nanoparticle mixture, a homogenizer is used for 5 minutes, which helps in proper mixing of the nanoparticles into the base fluid. Figure 26, shows the base fluid with nanoparticles.

Figure 26. Base fluid with nanoparticles

3.2.3. Evaporation Test for Carbon Black nanoparticles with 0.05%, 0.1%, 0.5% Concentration using Tap Water, Salt Water, and DI Water

In this evaporation process, the nanofluids are prepared with different concentrations of nanoparticles. The nanoparticles are weighed and mixed with the based fluid; the nanoparticles do not easily mix up with the base fluid. In order to obtain the suspended nanoparticle mixture, a homogenizer is used for 5 minutes, which helps in proper mixing of the nanoparticles into the base fluid. Once the nanofluid is prepared, the beaker containing the nanofluid is placed on the weighing scale to measure the amount of water evaporating with respect to time. The whole setup of beaker and weighing scale is kept under the infrared heat lamp. The light is then switched ON, and then the reading on the weighing scale was recorded, along with temperature rise for every 5 minutes for 1 hour. An infrared thermometer is used to check the temperature of the water.

The evaporations test is conducted for different concentrations of carbon black i.e. 0.05%, 0.1%, 0.5% with various base fluids i.e. water, salt water and DI water. The different concentration of carbon black and NaCl along with the amount of nanofluid is as shown in Table 4, 5 and 6.

TABLE 4. CARBON BLACK CONCENTRATION COMBINATION WITH WATER

Base Fluid (A)	**Nanoparticles (B) (%)**	**A+B (g)**	**Nanofluid (A+B=C) (g)**
Water	Carbon black 0.05	249.875 + 0.125	250g Carbon black Nanofluid
	Carbon black 0.1	249.75 + 0.25	
	Carbon black 0.5	248.75 + 1.25	

TABLE 5. CARBON BLACK CONCENTRATION COMBINATION WITH SALT WATER

Base Fluid (A)	**Nanoparticles (B) (%)**	**NaCl (3.5%) (g)**	**A+B+C (g)**	**Nanofluid (A+B+C=D) (g)**
Water (Salt Water)	Carbon black 0.05	8.75	241.125+0.125+8.27	250g Carbon black Nanofluid
	Carbon black 0.1	8.75	241+0.25+8.75	
	Carbon black 0.5	8.75	240+1.25+8.75	

TABLE 6. CARBON BLACK CONCENTRATION COMBINATION WITH DI WATER

Base Fluid (A)	**Nanoparticles (B) (%)**	**A+B (g)**	**Nanofluid (A+B=C) (g)**
DI Water	Carbon black 0.05	249.875 + 0.125	250g Carbon black Nanofluid
	Carbon black 0.1	249.75 + 0.25	
	Carbon black 0.5	248.75 + 1.25	

3.2.4. Evaporation Test for Graphene Nanoparticles with 0.05%, 0.1%, 0.5% Concentration using Tap Water, Salt Water, and Deionized Water

In this evaporation test for graphene, the nanofluids are prepared with different concentrations of graphene nanoparticles. The graphene nanoparticles are weighed and mixed with the based fluid; the nanoparticles do not easily mix up with the base fluid. In order to obtain the uniform suspension of nanoparticles in liquid, a homogenizer is used for 5 minutes, which helps in proper mixing of the nanoparticles into the base fluid. Once the nanofluid is prepared, the beaker containing the nanofluid is placed on the weighing scale to measure the amount of water evaporating with respect to time. The whole setup of beaker and weighing scale is kept under the infrared heat lamp. The light is then switched ON, and then the reading on the weighing scale was recorded, along with temperature rise for every 5 minutes for 1 hour. An infrared thermometer is used to check the temperature of the water.

The evaporations test is conducted for different concentrations of graphene, i.e., 0.05%, 0.1%, and 0.5%, with various base fluids, i.e., water, salt water, and DI water. The different concentrations of graphene nanoparticles, in combination with water, salt water, and DI water are shown in Tables 7, 8, and 9, respectively.

TABLE 7. GRAPHENE CONCENTRATION COMBINATION WITH WATER

Base Fluid (A)	Nanoparticles (B) (%)	(A+B) (g)	Nanofluid (A+B=C) (g)
Water	Graphene 0.05	249.875 + 0.125	250g Graphene Nanofluid
	Graphene 0.1	249.75 + 0.25	
	Graphene 0.5	248.75 + 1.25	

TABLE 8. GRAPHENE CONCENTRATION COMBINATION WITH SALT WATER

Base Fluid (A)	Nanoparticles (B) (%)	NaCl (3.5%) (g)	(A+B+C) (g)	Nanofluid (A+B+C=D) (g)
Water (Salt Water)	Graphene 0.05	8.75	241.125+0.125+8.27	250g Graphene Nanofluid
	Graphene 0.1	8.75	241+0.25+8.75	
	Graphene 0.5	8.75	240+1.25+8.75	

TABLE 9. GRAPHENE CONCENTRATION COMBINATION WITH DI WATER

Base Fluid (A)	Nanoparticles (B) (%)	(A+B) (g)	Nanofluid (A+B=C) (g)
DI Water	Graphene 0.05	249.875 + 0.125	250g Graphene Nanofluid
	Graphene 0.1	249.75 + 0.25	
	Graphene 0.5	248.75 + 1.25	

3.2.5. Preparation of Floatable Superhydrophobic Gauze Using Carbon Black, Graphene and Carbon Nanotubes

- A clean white cotton gauze is cut into a dimension of 11cms X 9cms and dried in the oven at 75^0 C for 1 hour to remove the moisture content from the gauze.
- The nanoparticles of 0.25g are mixed with the bottom coat of superhydrophobic liquid into the metal container of the HVLP spray gun.
- The superhydrophobic liquids can be sprayed by using a variety of air powered sprayers like Ultra-Mini Sprayer, Ultra-Power Sprayer, Air Brush and HVLP Spray Gun. In this research, HVLP spray gun is used.
- The bottom coat of superhydrophobic liquid mixed with the nanoparticles is sprayed on both the sides of cotton gauze with HVLP spray gun under the fume hood.
- The bottom coated cotton gauze is then allowed to dry in the oven for 2 hours at 75^0C.
- The coated cotton gauze is then coated with the top coat of superhydrophobic coating and then allowed to dry at room temperature for two hours.

- In this process, the bottom coat converts the material into the rough hydrophobic surface, while the top coat adheres to the base coat causing the whole surface to become a superhydrophobic surface along with the nanoparticles.
- The above superhydrophobic liquid coating procedure is used to coat the cotton gauze with the three types of nanoparticles i.e. carbon black, graphene, and CNT.
- Figure 27, shows cotton gauze before coating with nanoparticles and superhydrophobic liquid. Figure 28, shows cotton gauze coated with carbon black nanoparticles and superhydrophobic liquid. Figure 29, shows cotton gauze coated with graphene nanoparticles and superhydrophobic liquid and Figure 30, shows cotton gauze coated with CNT nanoparticles and superhydrophobic liquid.

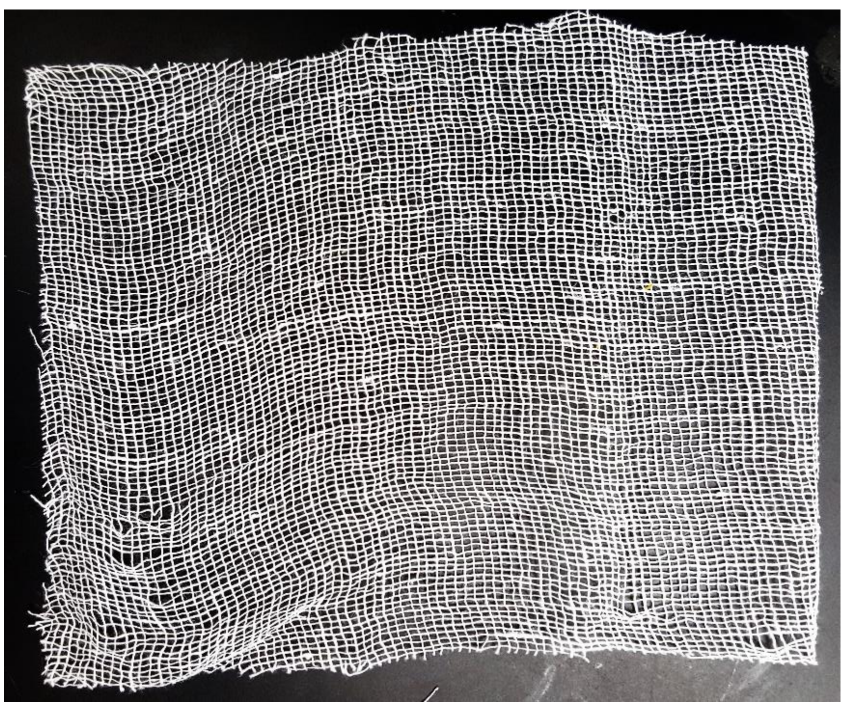


Figure 27. Cotton gauze before coating with nanoparticles and superhydrophobic liquid

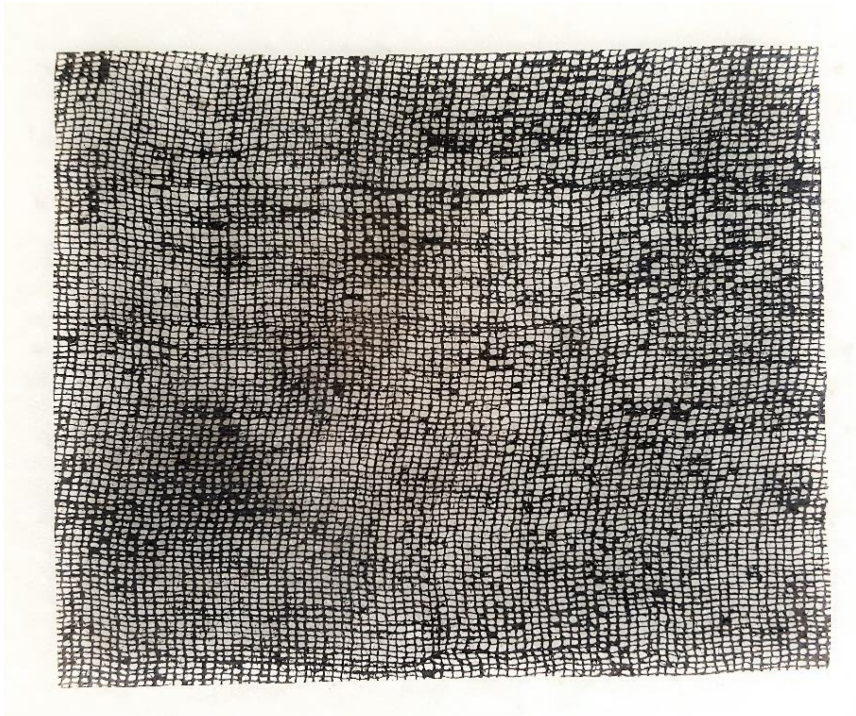


Figure 28. Cotton gauze coated with carbon black nanoparticles and superhydrophobic liquid

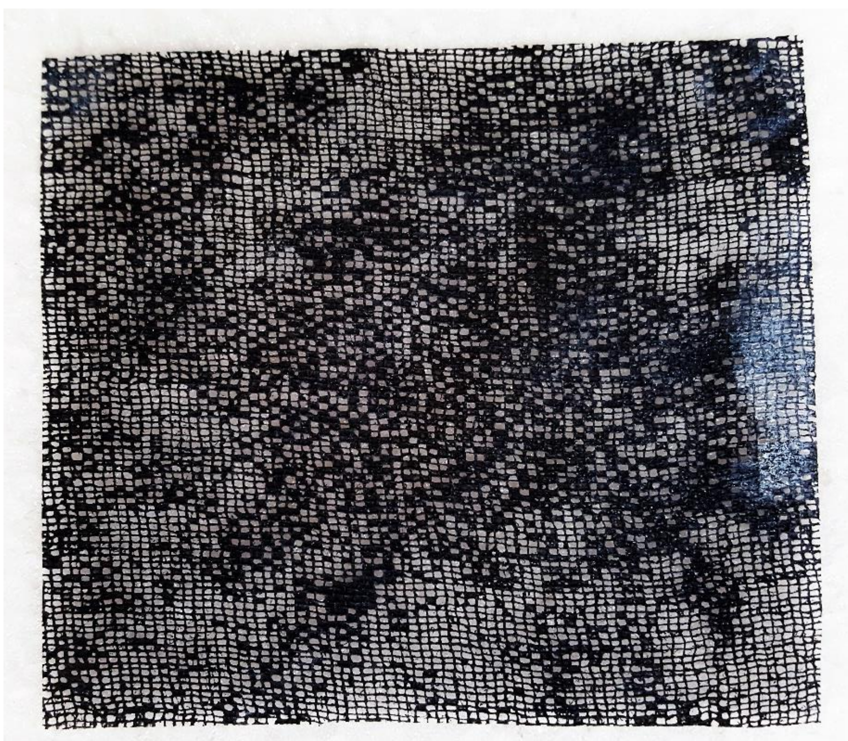


Figure 29. Cotton gauze coated with graphene nanoparticles and superhydrophobic liquid

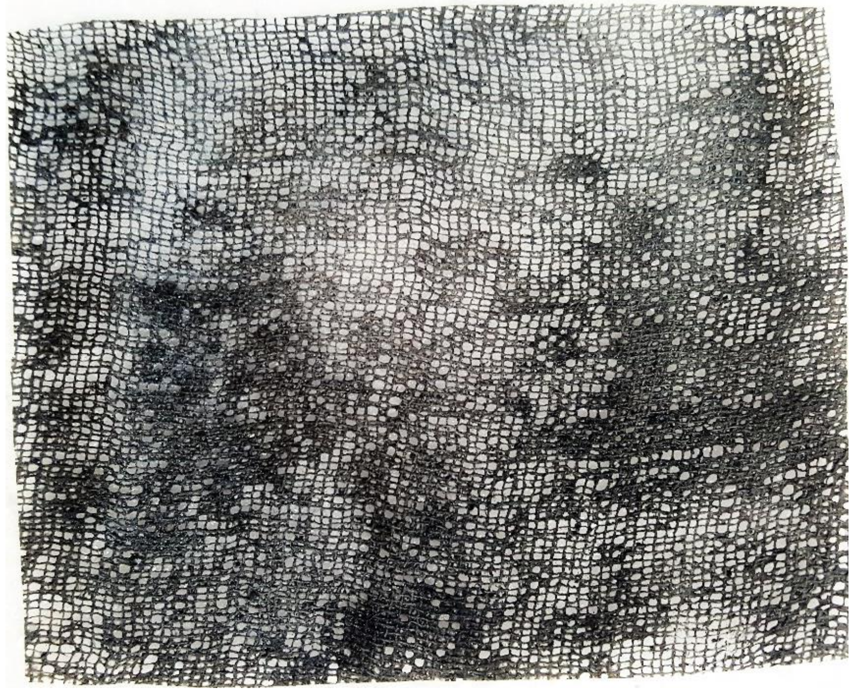


Figure 30. Cotton gauze coated with CNT nanoparticles and superhydrophobic liquid

3.2.6. Wettability Test for Floatable Nanoparticle Superhydrophobic Gauze

In this test, the floating ability of the cotton gauze was tested and recorded. The non-coated cotton gauze is slowly placed on the surface of the water, as soon as it comes in interaction with the water it slowly starts absorbing the water, gets wet and sinks down to the bottom most of the water. This shows that the non-coated cotton gauze is hydrophilic and absorbs water as soon as it comes in contact with it. Figure 31 shows the wettability test for non-coated cotton gauze.

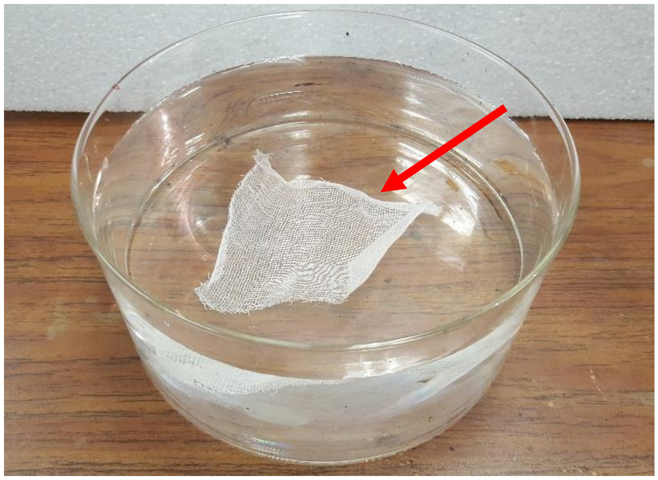


Figure 31. Cotton gauze sinking at the bottom of water

In next test, the cotton gauze is coated with the superhydrophobic coating and then slowly placed on the surface of the water. From the observation, it can be clearly seen that due to its superhydrophobic coating the gauze fails to get wet and remains floating on the surface of the water without sinking down in water. Figure 32 shows the wettability test for super-hydrophobic coated cotton gauze.

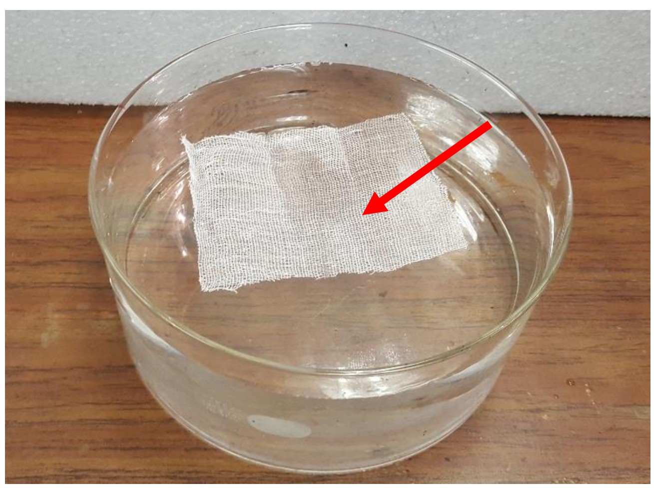


Figure 32. Superhydrophobic coated cotton gauze floating on water surface

In the third test, the cotton gauze is coated with nanoparticles and superhydrophobic coating and then slowly placed on the surface of the water. The results show that the coated cotton gauze remains floating off the surface of the water without sinking down. Figure 33, shows the wettability test for nanoparticles and superhydrophobic coated cotton gauze.

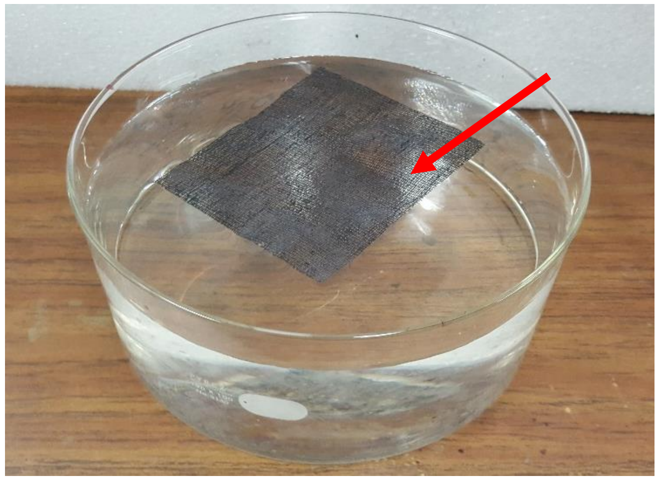


Figure 33. Nanoparticle and superhydrophobic coated cotton gauze floating on water surface

3.2.7. Evaporation Test for Nanoparticles with 0.1% Concentration with Water, Salt Water and Deionized Water in Presence and Absence of Black Base

In this experiment, the nanofluids are prepared by mixing 0.1% of nanoparticles into the fluid. The nanoparticles first are weighed and mixed with the based fluid; the nanoparticles do not easily mix up with the base fluid. In order to obtain the uniform suspension of nanoparticles in liquid, a homogenizer is used for 5 minutes, which helps in proper mixing of the nanoparticles into the base fluid. Once the nanofluid is prepared, the beaker containing the nanofluid is placed on the weighing scale to measure the amount of water evaporating with respect to time. The whole setup of beaker and weighing scale is kept under the infrared heat lamp. The light is then switched ON, and then the reading on the weighing scale was recorded, along with temperature rise for every 5 minutes for 2 hours. An infrared thermometer is used to check the temperature of the water.

The evaporations test is conducted for carbon black with 0.1% concentration along with the different base fluid i.e. water, salt water and DI water. The concentration of carbon black nanoparticles, amount of NaCl along with the quantity of Nanofluid is as shown in table 10, 11 and 12.

Figure 34 shows experimental setup for evaporation without nanoparticles. Figure 35, shows the experimental setup for evaporation with black base and the figure 36, shows the experimental setup for evaporation with nanoparticles and black base

TABLE 10. DIFFERENT COMBINATIONS OF NANOPARTICLES AND BLACK BASE WITH WATER

Base Fluid (A)	**Nanoparticles (B) (%)**	**(A+B) (g)**	**Nanofluid (A+B=C) (g)**
Water	Carbon black 0.1	249.75g+ 0.25	250g Nanofluid
	Graphene 0.1	249.75 + 0.25	
Water + Black Base	Carbon black 0.1	249.75 + 0.25	250g Nanofluid with Black Base
	Graphene 0.1	249.75 + 0.25	

TABLE 11. VARIOUS COMBINATIONS OF NANOPARTICLES AND BLACK BASE WITH SALT WATER

Base Fluid (A)	**Nanoparticles (B) (%)**	**NaCl (3.5%) (g)**	**(A+B+C) (g)**	**Nanofluid (A+B+C=D) (g)**
Salt Water	Carbon black 0.1	8.75	241+0.25+8.75	250g Nanofluid
	Graphene 0.1	8.75	241+0.25+8.75	
Salt Water + Black Base	Carbon black 0.1	8.75	249.75 + 0.25	250g Nanofluid with Black Base
	Graphene 0.1	8.75	249.75 + 0.25	

TABLE 12. DIFFERENT COMBINATIONS OF NANOPARTICLES AND BLACK BASE WITH DI WATER

Base Fluid (A)	**Nanoparticles (B) (g)**	**(A+B) (g)**	**Nanofluid (A+B=C) (g)**
DI Water	Carbon black 0.1	249.75 + 0.25	250g Nanofluid
	Graphene 0.1	249.75 + 0.25	
DI Water + Black Base	Carbon black 0.1	249.75 + 0.25	250g Nanofluid with Black Base
	Graphene 0.1	249.75 + 0.25	

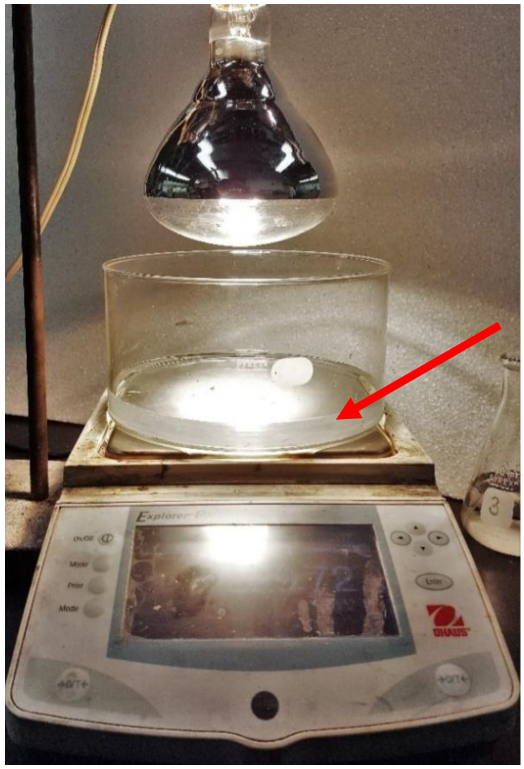


Figure 34. Experimental setup for evaporation without nanoparticles

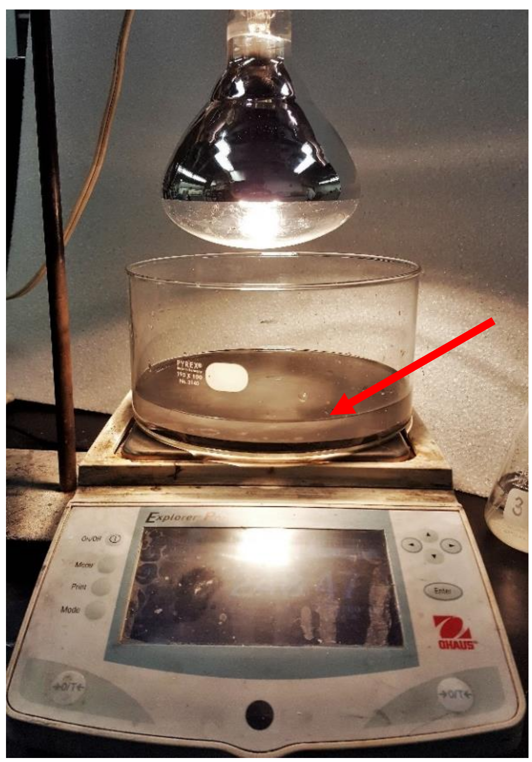


Figure 35. Experimental setup for evaporation with black base

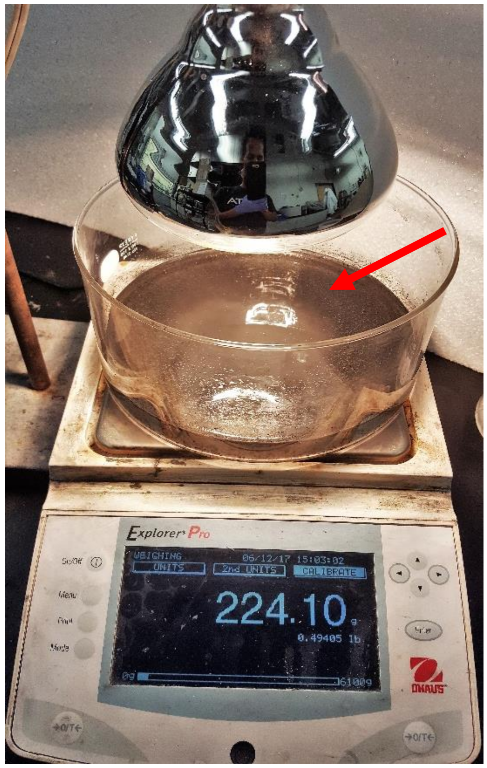


Figure 36. Experimental setup for evaporation with nanoparticles and black base

3.2.8. Evaporation Test for Superhydrophobic Floatable Nanoparticle Coated Gauze for Carbon Black, Graphene, and CNT with Water, Salt Water, and Deionized Water

In this evaporation test, the cotton gauze weighing 0.75g is coated with 0.25g of nanoparticle and superhydrophobic liquid, first with the bottom coat and then with the top coat. The water weighing 249g is taken in a beaker, and then the nanoparticle super-hydrophobic coated gauze which weighs around 1g is then slowly placed on the surface of the water. The beaker containing water, along with the floating gauze is then put on the weighing scale to measure the amount of water evaporating with respect to time. The whole setup of the beaker containing water, gauze and weighing scale is kept under the infrared heating lamp. The light is then switched ON, and then the reading on the weighing scale was recorded, along with temperature rise for every 5 minutes for 2 hours. An infrared thermometer is used to check the temperature of the water.

The evaporations tests are conducted by following the same above procedure for different nanoparticles, i.e. carbon black, graphene, and CNTs. The nanoparticle which gave the maximum amount of evaporation was then combined with the black rubber base to obtain some more evaporation. The process of evaporation was carried out with normal tap water, salt water, and DI water. The figure 37, shows the experimental setup of nanoparticle and superhydrophobic coated cotton gauze in water and the figure 38, shows the experimental setup of nanoparticle and superhydrophobic coated cotton gauze in water along with black base.

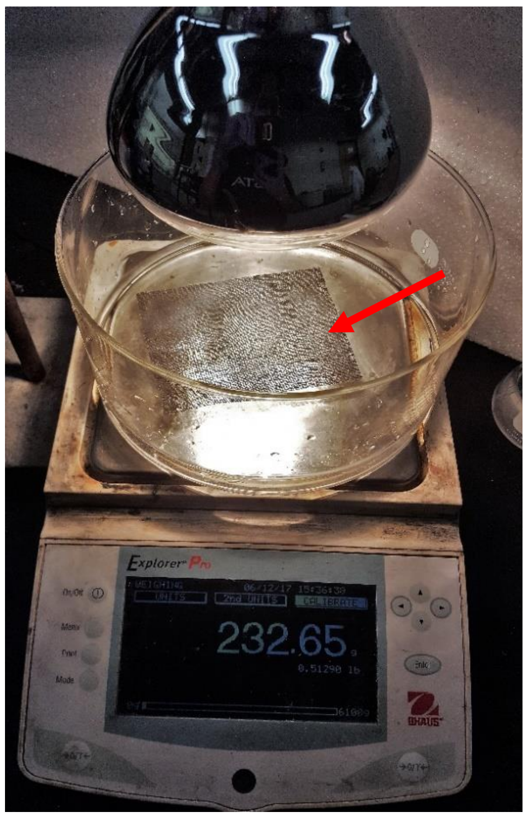


Figure 37. Experimental setup of nanoparticle and superhydrophobic coated cotton gauze in water

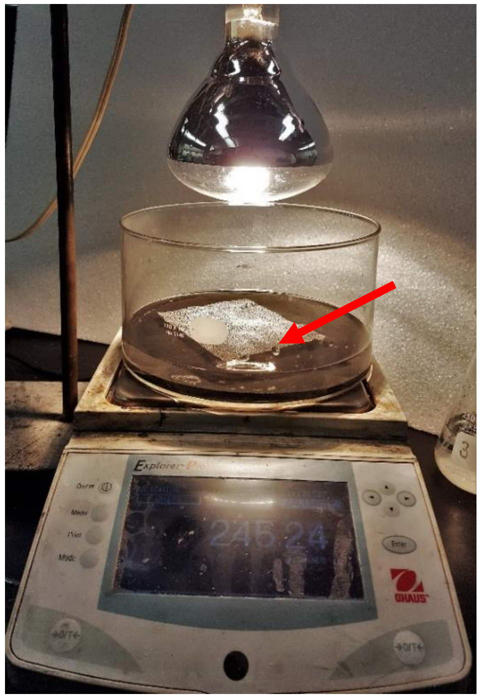


Figure 38. Experimental setup of nanoparticle and superhydrophobic coated cotton gauze in water along with black base

3.3. Surface Characterization

3.3.1. Water Contact Angle Test

The water contact angle is measured to determine the surface adhesion and wettability of the surface. To measure the contact angle the following steps are involved:

- The set up includes the screw syringe to precisely drop the water on the surface where the contact angle is to be measured.
- An adjustable stand is being set up where the sample which can be placed and can be moved up and down accordingly.
- A set of high-resolution camera used to capture the images and send them to the software to measure the contact angle.
- A monochromatic red light generated from the LED source, is set up right opposite to the camera, which helps in creating a sharper image of the droplet.

- The software used to calculate the contact angle is Cam 100.
- To measure the contact angle the syringe filled with the distilled water is fixed to the stand above the sample surface.
- The sample is set on the stand with proper alignment, and then the LED light is turned ON.
- The camera focus was adjusted till we get the clear image of the syringe needle tip and surface.
- Once the clear image is formed, a small drop of water was released from the surface; then the software is used to capture and calculate the contact angle of the water droplet.

3.3.2. Optical Microscope

The optical microscope test was carried out to get the magnified view of the deposition of nanoparticles and superhydrophobic liquid on the surface of the cotton gauze. To get the magnified view of the samples, the Zeiss Axio Imager is, and upright optical research microscope is used. This microscope has different magnification setting which can give the magnification of 5X, 20X, 50X and 100X with finest details of the sample. To get the magnified picture of the nanoparticle coated gauze, it is placed under the lens of the microscope and set to 10X zoom lens. The sample is then viewed from the eye piece of the upright microscope to make a clear focus on the sample along with the adjustment made to match the light coming from the lens. Once the center is formed on the sample, the view of the sample is then transferred to the personal computer with the help of camera attached to the microscope and the AXIO CAM software. This software gives the clear view of the samples which can be captured along with the scale with the help snapshot which captures the screen shot. This microscope is accessible in nine renditions standards of which four are mechanized models, and five are manual.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Contact Angle Measurement of Nanoparticle Coated Gauze

The cotton gauze was first coated with the nanoparticles and superhydrophobic liquid which changes the properties of the gauze from hydrophilic to nearly superhydrophobic. To test this property the contact angle analysis was performed which shows the precise transformation of the gauze property from hydrophilic to nearly superhydrophobic. The below images show the contact angle for cotton gauze coated with superhydrophobic liquid and different nanoparticles.

4.1.1. Cotton Gauze without Superhydrophobic Coating

From the below images it can be clearly seen that the cotton gauze without coating is completely hydrophilic and absorbs water. As soon as the water droplet comes in contact with the cotton gauze the water is being slowly absorbed by the cotton gauze and hence, the contact angle for this test was 0^0. Figure 39, shows the contact angle under Cam 100 software for cotton gauze when the water dropis being absorbed by it.

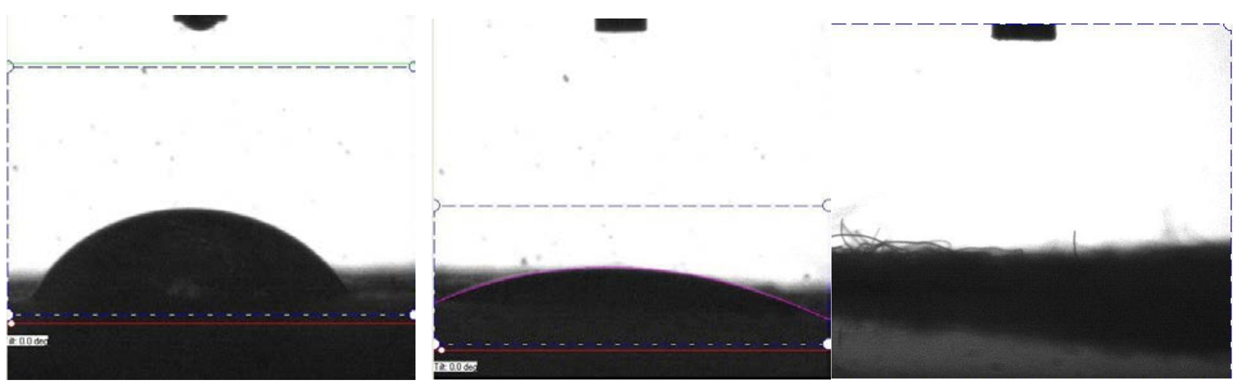


Figure 39. View of contact angle under cam 100 software for cotton gauze

4.1.2. Cotton Gauze Coated with Superhydrophobic Coating and Different Nanoparticles: Carbon Black, Graphene, and CNT

When the cotton gauze is coated with the is coated with superhydrophobic liquid it changes its water absorbing properties from hydrophilic to the nearly superhydrophobic gauze. The below show the contact angle for

- Cotton gauze coated with carbon black and super hydrophobic coating whose average contact angle is 147.45^0. Figure 40, shows the contact angle for carbon black nanoparticle.

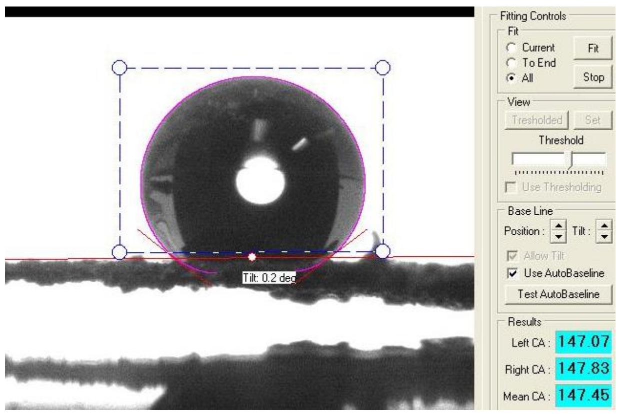


Figure 40. Contact angle for cotton gauze coated with carbon black nanoparticles and superhydrophobic liquid in cam 100 software

- Cotton gauze coated with graphene and super hydrophobic coating whose average contact angle is 140.61. Figure 41, shows the contact angle for graphene nanoparticle.

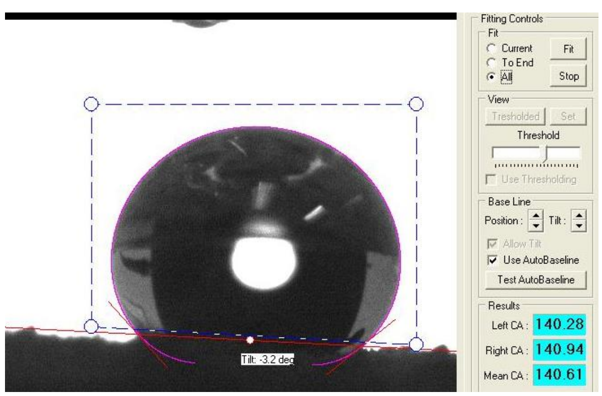


Figure 41. Contact angle for cotton gauze coated with graphene nanoparticles and superhydrophobic liquid in cam 100 software

- Cotton gauze coated with CNT and super hydrophobic coating whose average contact angle is 149.84. Figure 42, shows the contact angle for graphene nanoparticle.

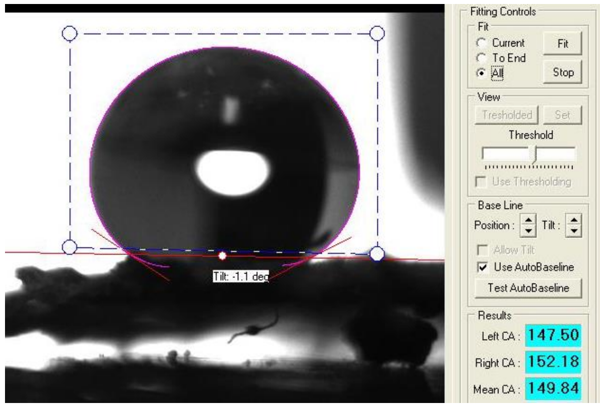


Figure 42. Contact angle for cotton gauze coated with cnt nanoparticles and superhydrophobic liquid in cam 100 software

4.1.3. Optical Images of Nanoparticle Coated Gauze

To observe the nanoparticles and superhydrophobic coating on the surface of the gauze the Optical Imaging was done. This test shows the pictures of the gauze before coating and after coating with the nanoparticles and superhydrophobic liquid. The images apparently show the small nanoparticles on the surface of each thread of the cotton gauze along with the superhydrophobic liquid sprayed over the cotton gauze. The below images show the optical images of the cotton gauze before coating and after coating with superhydrophobic liquid and different nanoparticles. Figure 43, show the optical images of cotton gauze before coating with nanoparticles and superhydrophobic coating. The Figure 44, shows the optical images of cotton gauze after coating with carbon black and superhydrophobic liquid. Figure 45, shows the optical images of cotton gauze coated with graphene and superhydrophobic liquid and the Figure 46, shows the optical Images of cotton gauze coated with CNT and superhydrophobic liquid

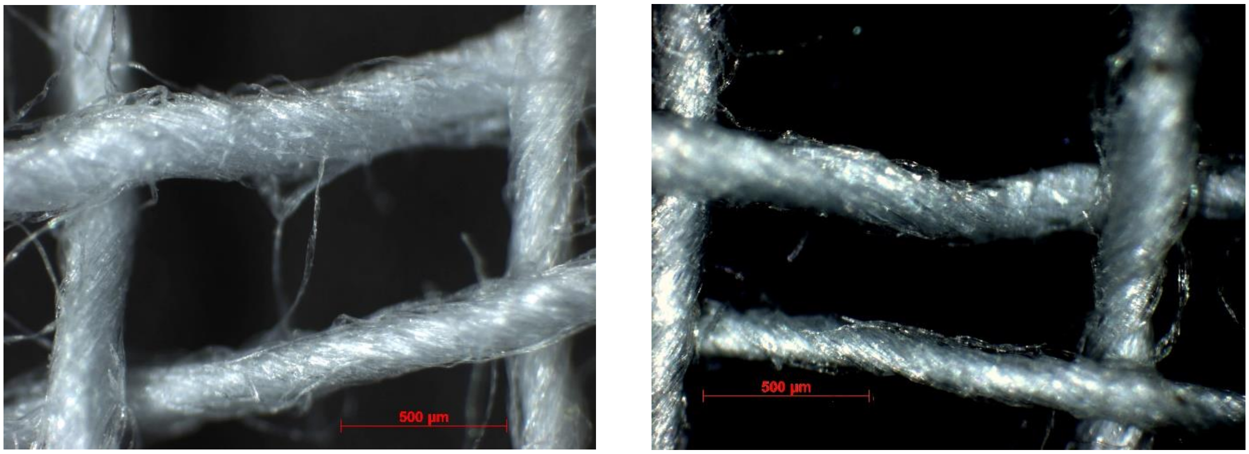


Figure 43. Optical images of cotton gauze before coating with nanoparticles and superhydrophobic liquid

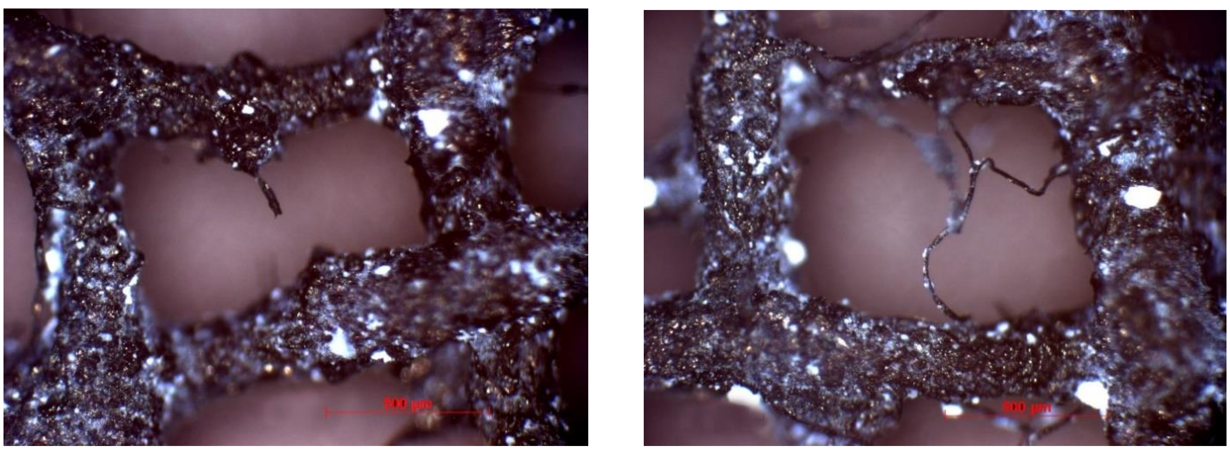


Figure 44. Optical images of cotton gauze coated with carbon black and superhydrophobic liquid

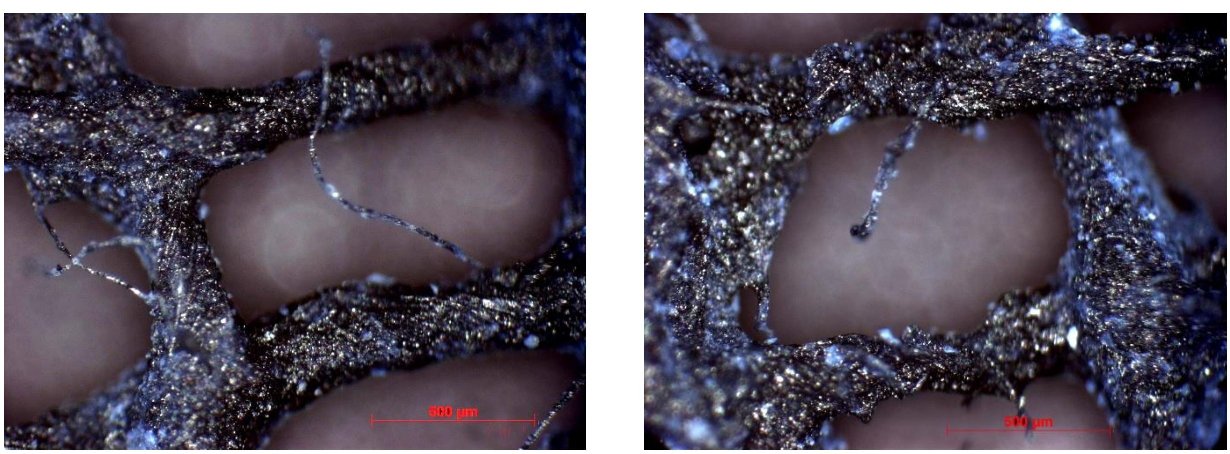


Figure 45. Optical images of cotton gauze coated with graphene and superhydrophobic liquid

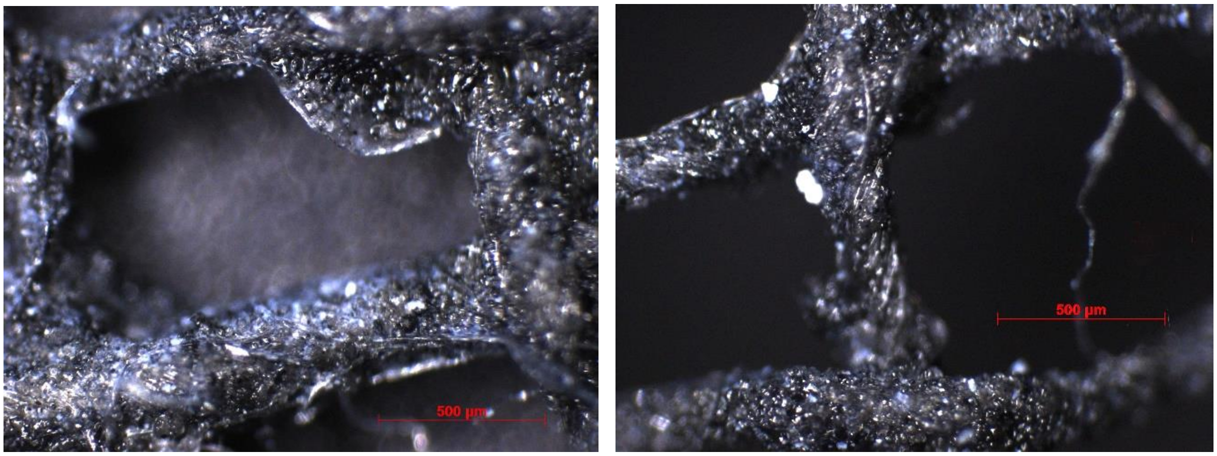


Figure 46. Optical Images of Cotton Gauze coated with CNT and Superhydrophobic liquid

4.2. Evaporation Tests

The following results show how the rate of evaporation differs with different nanoparticles, different concentration of nanoparticle and how this result can use to make a floatable superhydrophobic nanoparticle gauze which enhances the rate of evaporation of water. The following results also show the comparison of all the evaporation test along with which test shows the maximum evaporation rate.

4.2.1. Evaporation Test for Tap Water, Salt Water, and DI Water

Figure 47, indicates that the salt water had the least amount of evaporation as compared to the tap water and DI water with the evaporation of 72.38g for 2 hours. The main reason for the less evaporation of salt water is due to the presence of the NaCl ions in the salt water. These ions hold the molecules of salt water together forming a tighter bond than DI water and tap water. Whereas, the DI being the more purified form in terms of salt content has more evaporation rate then salt water and tap water. DI water gives the evaporation of 82.4g for 2 hours; it contents almost negligible amount of mineral due to which the molecular bond of the DI water can be easily broken and hence, the evaporation of DI water is much faster than tap water and salt water. Tap water, on the other hand, gives the evaporation of 77.71g for the duration of 2 hours; it has normalized contents of minerals due to which the evaporation of this water lies between that of salt water and DI water.

Figure 48, also shows an interesting fact that the temperature in which, the increase in the temperature of salt water which is 49.5^{0}C is much lesser than the growth in the temperature of the DI water and Salt water which is 56.6^{0}C and 56.1^{0}C. From this figure, we can clearly see why the evaporation of salt water is less than that of tap water and DI water.

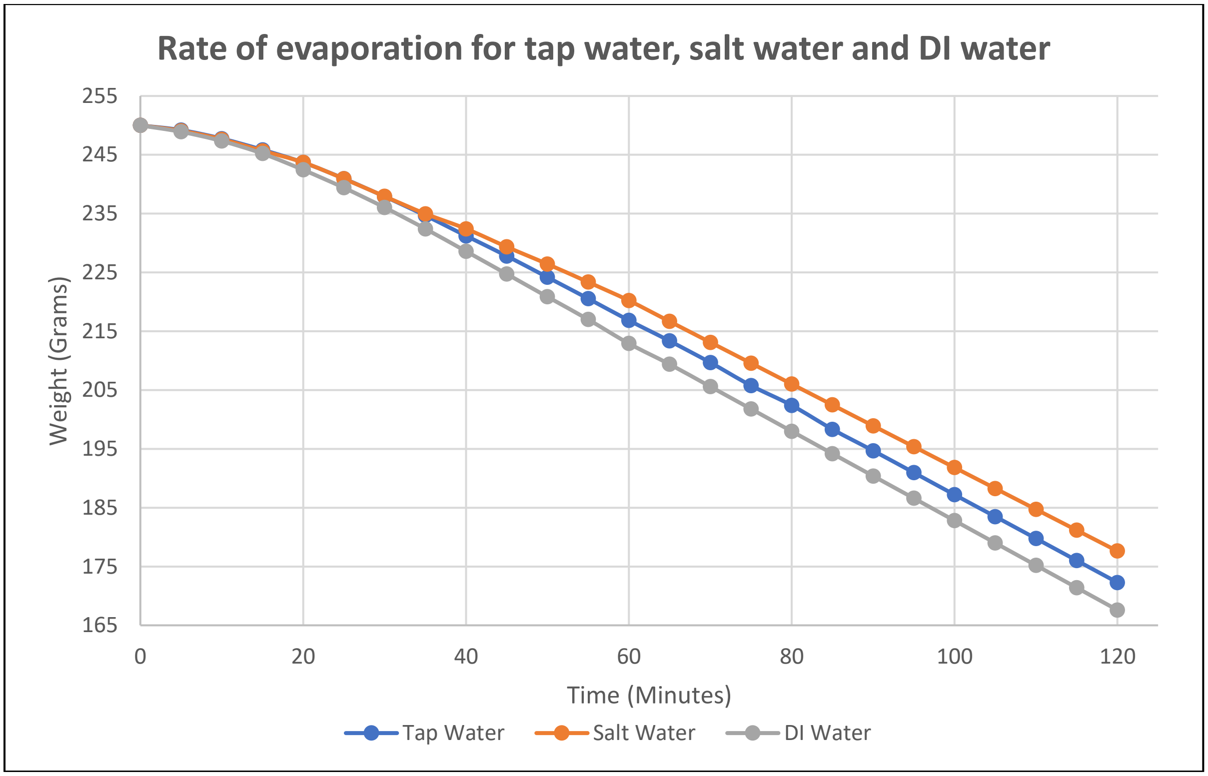


Figure 47. Rate of evaporation for tap water, salt water, and DI water

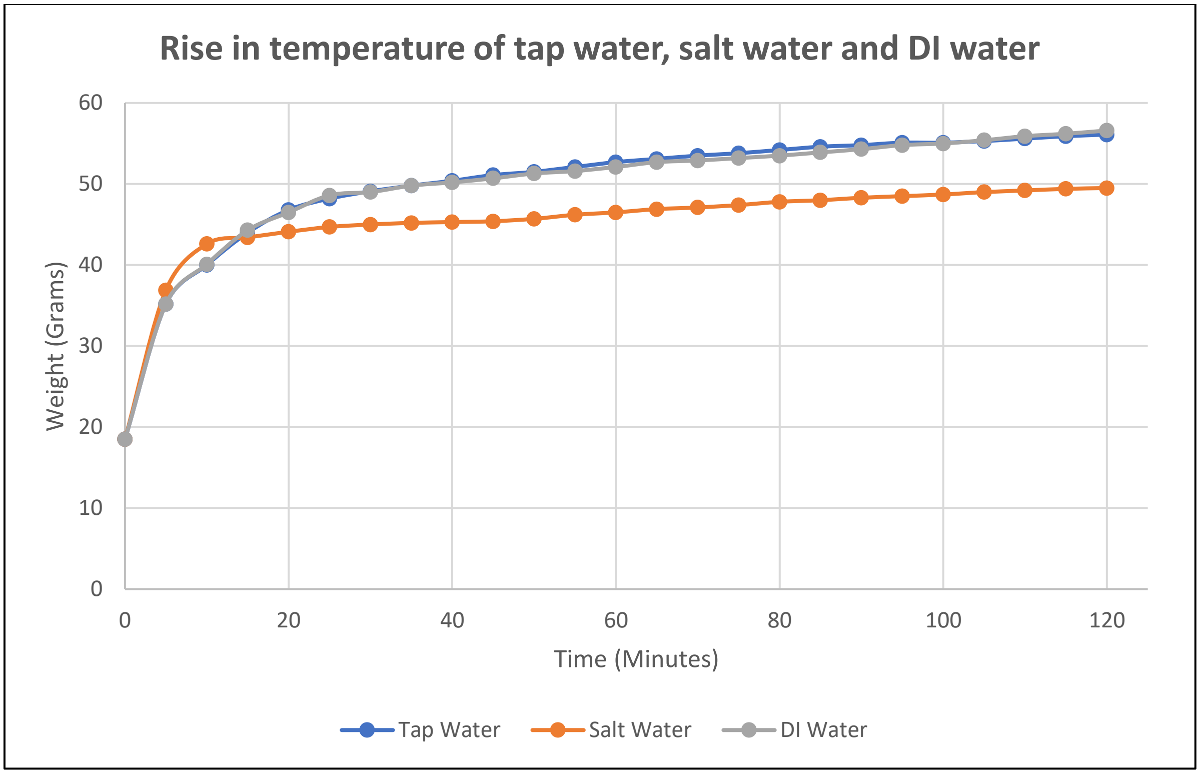


Figure 48. Rise in temperature of tap water, salt water and DI water

4.2.2. Evaporation Test for Carbon Black Nanoparticles with 0.05%, 0.1%, 0.5% Concentration Using Tap Water, Salt Water, and Deionized Water.

Tap Water

The concentration of nanoparticles in water played a significant role in the evaporation of water. The experiment of evaporation was carried out with three different concentrations carbon black nanoparticles, 0.05%, 0.1% and 0.5%, to determine if the concentration of nanoparticles varies the rate of evaporation. The different concentrations showed a different rate of evaporation. Figure 49 illustrates the rate of evaporation of tap water and Figure 50, shows how the temperature of tap water rises for various concentrations of carbon black nanoparticles.

The first experiment, the water containing 0.05% of carbon black nanoparticles gave the evaporation of 39.81g over the period of 1 hour and changing the temperature of water from 18.8^{0}C to 52.7^{0}C.

In the second experiment, the water containing 0.1% of carbon black nanoparticles showed a better result in evaporation of water by evaporating the 42.34g of water over the period of 1 hours and changing the temperature of water from 18.5^{0}C to 55.9^{0}C.

In the third experiment, the water containing 0.5% of carbon black nanoparticles showed the evaporation of 40.91g by changing the temperature of water from 18.5^{0}C to 54.2^{0}C over the period of 1 hour.

From all the above three experiments, we can see that the water with 0.1% of carbon black nanoparticles gave better evaporation rate as compared to the water containing the concentration of 0.05% and 0.5%. As the 0.1% of carbon black in water showed the optimal results in evaporation of water, the further all experiments were done with the 0.1% of carbon black nanoparticles.

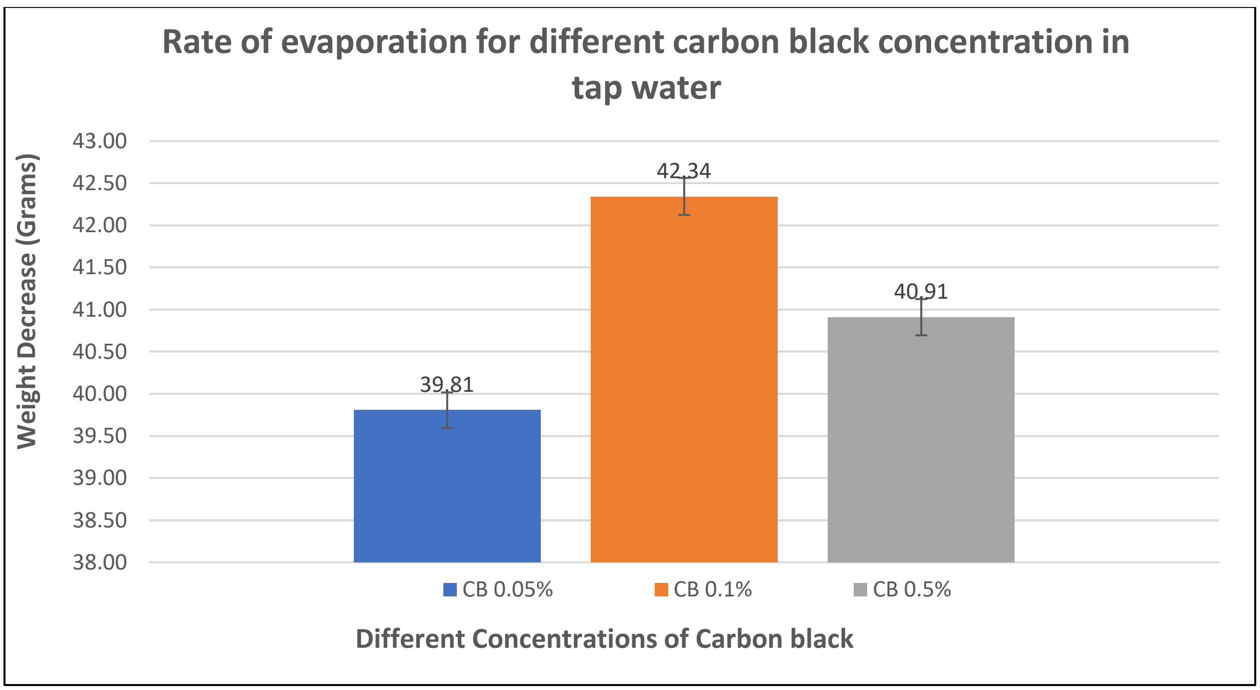


Figure 49. Rate of evaporation comparison for water with different concentrations of carbon black

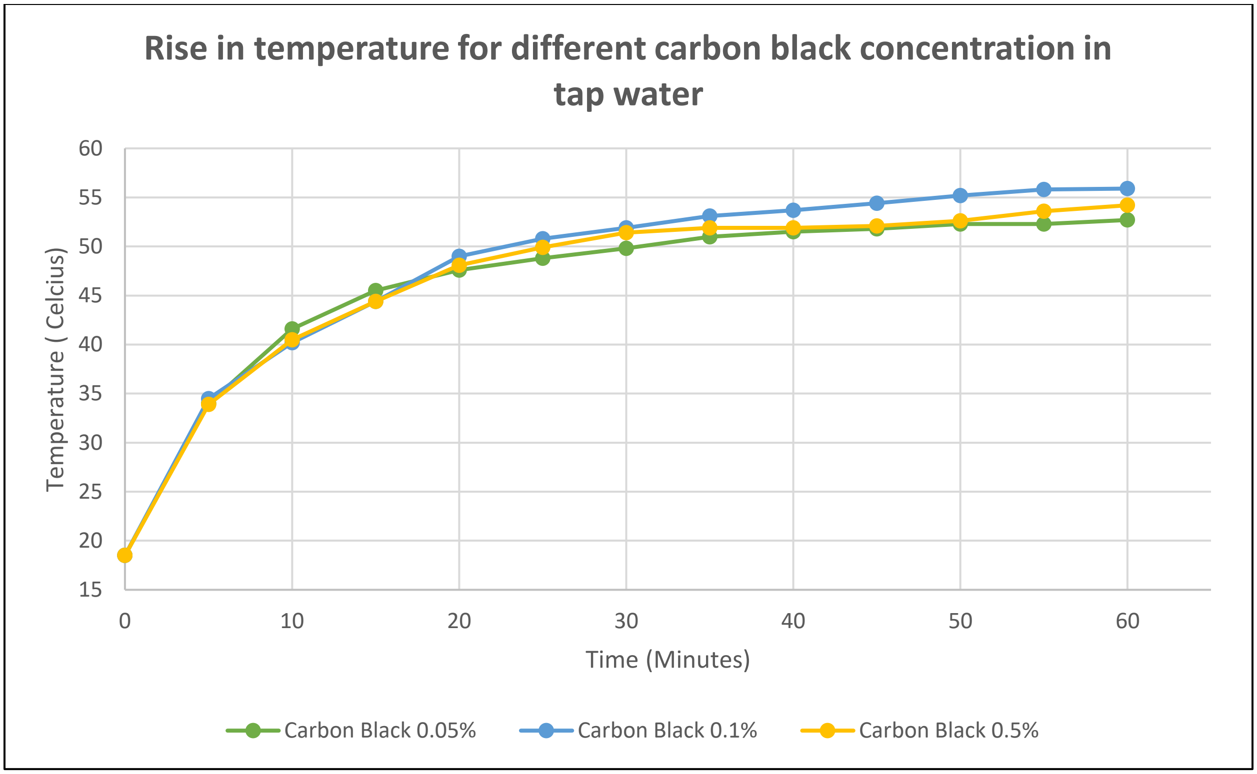


Figure 50. Rise in temperature comparison for water with various concentrations of carbon black

- **Salt Water**

Salt water showed the similar results to that of water with slightly less evaporation due to the presence of salts in water. The experimentation was carried out with three different concentrations carbon black nanoparticles, 0.05%, 0.1% and 0.5%, the different concentrations showed a different rate of evaporation with salt water. The figure 51, illustrates the rate of evaporation of water and figure 52, shows how the temperature of water rises for various concentration of carbon black nanoparticles.

The first experiment with salt water containing 0.05% of carbon black nanoparticles gave the evaporation of 38.18g over the period of 1 hour and changing the temperature of water from 18.8^{0}C to 53.9^{0}C.

In the second experiment, the salt water containing 0.1% of carbon black nanoparticles showed a better result in evaporation of water by evaporating the 40.97g of water over the period of 1 hours and changing the temperature of water from 18.5^{0}C to 58^{0}C.

In the third experiment, the water containing 0.5% of carbon black nanoparticles showed the evaporation of 38.94g by changing the temperature of water from 18.5^{0}C to 55.9^{0}C over the period of 1 hour.

From the above three tests, we can see that the water with 0.1% of carbon black nanoparticles gave better evaporation rate as compared to the salt water containing the concentration of 0.05% and 0.5%. As the 0.1% of carbon black in water showed the optimal results in evaporation of salt water, the further experiments with the salt water were done with the 0.1% of carbon black nanoparticles.

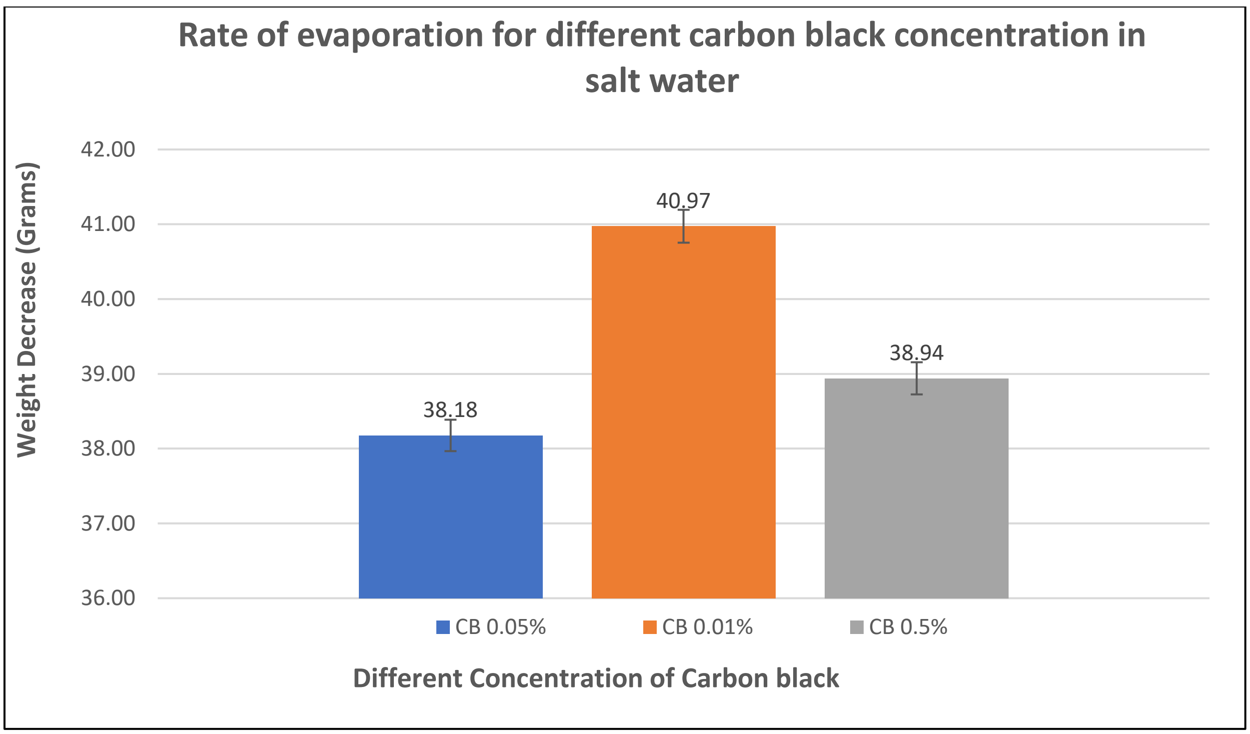


Figure 51. Rate of evaporation comparison for salt water with different concentration of carbon black

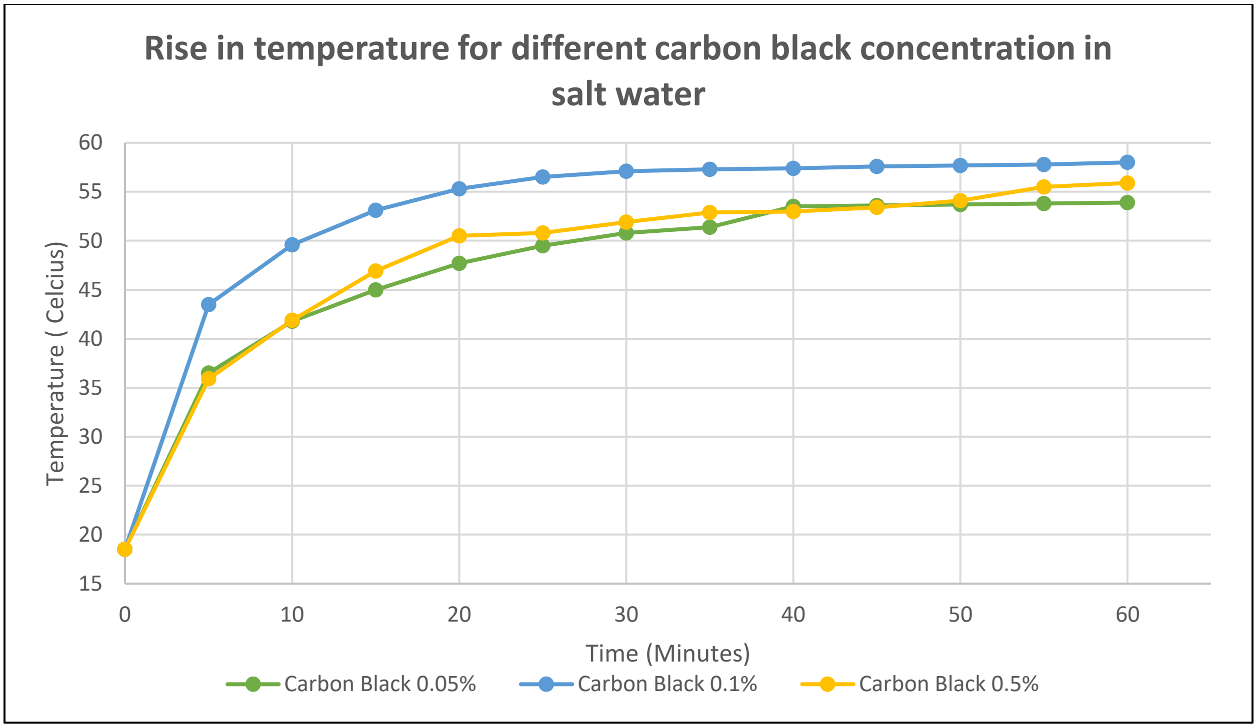


Figure 52. Rise in temperature comparison for salt water with various concentration of carbon black

- **Deionized Water**

The DI water also showed the similar results to that of water and salt water. The experiment was carried out with three different concentrations of carbon black nanoparticles, 0.05%, 0.1% and 0.5%; the different concentrations showed a different rate of evaporation of DI water. The figure 53, indicates the rate of evaporation of water and figure 54, shows how the temperature of water rises for various concentrations of carbon black nanoparticles.

The first experiment with the DI water containing 0.05% of carbon black nanoparticles gave the evaporation of 40.24g over the period of 1 hour and changing the temperature of water from 18.8^{0}C to 52.5^{0}C.

In the second experiment, the DI water containing 0.1% of carbon black nanoparticles showed a better result in evaporation of DI water by evaporating the 42.10g of water over the period of 1 hours and changing the temperature of water from 18.5^{0}C to 53.9^{0}C.

In the third experiment, the DI water containing 0.5% of carbon black nanoparticles showed the evaporation of 41.51g by changing the temperature of water from 18.5^{0}C to 53.3^{0}C over the period of 1 hour.

From all the above three experiments, we can see that the water with 0.1% of carbon black nanoparticles gave better evaporation rate as compared to the DI water containing the concentration of 0.05% and 0.5%. As the 0.1% of carbon black in DI water showed the optimal results in evaporation of DI water, the further all experiments with DI were done with the 0.1% of carbon black nanoparticles.

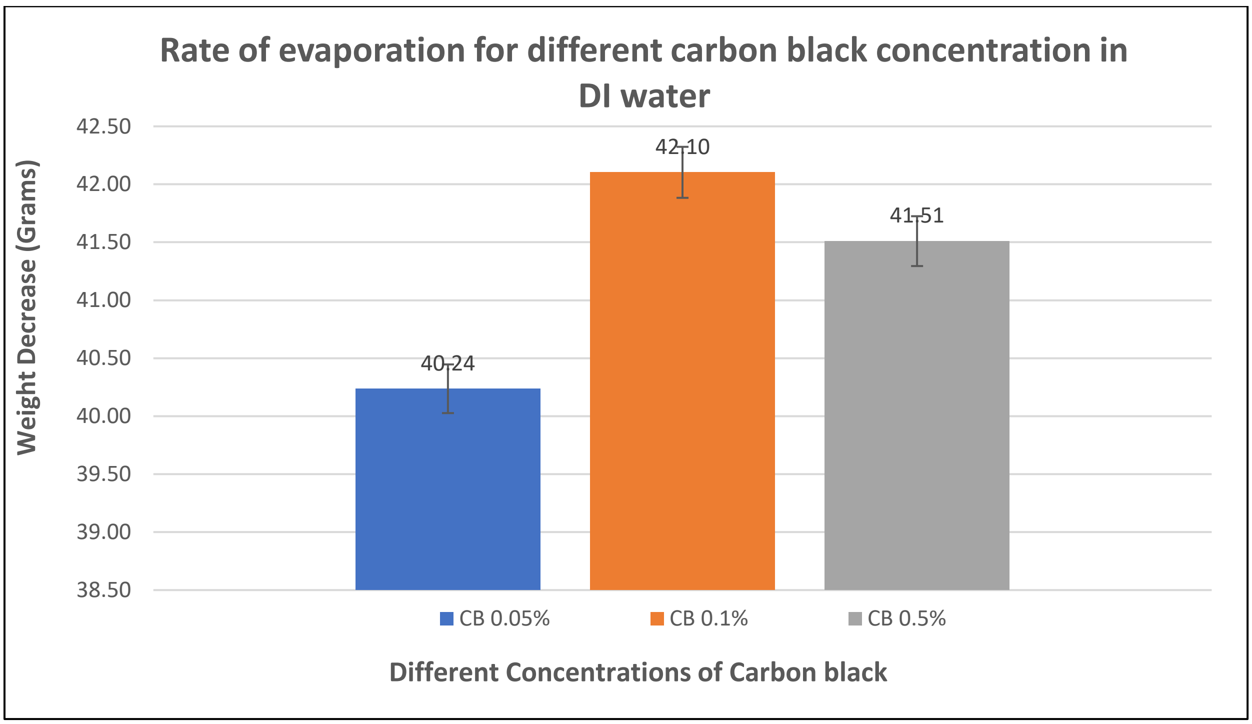


Figure 53. Rate of evaporation comparison for DI water with different concentration of carbon black

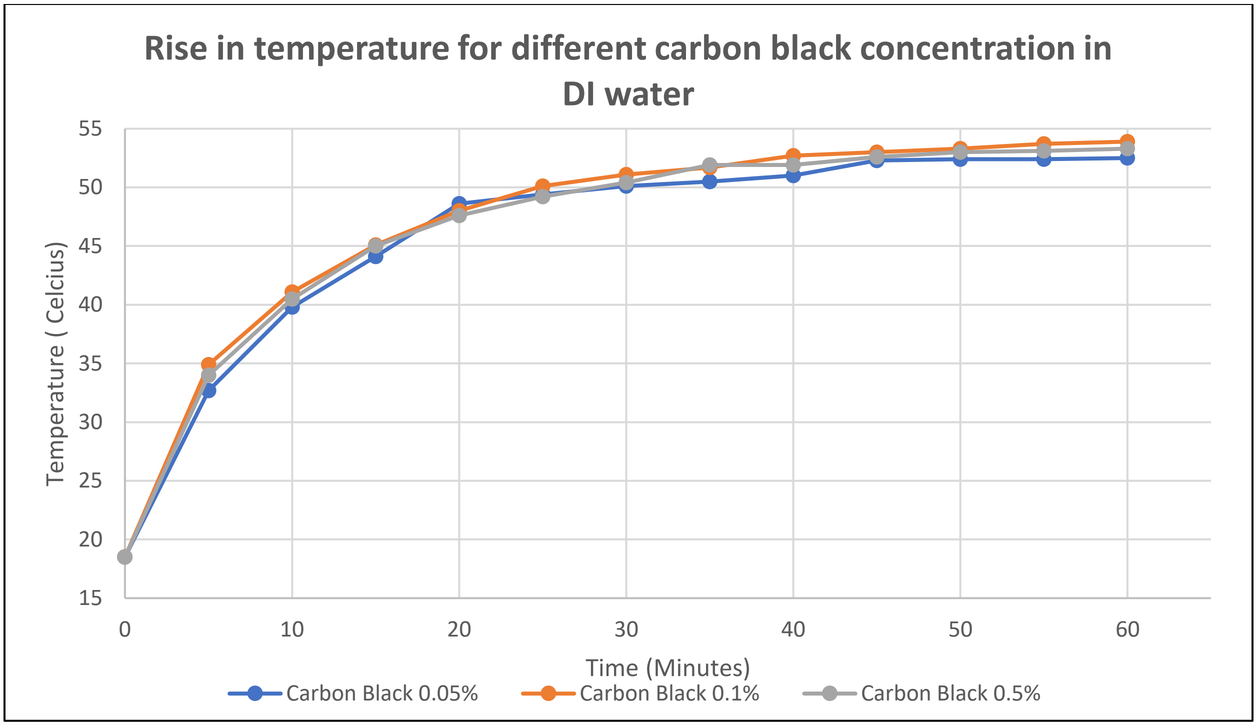


Figure 54. Rise in temperature comparison for DI water with various concentration of carbon black

4.2.3. Evaporation Test for Graphene Nanoparticles with 0.05%, 0.1%, 0.5% Concentration Using Tap Water, Salt Water, and Deionized Water.

The concentration of graphene nanoparticle didn't show much difference in the rate of evaporation as compared to the carbon black nanoparticle. Similar like carbon black three experiments were conducted with different concentration, 0.05%, 0.1% and 0.5% with regular tap water, salt water, and DI water.

- **Water**

Figure 55, show the different concentration of graphene nanoparticles with tap water as the nanofluid and figure 56, shows temperature rise of the tap water for different concentrations of graphene nanoparticles. The water along with the graphene of concentration 0.05% showed the evaporation of 38.62g with the rise in temperature from 18.5^0C to 53.1^0C for the duration of 1 hour. In the second experiment, the water with graphene concentration of 0.1% showed the evaporation of 39.16g and the temperature rise from 18.5^{0}C to 53.3^{0}C for the duration of 1 hour. In the third experiment, the water with graphene concentration of 0.05% showed the evaporation of 38.93g with the temperature rises from 18.5^{0}C to 53.5^{0}C for the duration of 1 hour.

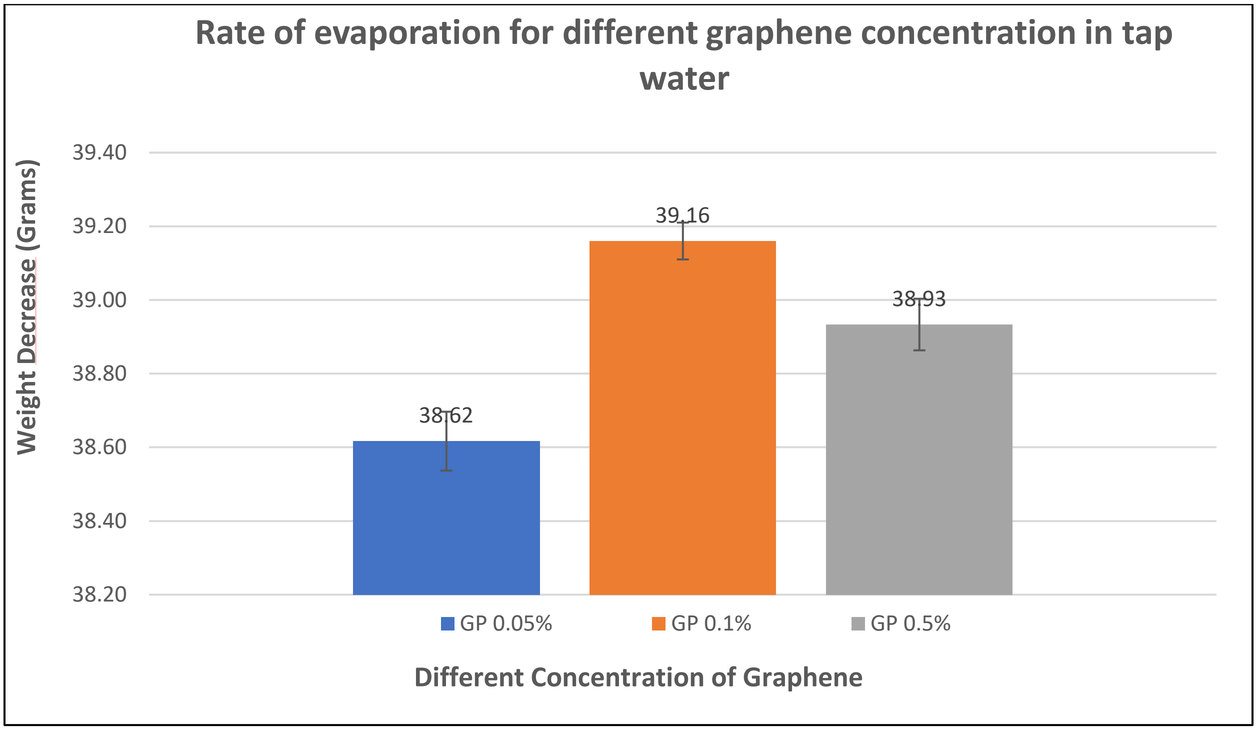


Figure 55. Rate of evaporation comparison for water with different concentration of graphene

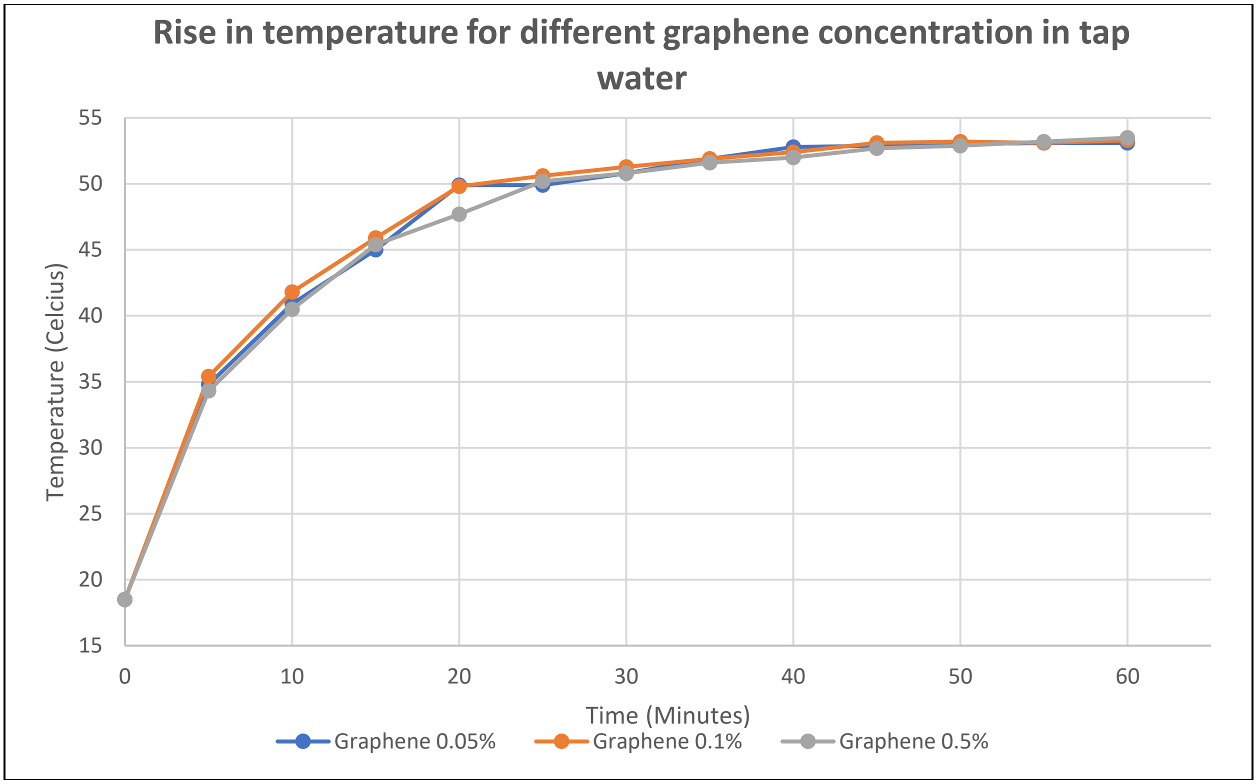


Figure 56. Rise in temperature comparison for water with various concentration of graphene

- **Salt Water**

Figure 57, show the different concentration of graphene nanoparticles with salt water as the nanofluid and figure 58, shows temperature rise of the salt water for different concentrations of graphene nanoparticles. The first experiment of salt water with the graphene concentration of 0.05% showed the evaporation of 37.23 with the temperature rises from 18.5^{0}C to 53.1^{0}C for the period of 1 hour. The second experiment with the graphene concentration of 0.1% gave the total evaporation of 38.87g with the temperature rise from 18.5^{0}C to 53.4^{0}C for the duration of 1 hour. In the third experiment, with the graphene concentration of 0.5% given the evaporation of 38.16g with the rise in temperature from 18.5^{0}C to 54.5^{0}C for the duration of 1 hour. Among all the three experiments conducted for salt water with different concentrations, the one with 0.1% gave the maximum evaporation rate.

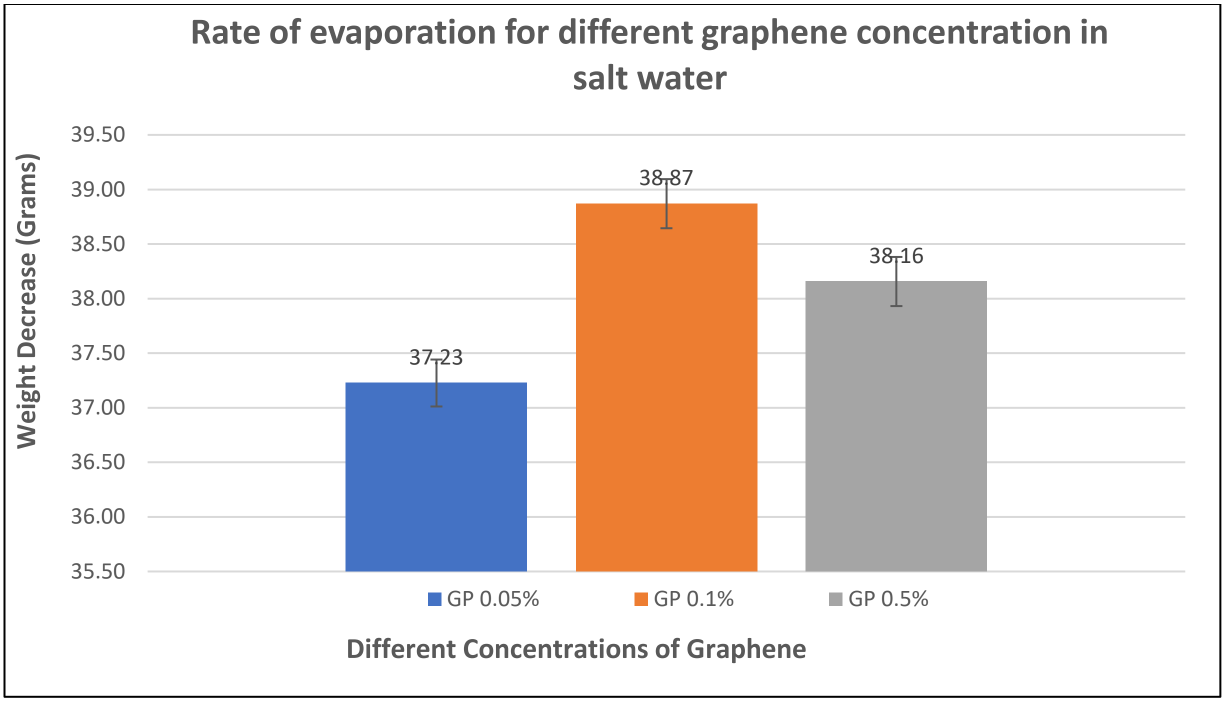


Figure 57. Rate of evaporation comparison for salt water with various concentrations of graphene

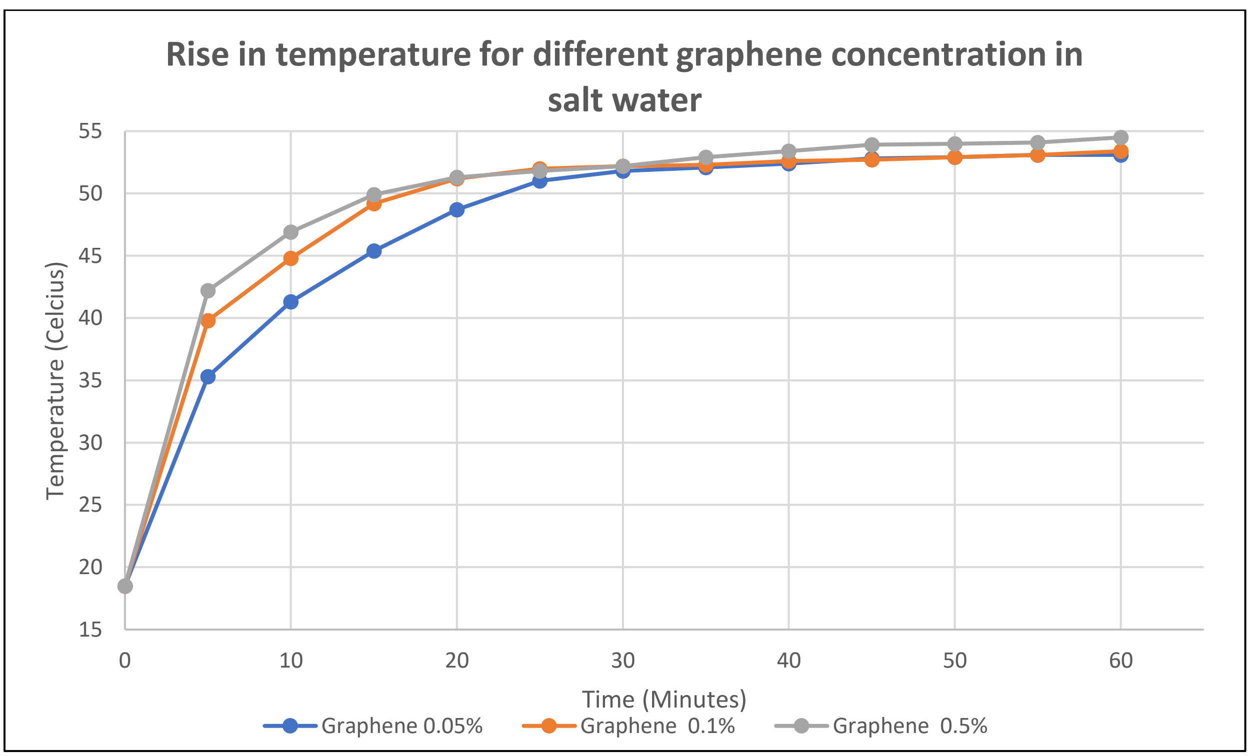


Figure 58. Rise in temperature comparison for salt water with various concentration of graphene

- **Deionized Water**

Figure 59, show the different concentration of graphene nanoparticles with DI water as the nanofluid and figure 60, shows temperature rise of the DI water for different concentrations of graphene nanoparticles. In the first experiment, the DI water with 0.05% of graphene concentration showed the evaporation of 41.40g with the rise in temperature from 18.5^{0}C to 51.7^{0}C over the period of 1 hour. In the second experiment, the DI water with 0.1% concentration of graphene gave the evaporation of 42.46g with the temperature rise from 18.5^{0}C to 53.2^{0}C over the period of 1 hour. In the third experiment, DI water with the graphene concentration of 0.5% showed the evaporation of 41.98g with a temperature rises from 18.5^{0}C to 53^{0}C over the period of 1 hour.

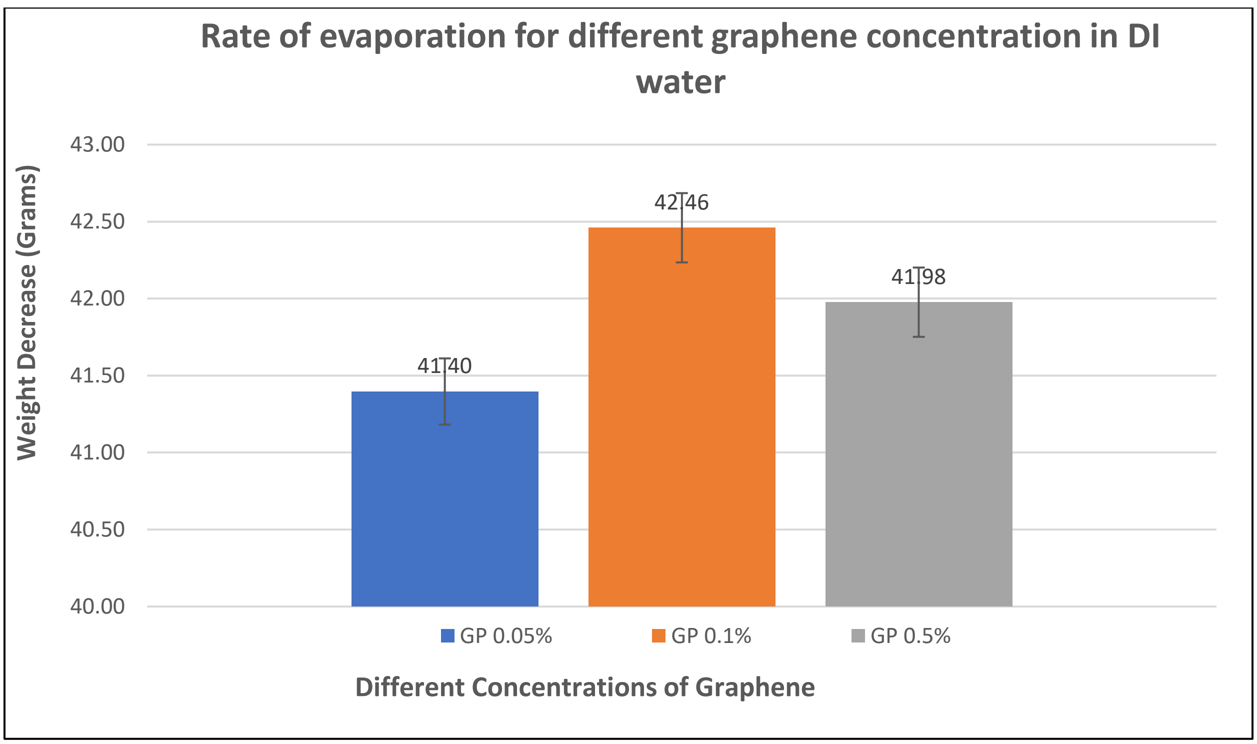


Figure 59. Rate of evaporation comparison for DI water with different concentration of graphene

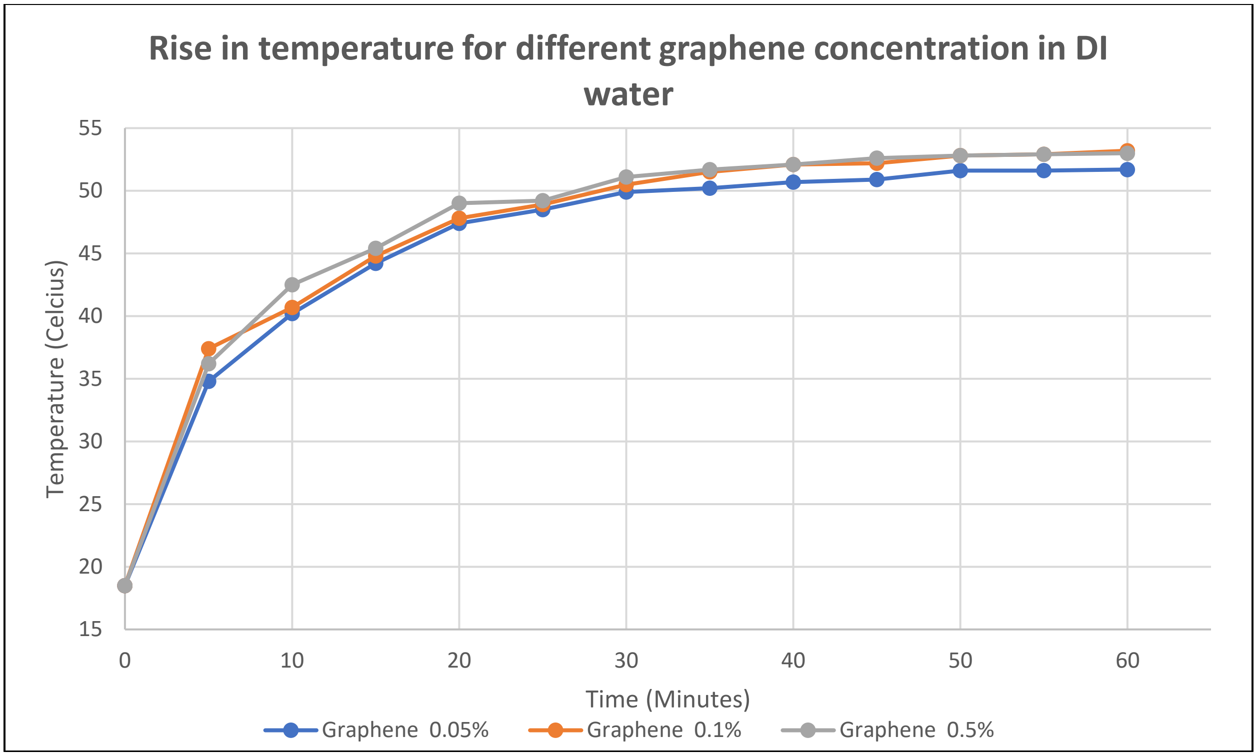


Figure 60. Rise in temperature comparison for DI water with various concentration of graphene

From all the above experiments with the various concentration of graphene in tap water, salt water, and DI water, we can clearly see that the graphene concentration of 0.1% gave a better rate of evaporation as compared to the 0.05% and 0.5%. This shows how the concentration of nanoparticles plays a significant role in the evaporation process. The rate of evaporation and temperature rise with graphene nanoparticles is less when compared to the carbon black nanoparticles.

4.2.4. Evaporation Test for Nanoparticles with 0.1% Concentration with Tap Water, Salt Water and DI Water in Presence and Absence of Black Base

4.2.4.1. Tap water

The figure 61, shows the comparison of various evaporation test done with tap water and the figure 62, shows the change in temperature with respect to different nanoparticles and black rubber base. All the evaporation test was carried out in a beaker of constant diameter of 19cm which had the area of 283.565cm^2.

- **Tap Water**

The evaporation test of regular tap water showed the total evaporation of 10.99g for 2 hours of test where the weight decreased from 250g to 239.01g over the period of 2 hours. We can also see the increase in the temperature of water from 18.5^{0}C to 20.7^{0}C. This test was conducted without any heat and light source.

- **Tap Water + IR Light**

This evaporation of test was done in the presence of infrared heat lamp. This test showed the total evaporation of 77.71g, where the weight decreased from 250g to 172g over the period of 2 hours. This test indicates the increase in the temperature from 18.5^{0}C to 56.1^{0}C.

- **Tap Water + Carbon black + IR Light**

The evaporation test of nanofluid with carbon black as the nanoparticle and water as nanofluid showed the significant change in the evaporation of water. This test had the total evaporation of 95.06g with the difference of 17.35g with respect to the evaporation of water with light. The test showed the decrease in the weight from 250g to 154.94g and the temperature increase from 18.5^{0}C to 60.2^{0}C over the period of 2 hours. This test showed the evaporation of 6.11mg/h.cm^2 and percentage increase of 11.19% with respect to water evaporation with light.

- **Tap Water + Graphene + IR Light**

The evaporation test of nanofluid with graphene as the nanoparticle and water as the nanofluid showed the less evaporation than the nanofluid with carbon black. This test with graphene has the total evaporation of 93.17g with the difference of 15.46g with respect to the evaporation of water with light. This test showed the increase in the temperature from 18.5^{0}C to

57.9^{0}C over the period of 2 hours. This test showed the evaporation of 5.45mg/h.cm^2 and the percentage increase of 9.85% with respect to evaporation of water with light.

- **Tap Water + Rubber Black Base + IR Light**

This test was conducted without any nanoparticles, but only with water and rubber black base. This test showed the evaporation of water of about 93.94g with the difference of 16.23 with respect to evaporation of water with light, which is almost similar to the water-graphene combination This evaporation test showed the temperature change from18.5^{0}C to 66.1^{0}C over the period of 2 hours showing the evaporation of 5.72mg/h.cm^2 and the percentage increase of 10.38% with respect to evaporation of water with light.

- **Tap Water + Rubber Black Base + Carbon black + IR Light**

This test showed the significant change in the evaporation of water which included the combination of Rubber black base and carbon black nanoparticle. It showed the evaporation of water of about 103.97g with the difference of 26.26g with respect to evaporation of water with light. This setup showed the temperature change from 18.5^{0}C to 68.1^{0}C over the period 2 hours. This test showed the evaporation of 9.26mg/h.cm^2 and the percentage increase of 17.98% with respect to evaporation of water with light.

- **Tap Water + Rubber Black Base + Graphene + IR Light**

This combination of black rubber base and graphene showed a bit less evaporation rate as compared to the as compared to the rubber black base and carbon black combination. It showed the total evaporation of 99.46g with the difference of 21.75g with respect to evaporation of water with light. This combination showed the temperature change from 18.5^{0}C to 66.3^{0}C over the period of 2 hours. This test showed the evaporation of 7.67mg/h.cm^2 and the percentage increase of 14.44% with respect to evaporation of water with light.

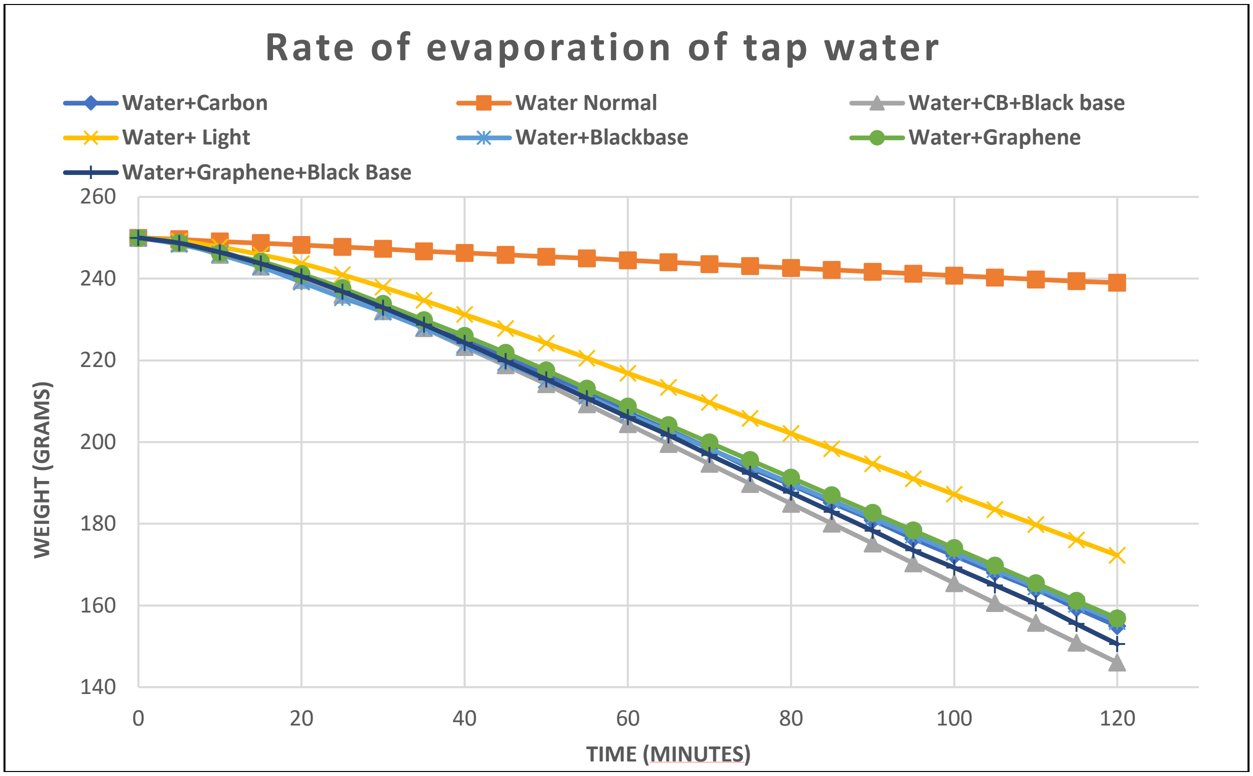


Figure 61. Comparison of rate of evaporation of water with and without carbon black, graphene nanoparticles, and rubber black base

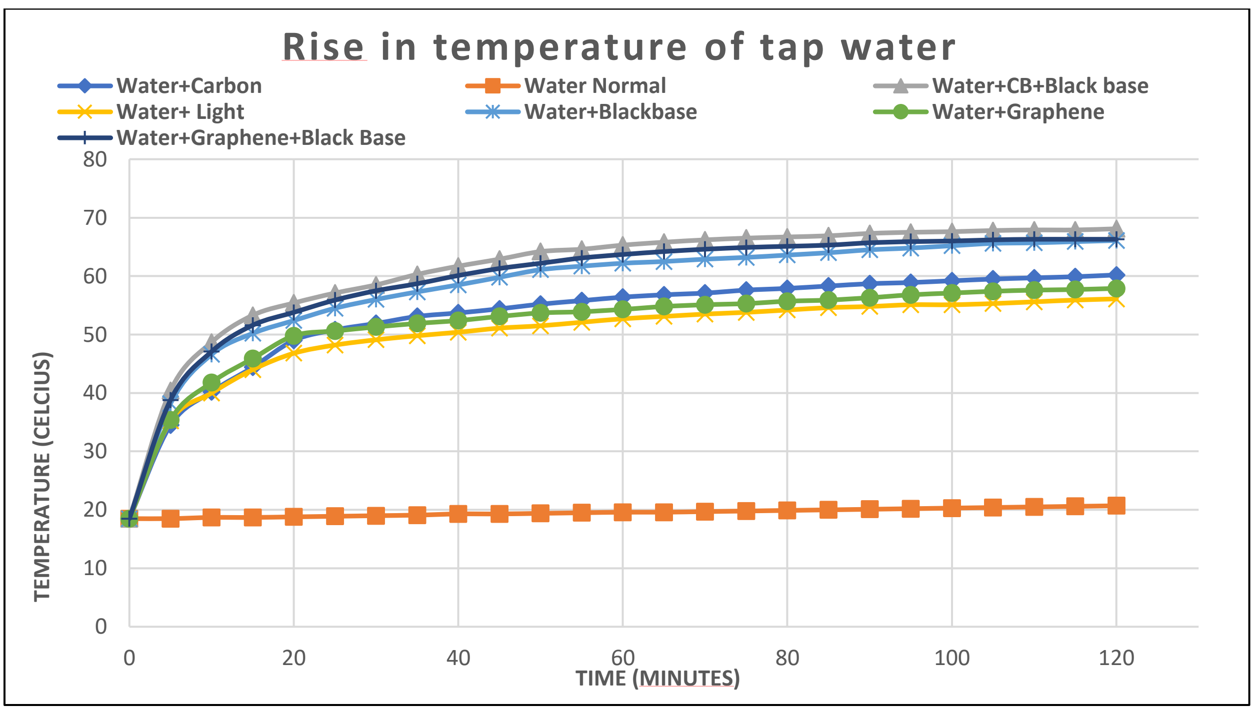


Figure 62. Comparison of rising in temperature of water with and without carbon black, graphene nanoparticles, and rubber black base

From the figure 63, we can clearly see that the regular tap water with carbon black nanoparticle gave the maximum amount of evaporation rate with 11.02% with respect to just normal tap water with IR light among all the compared nanoparticles. On the other hand, the combination of the black rubber base along with carbon black nanoparticles gave the maximum amount of evaporation rate with 17.98% with respect to just regular tap water with IR light.

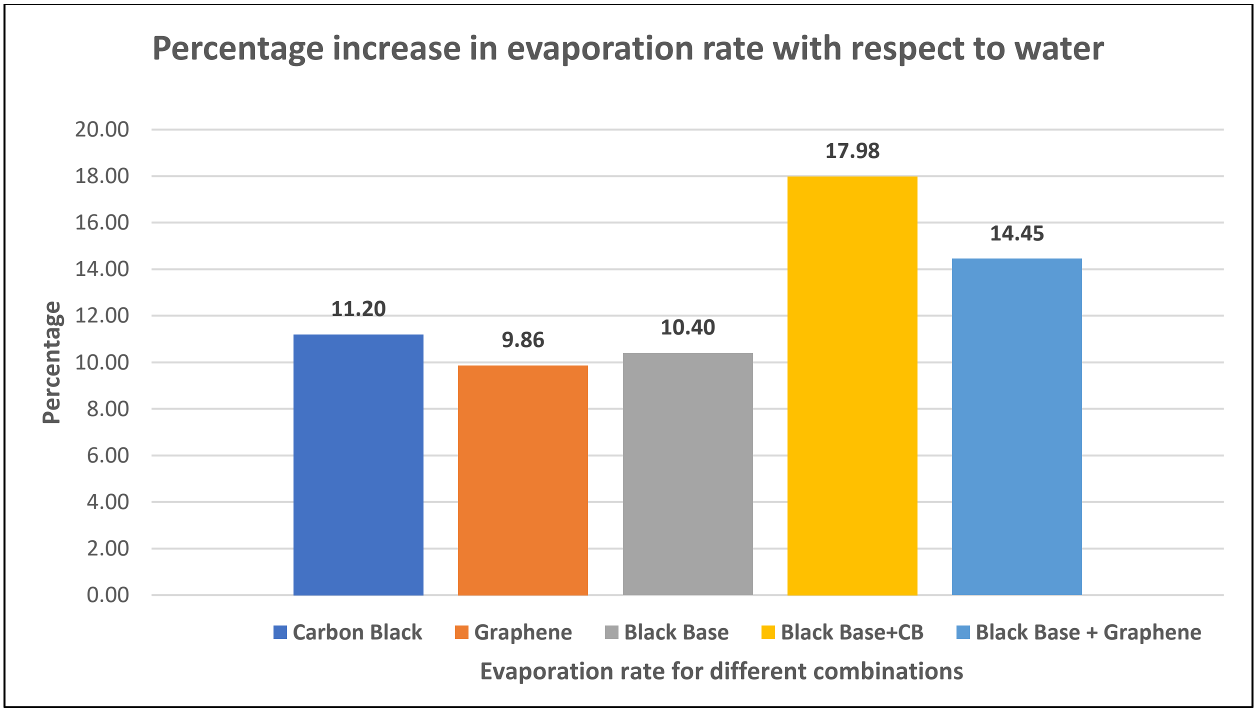


Figure 63. Comparison of percentage increase in evaporation rate with respect to water

4.2.4.2. Salt Water

The figure 64, shows the comparison of various evaporation test done with salt water and figure 65, shows the change in temperature with respect to different nanoparticles and black rubber base. All the evaporation test was carried out in a beaker of constant diameter of 19cm which had the area of 283.565cm^2.

The rate of evaporation seen with the salt water is considerably less than the regular tap water and DI water due to the presence of the salt which holds the molecules of the salt water together, due to which rate of evaporation of salt water decreases. The below discussion shows how the salt water reacts with different nanoparticles, black rubber base and both together.

- **Salt Water**

The evaporation test for salt water showed the total evaporation of 6.35g, where the weight decreased from 250g to 243.65 over the period of 2 hours. We can also see the increase in the temperature of water from 18.5^0C to 19.9^0C. This test was conducted without any heat and light source by placing the beaker of water at the room temperature of 22^0C.

- **Salt Water + IR Light**

This evaporation of test was conducted in the presence of infrared heat lamp. This test showed the total evaporation of 72.38g, where the weight decreased from 250g to 177.62g over the period of 2 hours. This test indicates the increase in the temperature from 18.5^0C to 49.5^0C.

- **Salt Water + Carbon black + IR Light**

The evaporation test of nanofluid with carbon black as the nanoparticle and salt water as nanofluid showed some real change in the evaporation of water. This test had the total evaporation of 94.49g with the difference of 22.11g with respect to the evaporation of salt water with light. The test showed the decrease in the weight from 250g to 155.51g and the temperature increase from 18.5^0C to 59.7^0C over the period of 2 hours. This test showed the evaporation of 7.79mg/h.cm^2 and percentage increase of 14.21% with respect to salt water evaporation with light.

- **Salt Water + Graphene + IR Light**

The evaporation test of nanofluid with graphene as the nanoparticle and salt water as the nanofluid showed the less evaporation than the nanofluid with carbon black. This test with graphene has the total evaporation of 88.15g with the decrease in the weight from 250g to 161.85g and the difference of 15.77g with respect to the evaporation of salt water with light. This test showed the increase in the temperature from 18.5^0C to 54.7^0C over the period of 2 hours. This test showed the evaporation of 5.56mg/h.cm^2 and the percentage increase of 9.74% with respect to evaporation of salt water with light.

- **Salt Water + Rubber Black Base + IR Light**

This test was conducted without any nanoparticles, but only with salt water and black rubber base. This test showed the evaporation of salt water of about 92.79g with the decrease in the weight from 250g to 157.21 the difference of 20.41g with respect to evaporation of salt water with light, which is almost similar to the water-graphene combination This evaporation test showed the temperature change from18.5^0C to 65.9^0C over the period of 2 hours showing the evaporation of 7.19mg/h.cm^2 and the percentage increase of 12.98% with respect to evaporation of salt water with light.

- **Salt Water + Rubber Black Base + Carbon black + IR Light**

This test showed the significant change in the evaporation of salt water which included the combination of Rubber black base and carbon black nanoparticle. It showed the evaporation of salt water of about 100.46g with the decrease in the weight from 250g to 149.54g and the difference of 28.08g with respect to evaporation of salt water with light. This setup showed the temperature change from 18.5^0C to 67.7^0C over the period 2 hours. This test showed the evaporation of 9.90mg/h.cm^2 and the percentage increase of 18.77% with respect to evaporation of salt water with light.

- **Salt Water + Rubber Black Base + Graphene + IR Light**

This combination of black rubber base and graphene showed a bit less evaporation rate as compared to the as compared to the rubber black base and carbon black combination. It showed the total evaporation of 96.33g with the decrease in the weight from 250g to 153.67g and the difference of 23.95g with respect to evaporation of salt water with light. This combination showed the temperature change from 18.5^{0}C to 65.3^{0}C over the period of 2 hours. This test showed the evaporation of 8.44mg/h.cm^2 and the percentage increase of 15.58% with respect to evaporation of salt water with light.

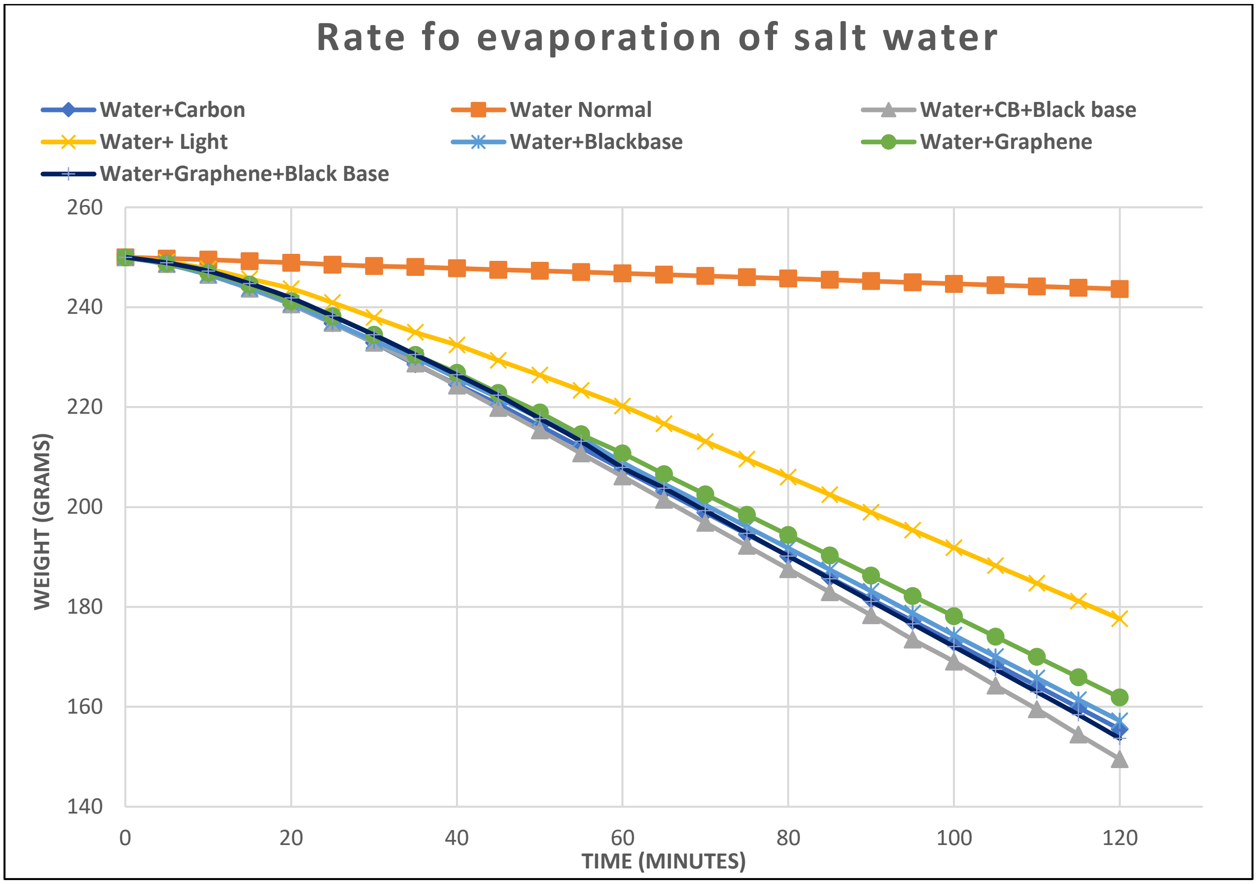


Figure 64. Comparison of rate of evaporation of salt water with and without carbon black, graphene nanoparticles, and rubber black base

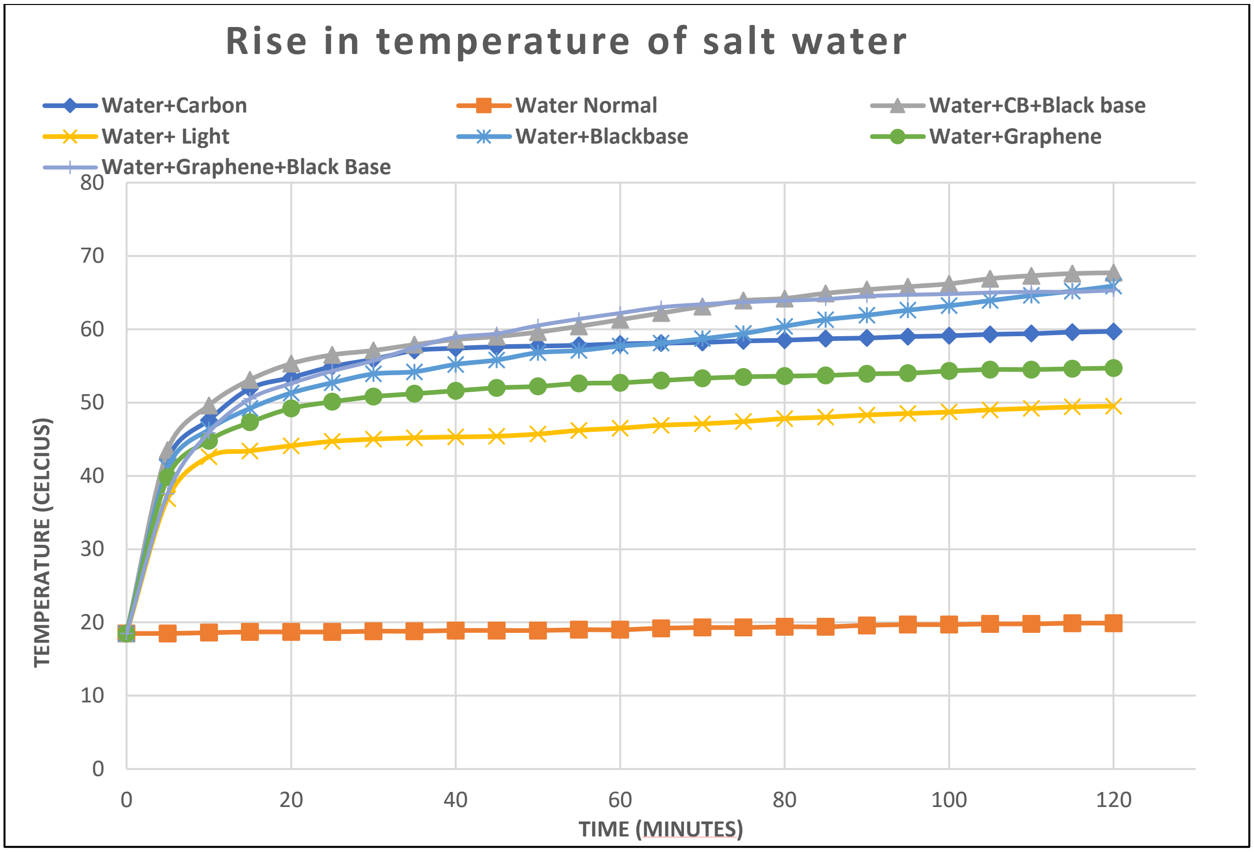


Figure 65. Comparison of rising in temperature of salt water with and without carbon black, graphene nanoparticles, and rubber black base

From the figure 66, we can see that the carbon black Nanoparticle gave the maximum amount of evaporation rate with 14.22% with respect to just Salt water with IR light among all the compared nanoparticles. On the other hand, the combination of the black rubber base along with carbon black nanoparticles gave the maximum amount of evaporation rate with 18.78% with respect to just Salt water with IR light.

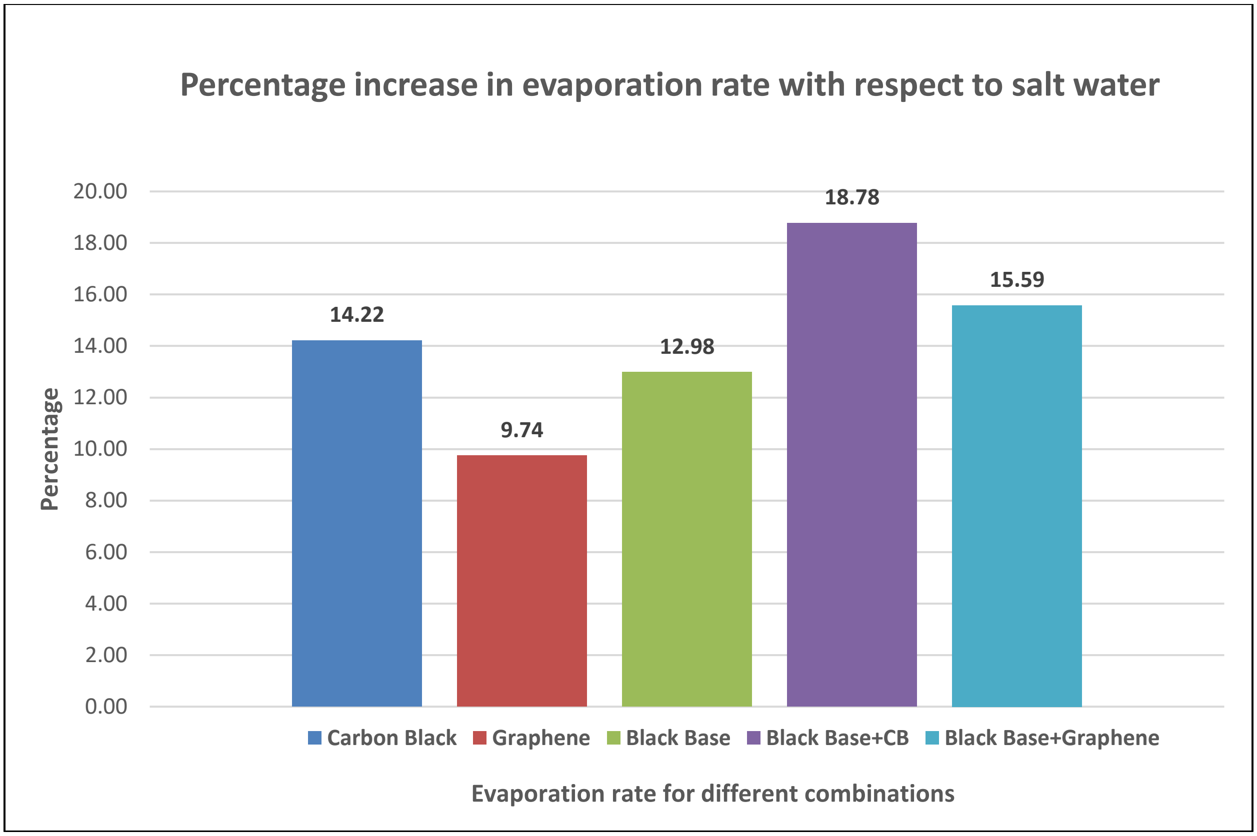


Figure 66. Comparison of percentage increase in evaporation rate with respect to salt water

4.2.4.3. Deionized Water

The figure 67, shows the comparison of various evaporation test done with DI water and figure 68, shows the change in temperature with respect to different nanoparticles and black rubber base. All the evaporation test was carried out in a beaker of constant diameter of 19cm which had the area of 283.565cm^2.

The rate of evaporation seen with the DI water is considerably more than the regular tap water and salt water due to the absence of the salt which due to which the molecules of the water are not tightly bonded to each other. The below discussion shows how the DI water reacts with different nanoparticles, black rubber base and both together.

- **Deionized Water**

The evaporation test of DI water showed the total evaporation of 11.51g for 2 hours of test where the weight decreased from 250g to 238.49g over the period of 2 hours. We can also see the increase in the temperature of water from 18.5^{0}C to 20.8^{0}C. This test was conducted without any heat and light source.

- **Deionized Water + IR Light**

This evaporation of test was done in the presence of infrared heat lamp. This test showed the total evaporation of 82.40g, where the weight decreased from 250g to 167.6g over the period of 2 hours. This test demonstrates the increase in the temperature from 18.5^{0}C to 56.6^{0}C.

- **Deionized Water + Carbon black + IR Light**

The evaporation test of nanofluid with carbon black as the nanoparticle and DI water as nanofluid showed some real change in the evaporation of water. This test had the total evaporation of 96.24g with the difference of 13.94g with respect to the evaporation of DI water with light. The test showed the decrease in the weight from 250g to 153.66g and the temperature increase from 18.5^{0}C to 58.8^{0}C over the period of 2 hours. This test showed the evaporation of 4.91mg/h.cm^2 and percentage increase of 9.07% with respect to DI water evaporation with light.

- **Deionized Water + Graphene + IR Light**

The evaporation test of nanofluid with graphene as the nanoparticle and DI water as the nanofluid showed the less evaporation than the nanofluid with carbon black. This test with graphene has the total evaporation of 91.52g with the decrease in the weight from 250g to 158.48g and the difference of 9.12g with respect to the evaporation of DI water with light. This test showed the increase in the temperature from 18.5^{0}C to 57.8^{0}C over the period of 2 hours. This test showed the evaporation of 3.21mg/h.cm^2 and the percentage increase of 5.75% with respect to evaporation of DI water with light.

- **Deionized Water + Rubber Black Base + IR Light**

This test was conducted without any nanoparticles, but only with DI water and black rubber base. This test showed the evaporation of DI water of about 94.05g with the decrease in the weight from 250g to 155.95g the difference of 11.65g with respect to evaporation of DI water with light, which is almost similar to the water-graphene combination This evaporation test showed the temperature change from 18.5^{0}C to 65.4^{0}C over the period of 2 hours showing the evaporation of 4.10mg/h.cm^2 and the percentage increase of 7.47% with respect to evaporation of DI water with light.

- **Deionized Water + Rubber Black Base + Carbon black + IR Light**

This test showed the significant change in the evaporation of DI water which included the combination of rubber black base and carbon black nanoparticle. It showed the evaporation of DI water of about 105.58g with the decrease in the weight from 250g to 144.42g and the difference of 23.18g with respect to evaporation of DI water with light. This setup showed the temperature change from 18.5^{0}C to 68^{0}C over the period 2 hours. This test showed the evaporation of 8.17mg/h.cm^2 and the percentage increase of 16.05% with respect to evaporation of DI water with light.

- **Deionized Water + Rubber Black Base + Graphene + IR Light**

This combination of black rubber base and graphene showed a bit less evaporation rate as compared to the as compared to the rubber black base and carbon black combination. It showed the total evaporation of 100.14g with the decrease in the weight from 250g to 149.86g and the difference of 17.74g with respect to evaporation of DI water with light. This combination showed the temperature change from 18.5^{0}C to 67.1^{0}C over the period of 2 hours. This test showed the evaporation of 6.25mg/h.cm^2 and the percentage increase of 11.83% with respect to evaporation of DI water with light.

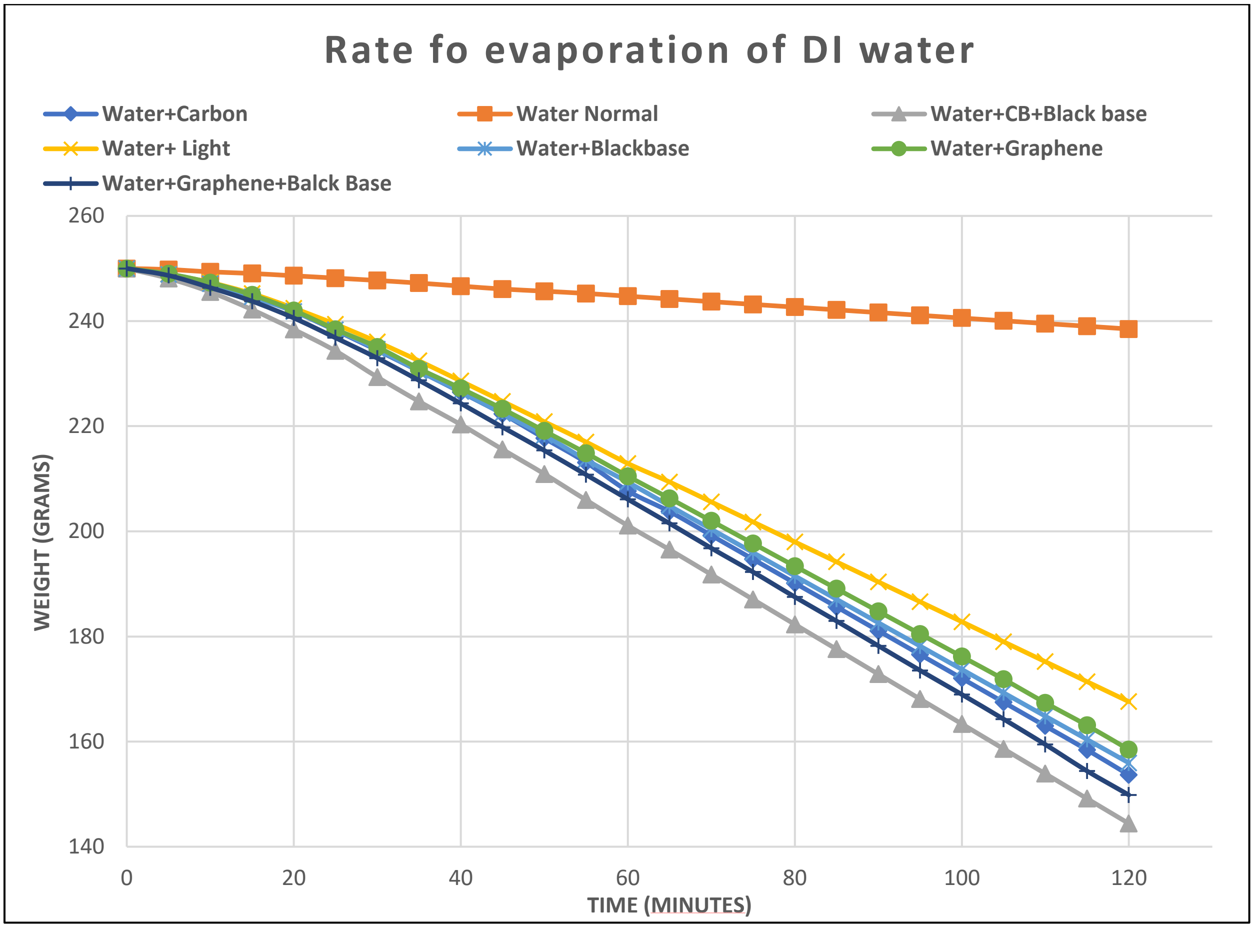


Figure 67. Comparison of rate of evaporation of di water with and without carbon black, graphene nanoparticles, and rubber black base

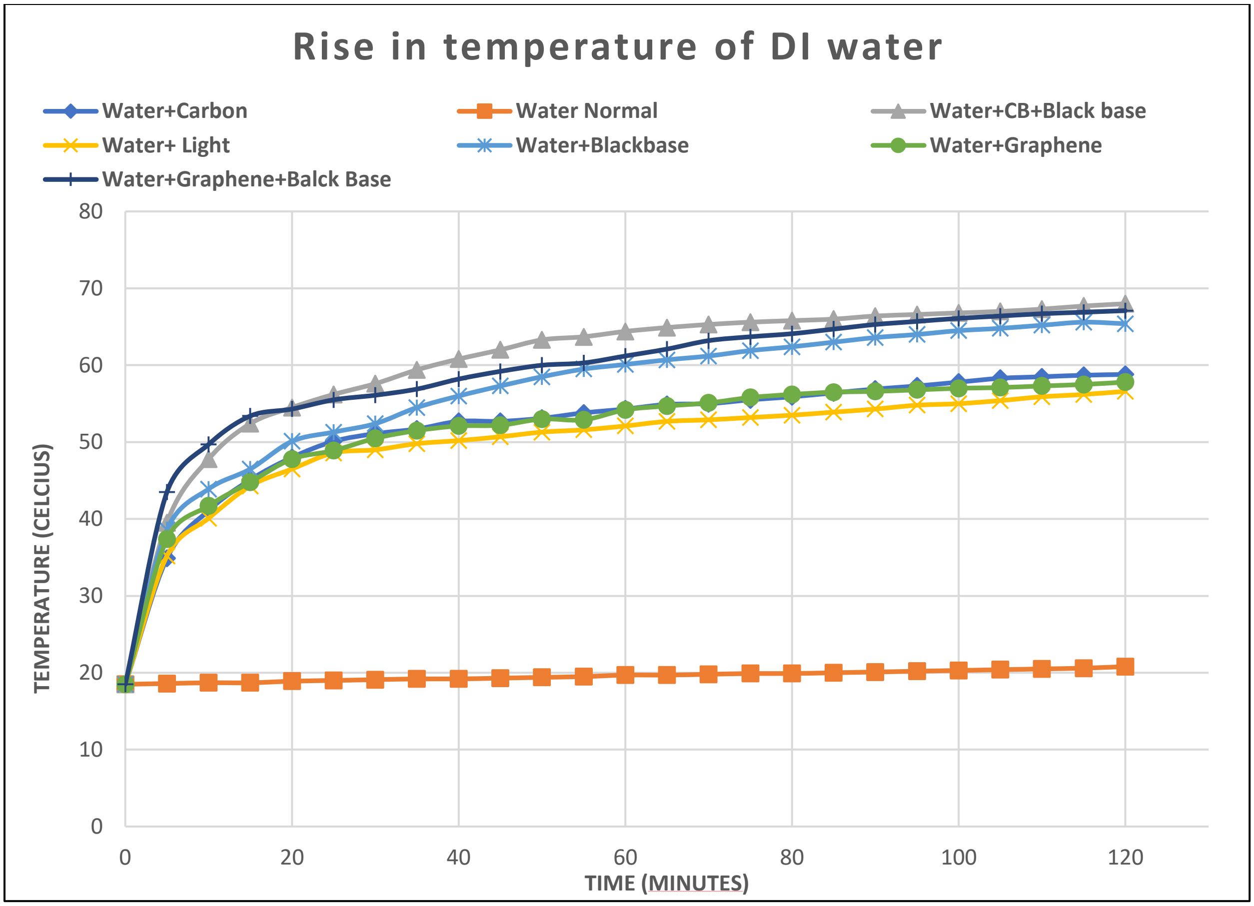


Figure 68. Comparison of rising in temperature of DI water with and without carbon black, graphene nanoparticles, and rubber black base

From the figure 69, we can clearly see that the DI water with carbon black Nanoparticle gave the maximum amount of evaporation rate with 9.07% with respect to just DI water with IR light among all the compared nanoparticles. On the other hand, the combination of the black rubber base along with carbon black nanoparticles gave the maximum amount of evaporation rate with 16.05% with respect to just DI water with IR light.

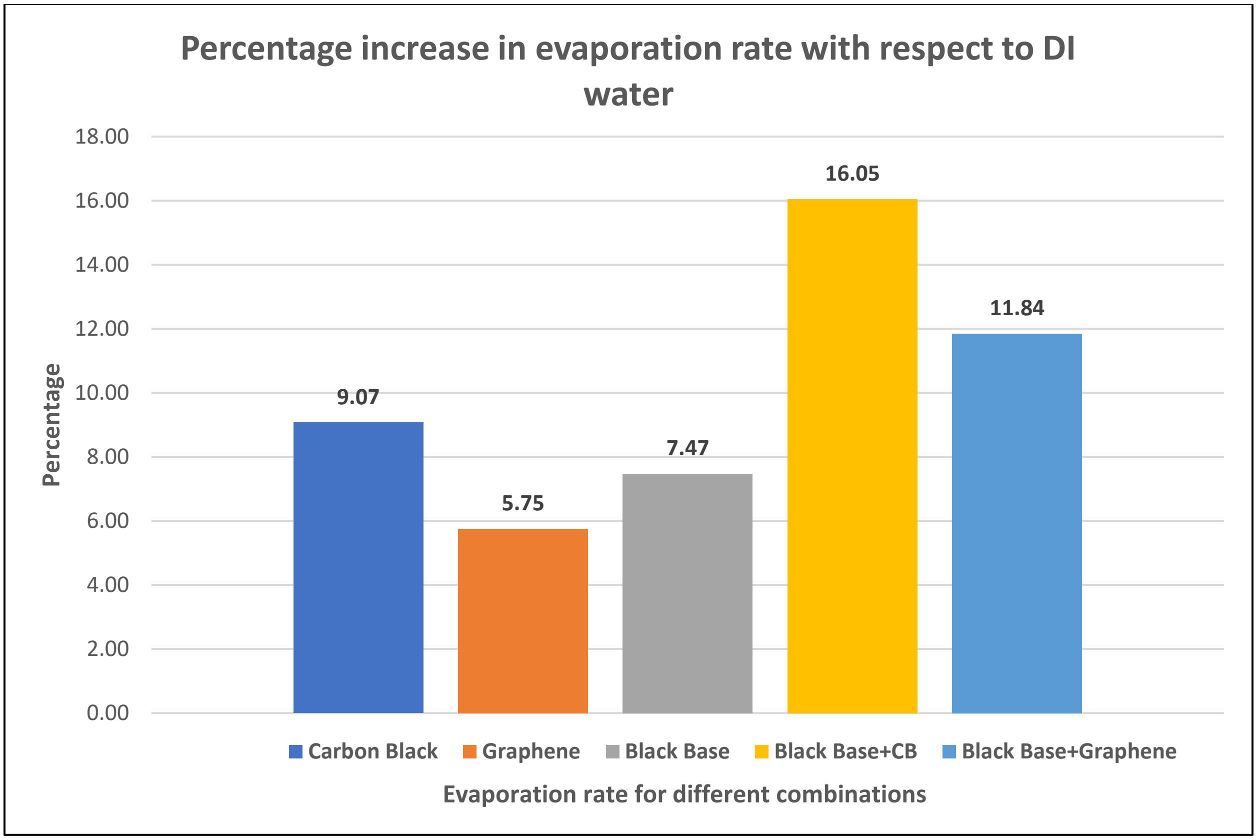


Figure 69. Comparison of percentage increase in evaporation rate with respect to DI water

From all the above experimental results, we can see that the carbon black with the black base gave the maximum amount of evaporation of the water along with the rise in temperature. It showed the same results for tap water, salt water, and DI water. The above experiments show how the different combinations of nanoparticles in water can alter the evaporation rate and temperature change. This is how we can enhance the rate of evaporation of water with the use of nanoparticles.

4.2.4.4. Statistical Analysis

The statistical analysis was done by comparing all the above experimental results using the Design of Experiments V7.0 Software with 2k factorial design method which gave the following statistical analysis results.

- **Model Graph for Percentage Evaporation of carbon black and graphene with Water**

According to the figure 70, which shows the Model Graph for the percentage evaporation of carbon black and graphene with water, in which the black line indicates the evaporation of water with and without carbon black and the red line indicates the evaporation of water with graphene and graphene plus carbon black. According to the model graph, the slope of the black line is more than the slope of the red line, which indicates that the addition of just carbon black to the water would enhance the evaporation of water more than adding carbon black and graphene together in water. This show that the carbon black nanoparticles are more effective in enhancing the evaporation rate of tap water than graphene.

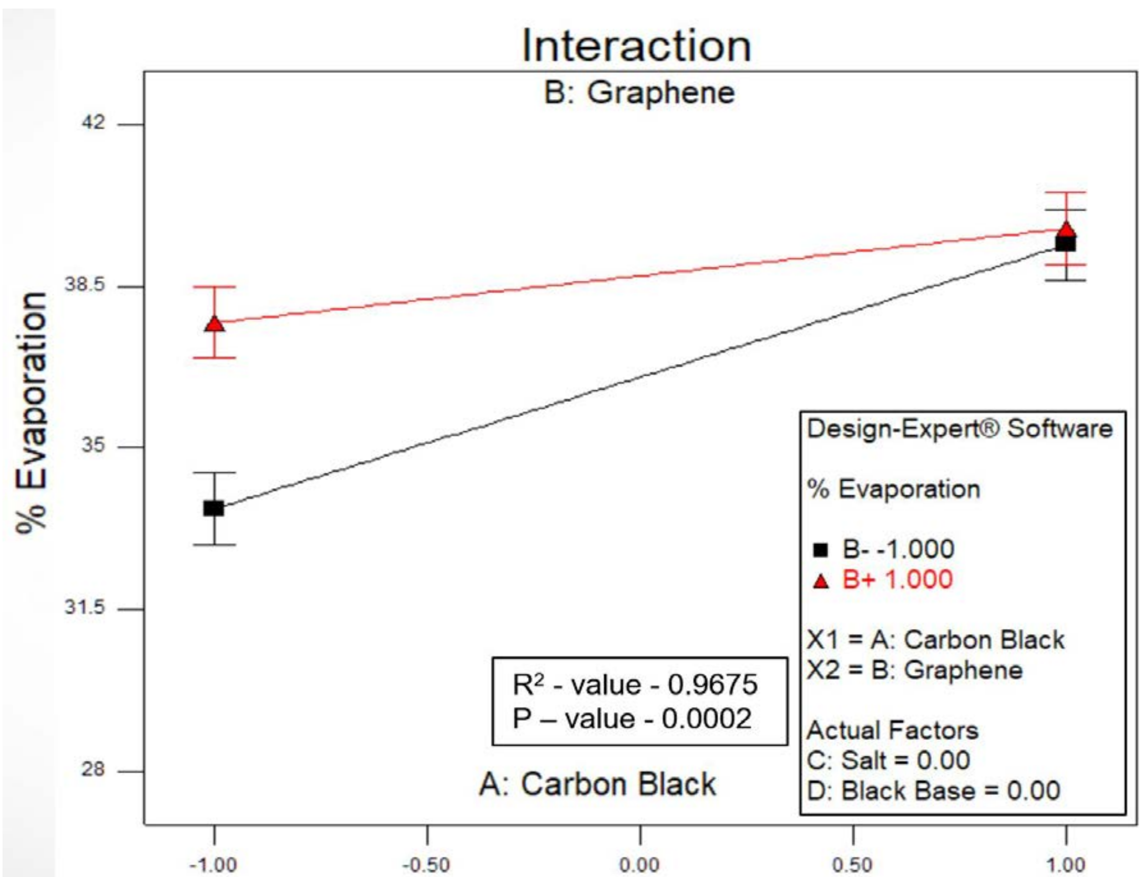


Figure 70. Model graph for the percentage evaporation of carbon black and graphene with water

- **Model Graph for the Percentage Evaporation of carbon black and Salt with Water**

According to figure 71, which shows the Model Graph for the Percentage Evaporation of carbon black and salt with water, in which the black line indicates the evaporation of water with and without carbon black and the red line indicates the evaporation of water with salt and salt plus carbon black. According to the model graph, the slope of red line is more than the slope of the black line which indicates that the addition of carbon black to the salt water would enhance the evaporation of salt water more than adding carbon black to the normal tap water, it also shows that the rate of evaporation decreases with addition of salt. This indicates that the carbon black nanoparticles are more effective in enhancing the evaporation rate of salt water.

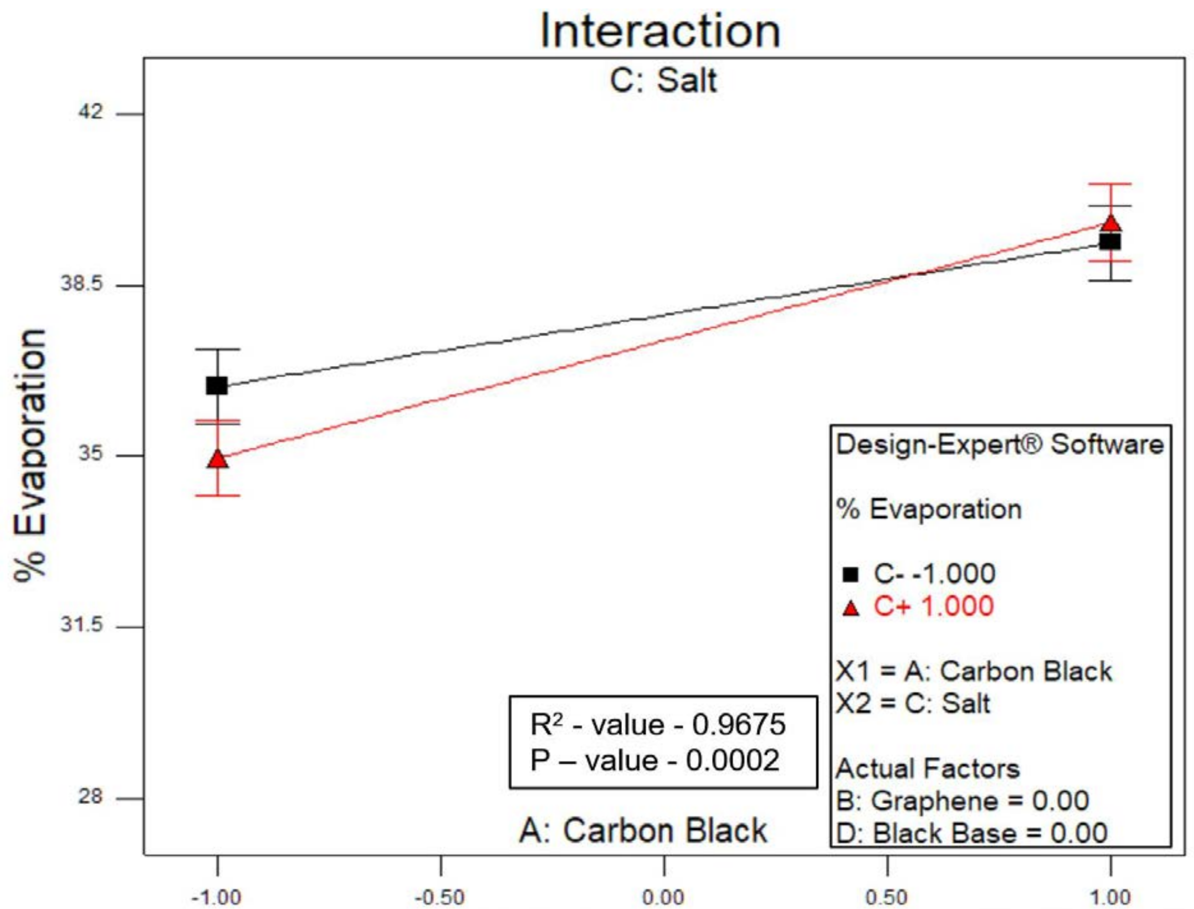


Figure 71. Model graph for the percentage evaporation of carbon black and salt with water

- **Model Graph for Percentage Evaporation of carbon black and Black Base with Water**

According to the figure 72, which shows the model graph for the percentage evaporation of carbon black and black base with water, in which the black line indicates the evaporation of water with and without carbon black and the red line indicates the evaporation of water with carbon black and carbon black plus black base. According to the graph, the slope of black line is more than that of red line, which indicates that the addition of just carbon black to the water would enhance the evaporation of water more than the combination of carbon black and black base together in water. This show how the carbon black nanoparticles are more effective in enhancing the rate of evaporation of water than black base.

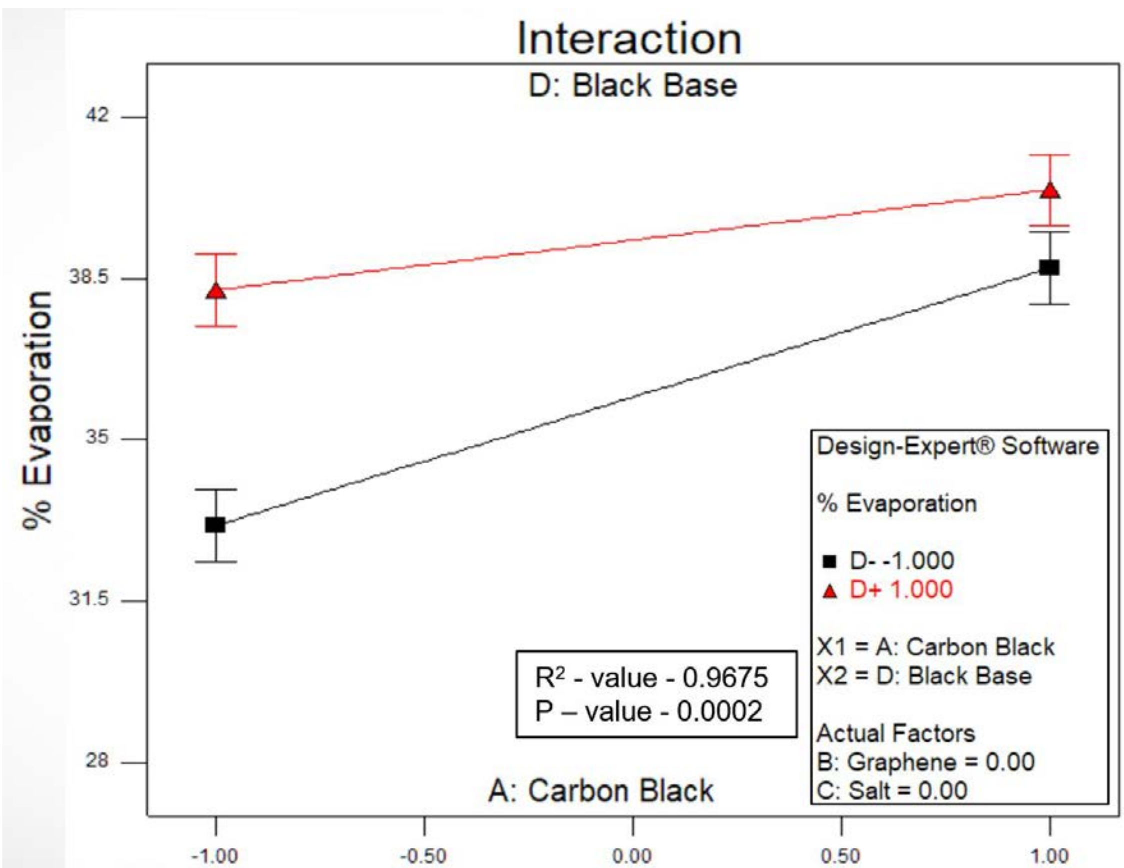


Figure 72. Model graph for the percentage evaporation of carbon black and black base with water

- **Model Graph for Percentage Evaporation of graphene and Black Base with Water**

According to the figure 73, which shows the model graph for the percentage evaporation of graphene and black base with water, in which the black line indicates the evaporation of water with and without graphene and the red line indicates the evaporation of water with graphene and graphene plus black base. According to the graph, the slope of black line is more than that of red line, which indicates that the addition of just graphene to the water would enhance the evaporation of water more than the combination of graphene and black base together in water. This also show that the graphene nanoparticles are much effective in enhancing the rate of evaporation of water in the presence of black base and lies below that of carbon black in enhancing the rate of evaporation of water.

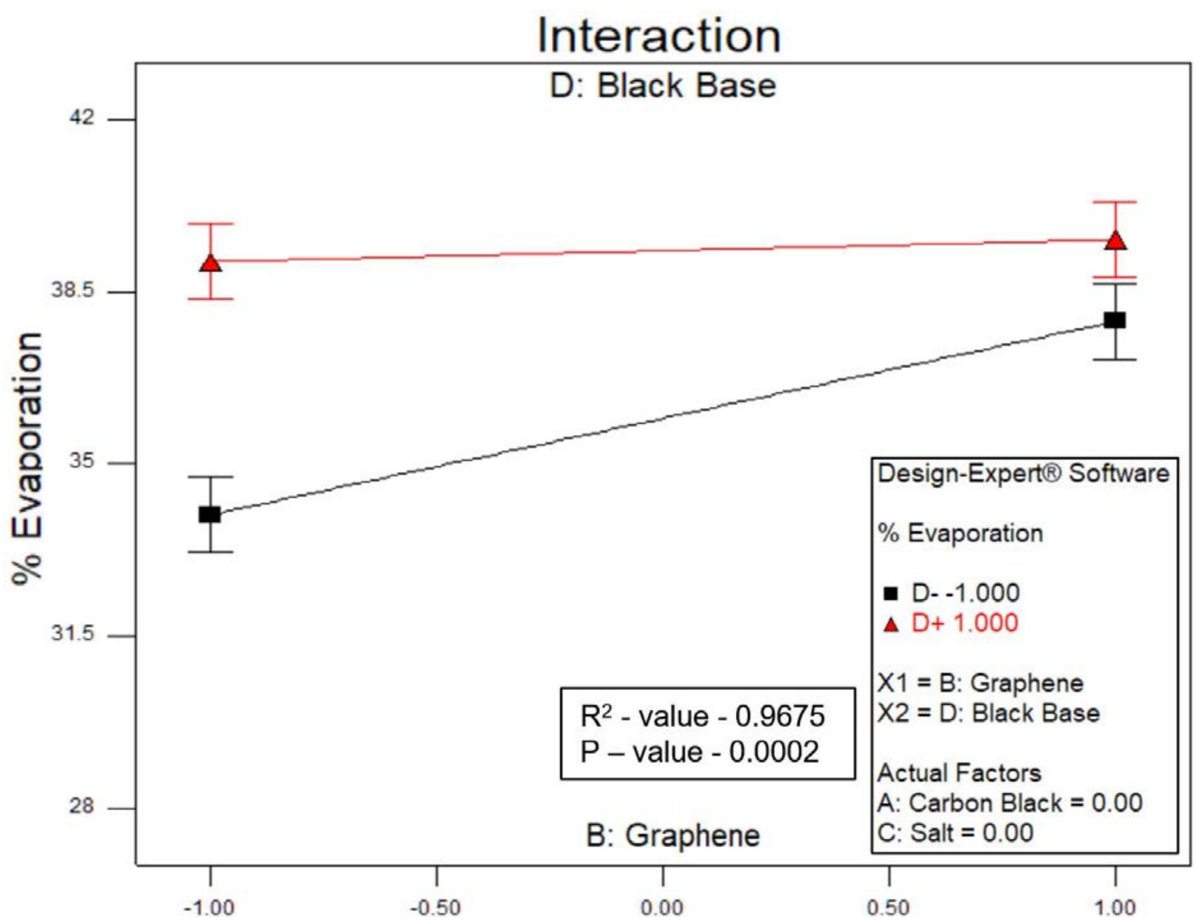


Figure 73. Model graph for the percentage evaporation of graphene and black base with water

4.2.5. Evaporation Test for Superhydrophobic Floatable Nanoparticle Coated Gauze for Carbon, Graphene, and CNT with Water, Salt Water and DI Water

The previous experimental results showed how the nanoparticles could play a significant role in enhancing the rate of evaporation of water. In this experimental result, we can see how the nanoparticles and superhydrophobic coated gauze can be used to improve the rate of evaporation for tap water, salt water, and DI water.

4.2.5.1. Tap Water

Figure 74, shows the comparison of various evaporation test done with tap water, and Figure 75, shows the rise in temperature with respect to the different nanoparticles and superhydrophobic coatings on the cotton gauze along with the black rubber base. All the evaporation experiments are done in the beaker of diameter 19cms and height of 10cms which has the area of 283.565cm^2.

- **Tap Water + IR Light**

The evaporation test for regular tap water showed the total evaporation of 77.71g, where the weight decreased from 250g to 172.29g over the period of 2 hours. We can also see the increase in the temperature of water from 18.5^{0}C to 56.1^{0}C. This test was conducted under IR light without any nanoparticles and black base.

- **Tap Water + Carbon black Gauze + IR Light**

In this experiment, the carbon back gauze was floated on the surface of the water by using hydrophobic properties which showed the total evaporation of 85.92g and 8.21g as compared to the tap water with IR light. This showed the decrease in the weight from 250g to 164.08g with the increase in the temperature from 18.5^{0}C to 56.9^{0}C over the period of 2 hours. During the test, the gauze temperature also rose from 18.5^{0}C to 75.6^{0}C. This test showed the evaporation rate of 2.8mg/h.cm^2 with the percentage increase of 5% as compared to tap water with IR light.

- **Tap Water + Graphene Gauze + IR Light**

In this experiment, the graphene gauze was floated on the surface of the water with the help of hydrophobic properties which gave the evaporation of 82.5g and 4.79g as compared to tap water with IR light. The water showed the decrease in the weight from 250g to 167.5g and the rise in temperature from 18.5^{0}C to 55.4^{0}C over the period of 2 hours. During this test, the temperature of the gauze also increased from 18.5^{0}C to 69.4^{0}C. This test showed the evaporation rate of 1.16mg/h.cm^2 with the percentage increase of 1.95% when compared to tap water with IR light

- **Tap Water + CNT Gauze + IR Light**

In next experiment, the CNT nanoparticle gauze was floated on the surface of the water by using hydrophobic properties which gave the total evaporation of 81.02g and 3.31g as compared to the tap water with IR light. This showed the decrease in the weight from 250g to 168.98g with the increase in the temperature from 18.5^{0}C to 55.4^{0}C over the period of 2 hours. During the evaporation test, the gauze temperature also rose from 18.5^{0}C to 68.4^{0}C. This test showed the evaporation rate of 2.8mg/h.cm^2 with the percentage increase of 1.95% as compared to tap water with IR light.

- **Tap Water + Carbon black Gauze + Black Base + IR Light**

In the last experiment of tap water evaporation, the carbon black nanoparticles gauze was floated on the surface of the water by using hydrophobic properties along with the black rubber base, as the combination of black base and nanoparticles showed good results in the previous experiments. This combination gave the total evaporation of 98.99 g and 21.28 g as compared to tap water with IR light this process showed the decrease in the weight of water from 250g to 151.01g and rose in the temperature from 18.5^{0}C to 53.9^{0}C along with the gauze temperature rising from 18.5^{0}C to 74.5^{0}C. This process shows the evaporation of 7.50 mg/h.cm^2 with the percentage increase of 14.09% as compared to the tap water with IR light.

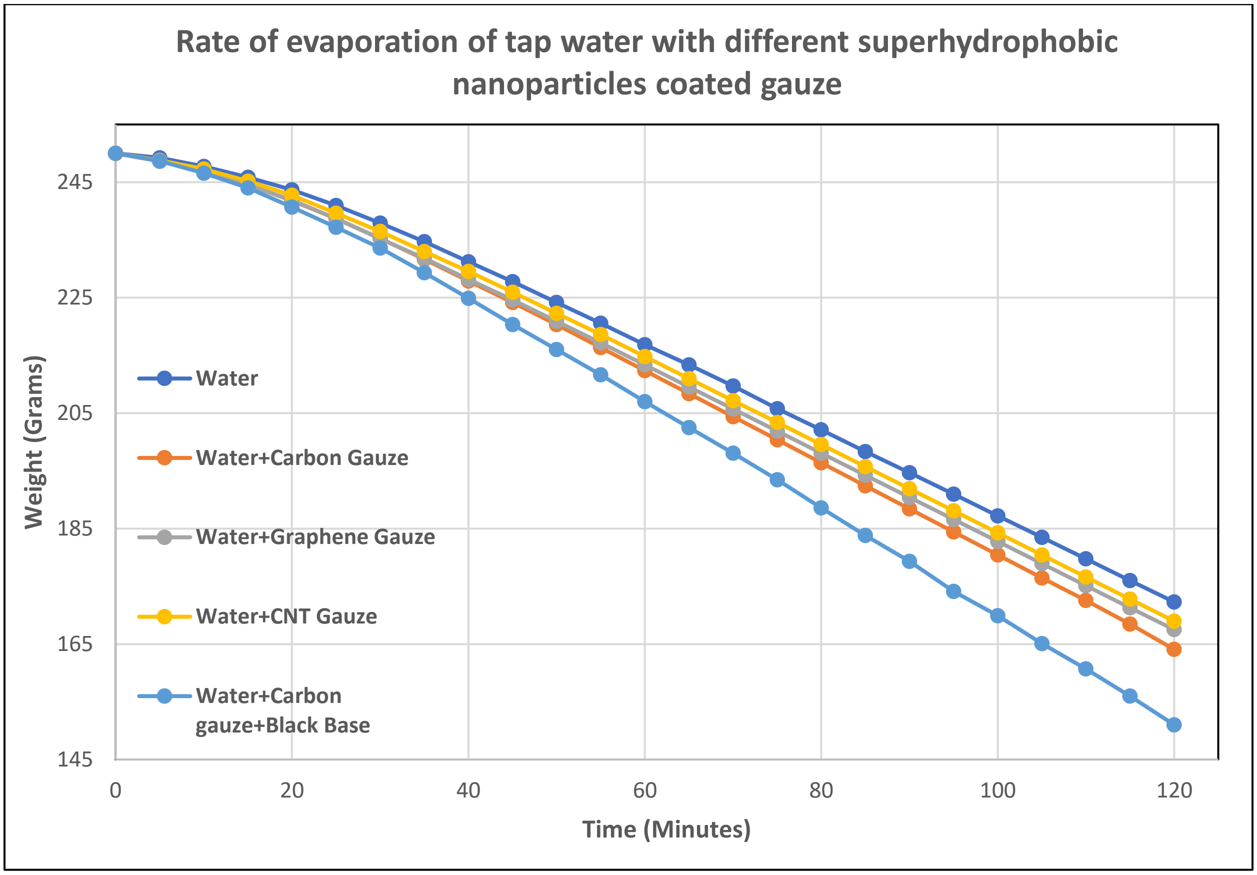


Figure 74. Comparison of rate of evaporation of water with carbon black and graphene nanoparticles along with rubber black base

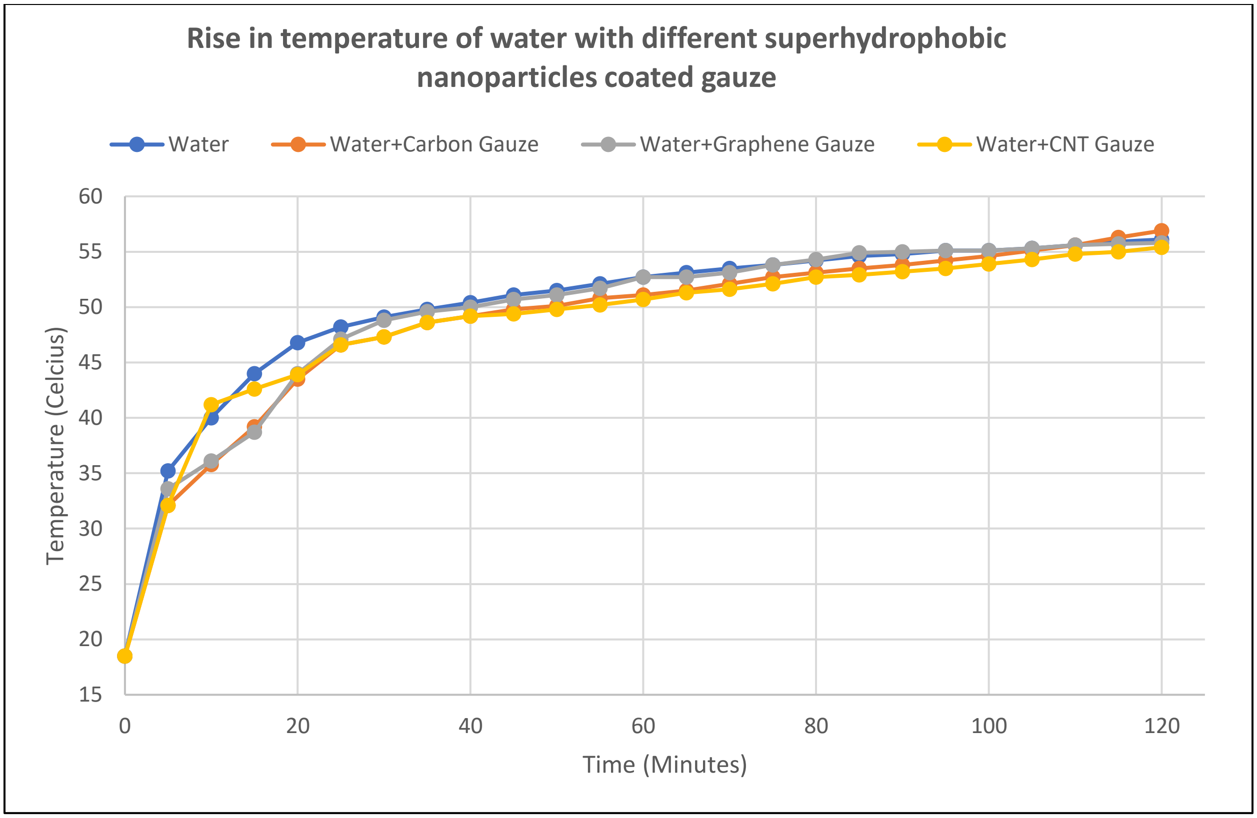


Figure 75. Comparison of rising in temperature of water with carbon black and graphene nanoparticles along with rubber black base

4.2.5.2. Salt Water

Figure 76, shows the comparison of the various rate of evaporation of salt water and the figure 77, shows the rise in temperature of salt water along with the nanoparticle and superhydrophobic coatings on cotton gauze and black rubber base. All the evaporation experiments were done in a flat beaker of diameter19cms and height of 10cms which has the area of 283.565cm^2.

- **Salt Water + IR Light**

The evaporation experiment for salt water showed the total evaporation of 72.38g, where the weight decreased from 250g to 177.62g over the period of 2 hours. We can also see from this experiment that the temperature of water increased from 18.5^0C to 49.5^0C. This test was conducted under IR light without any nanoparticles and black base.

- **Salt Water + Carbon black Gauze + IR Light**

In the second experiment, the carbon back gauze was floated on the surface of the salt water by using superhydrophobic properties which showed the total evaporation of 85.13g and 12.75g when compared to the salt water with IR light. This showed the decrease in the weight from 250g to 164.87g with the increase in the temperature from 18.5^0C to 56.1^0C over the period of 2 hours. During the test, the gauze temperature also rose from 18.5^0C to 72.8^0C. This test showed the evaporation rate of 4.4mg/h.cm^2 with the percentage increase of 7.73% as compared to salt water with IR light.

- **Salt Water + Graphene Gauze + IR Light**

In the next experiment, the graphene gauze was floated on the surface of the salt water with the help of superhydrophobic properties which gave the evaporation of 82.57g and the difference of 10.19g when compared to tap water with IR light. The water showed the decrease in the weight from 250g to 167.43g and the rise in temperature from 18.5^0C to 56.8^0C over the period of 2 hours. During this test, the temperature of the gauze also increased from 18.5^0C to 70.2^0C. This test showed the evaporation rate of 3.59mg/h.cm^2 with the percentage increase of 6.08% when compared to salt water with IR light

- **Salt Water + CNT Gauze + IR Light**

In the next experiment, the CNT nanoparticle gauze was floated on the surface of the salt water by using hydrophobic properties which gave the total evaporation of 80.03g and 7.65g as compared to the salt water with IR light. This showed the decrease in the weight from 250g to 169.96g with the increase in the temperature from 18.5^0C to 54.5^0C over the period of 2 hours.

During the evaporation test, the gauze temperature also rose from 18.5^0C to 69.9^0C. This test showed the evaporation rate of 2.6mg/h.cm^2 with the percentage increase of 4.50% as compared to salt water with IR light.

- **Salt Water + Carbon black Gauze + Black Base + IR Light**

In the last experiment, the carbon black nanoparticle gauze was floated on the surface of the salt water by using the superhydrophobic properties along with the black base placed at the bottom of the salt water. This setup gave the evaporation of 93.04g, and as compared to salt water with the light it gave 20.66g more. This showed the decrease in the weight from 250g to 156.96g with the increase in the temperature of salt water from 18.5^0C to 56.1^0C and that of the gauze from 18.5^0C to 75.7^0C over the period of 2 hours. This test showed the evaporation rate of 7.28mg/h.cm^2 with the percentage of 13.16% as compared to salt water with IR light for the duration of 2 hours.

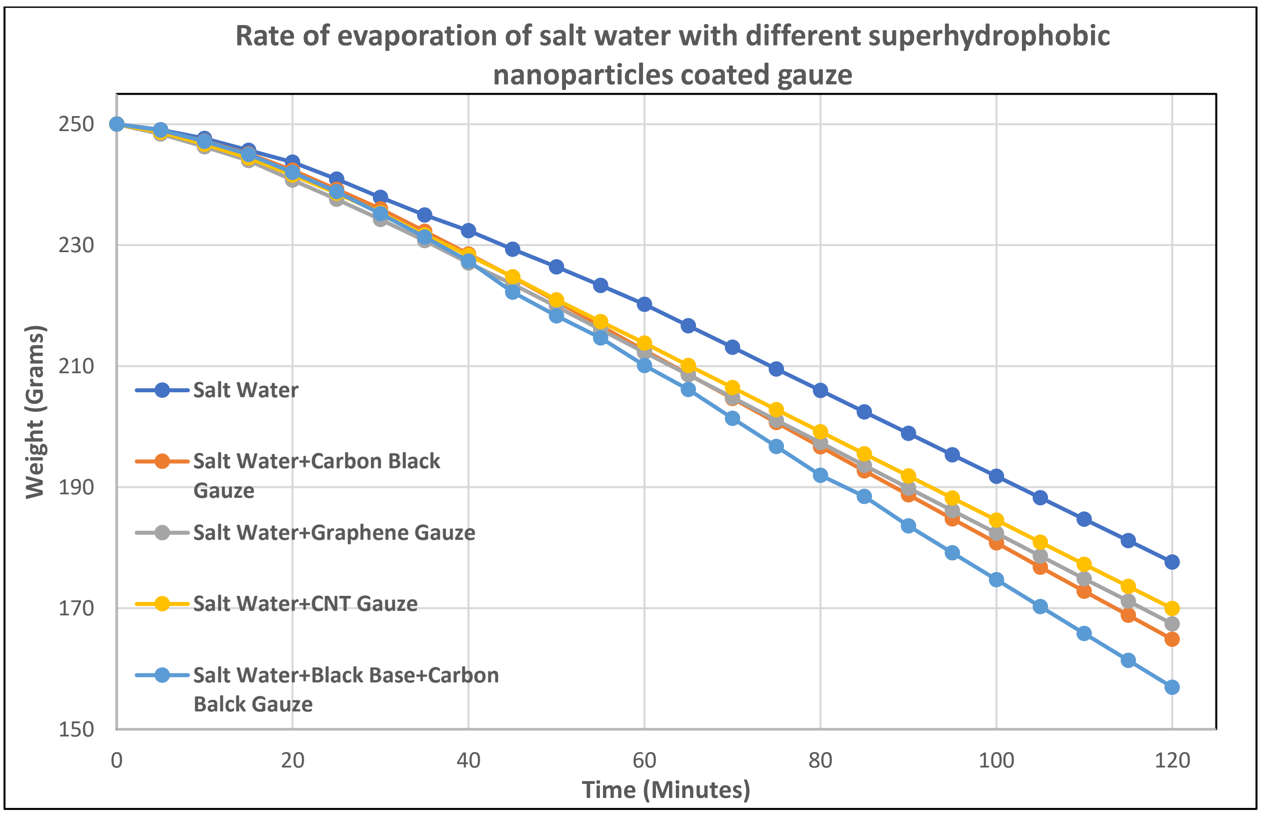


Figure 76. Comparison of rate of evaporation of salt water with carbon black and graphene nanoparticles along with rubber black base

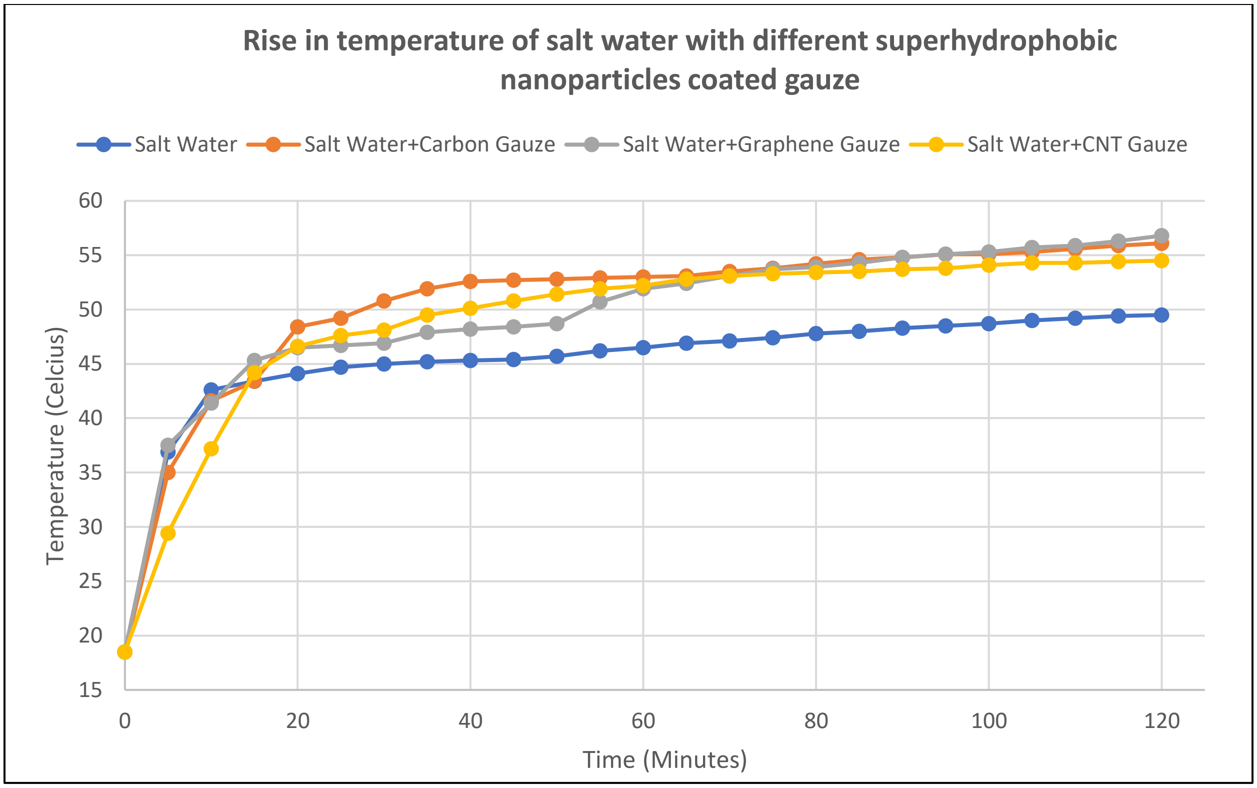


Figure 77. Comparison of rising in temperature of salt water with carbon black and graphene nanoparticles along with rubber black base

4.2.5.3. Deionized Water

Figure 78, shows the comparison of the various rate of evaporation for DI water and Figure 79, indicates the rise in temperature of DI water because of the nanoparticle and superhydrophobic coatings on cotton gauze and black rubber base. All the evaporation experiments were done in a flat beaker of diameter19cms and height of 10cms which has the area of 283.565cm^2.

- **Deionized Water + IR Light**

The first experiment for DI water showed the total evaporation of 82.4g, where the weight of the water decreased from 250g to 167.6g over the period of 2 hours. We can also see from this experiment that the temperature of water increased from 18.5^{0}C to 56.6^{0}C. This test was conducted under IR light without any nanoparticles and black base.

- **Deionized Water + Carbon black Gauze + IR Light**

In the second experiment with DI water, the carbon black gauze was floated on the surface of the DI water by using superhydrophobic properties which showed the total evaporation of 89.16g and 6.76g when compared to that of DI water with IR light. This set up showed the decrease in the weight from 250g to 160.84g with the increase in the temperature from 18.5^0C to 57.3^0C and the gauze temperature rose from 18.5^0C to 71.7^0C over the period of 2 hours. This test showed the evaporation rate of 2.38mg/h.cm^2 with the percentage increase of 4.20% as compared to DI water with IR light.

- **Deionized Water + Graphene Gauze + IR Light**

In the third experiment with DI water, the graphene gauze was floated on the surface of the DI water with the help of superhydrophobic properties which gave the total evaporation of 85.41g and the difference of 3.01g when compared to that of DI water with IR light. The water showed the decrease in the weight from 250g to 164.59g and the rise in temperature from 18.5^0C to 55.9^0C and the temperature of the gauze also increased from 18.5^0C to 69.8^0C over the period of 2 hours. This test showed the evaporation rate of 1.06mg/h.cm^2 with the percentage increase of 1.82% when compared to DI water with IR light.

- **Deionized Water + CNT Gauze + IR Light**

In the next experiment of DI water, the CNT nanoparticle gauze was floated on the surface of the DI water by using superhydrophobic properties which gave the total evaporation of 84.1g and 1.7g as compared to the DI water with IR light. This showed the decrease in the weight of DI water from 250g to 165.9g with the increase in the temperature from 18.5^0C to 55.9^0C and the gauze temperature rose from 18.5^0C to 68.1^0C over the period of 2 hours. This test showed the evaporation rate of 0.5mg/h.cm^2 with the percentage increase of 1.02% as compared to DI water with IR light.

- **Deionized Water + Carbon black Gauze + Black Base + IR Light**

In the last experiment of DI water, the carbon black nanoparticle gauze was floated on the surface of the DI water by using the superhydrophobic properties along with the black rubber base placed at the bottom of the salt water. This setup gave the total evaporation of 100.91g and as compared to DI water with light which gave 18.51g more. This process showed the decrease in the weight from 250g to 149.09g with the increase in the temperature of salt water from 18.5^{0}C to 56.6^{0}C and that of the gauze from 18.5^{0}C to 76^{0}C over the period of 2 hours. This test showed the evaporation rate of 6.52mg/h.cm^2 with the percentage of 12.41% as compared to DI water with IR light for the duration of 2 hours.

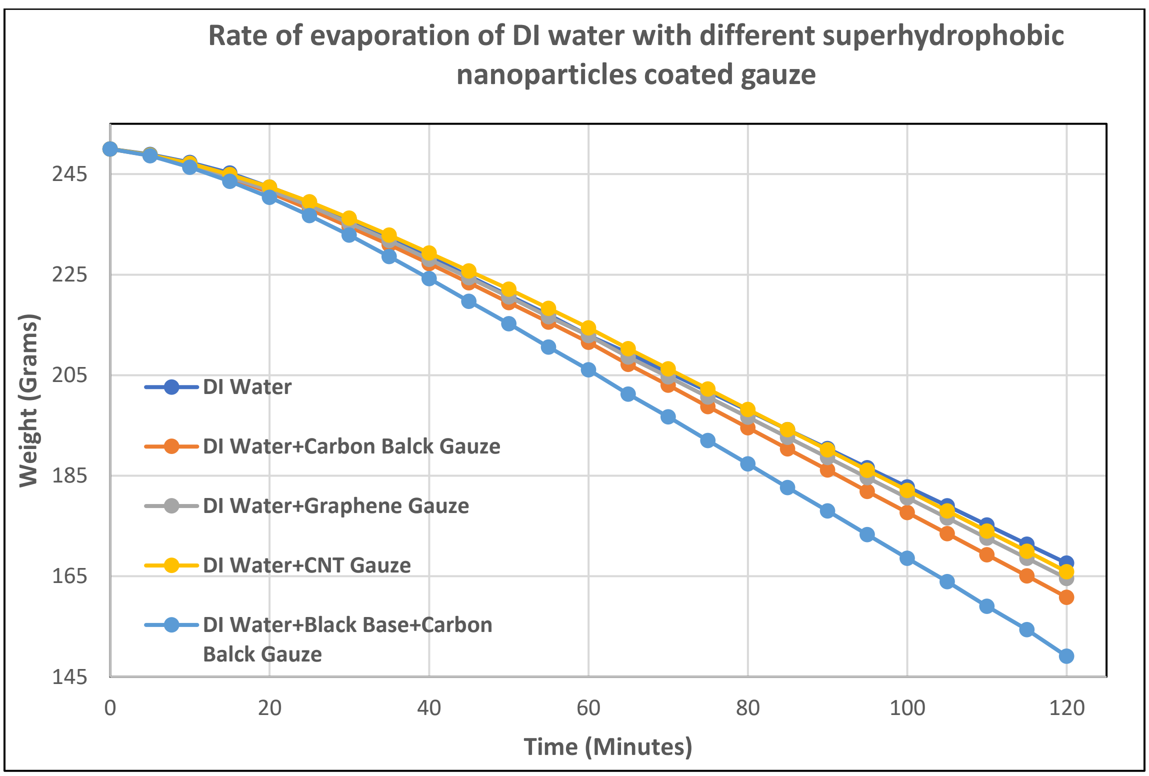


Figure 78. Comparison of rate of evaporation of DI water with carbon black and graphene nanoparticles along with rubber black base

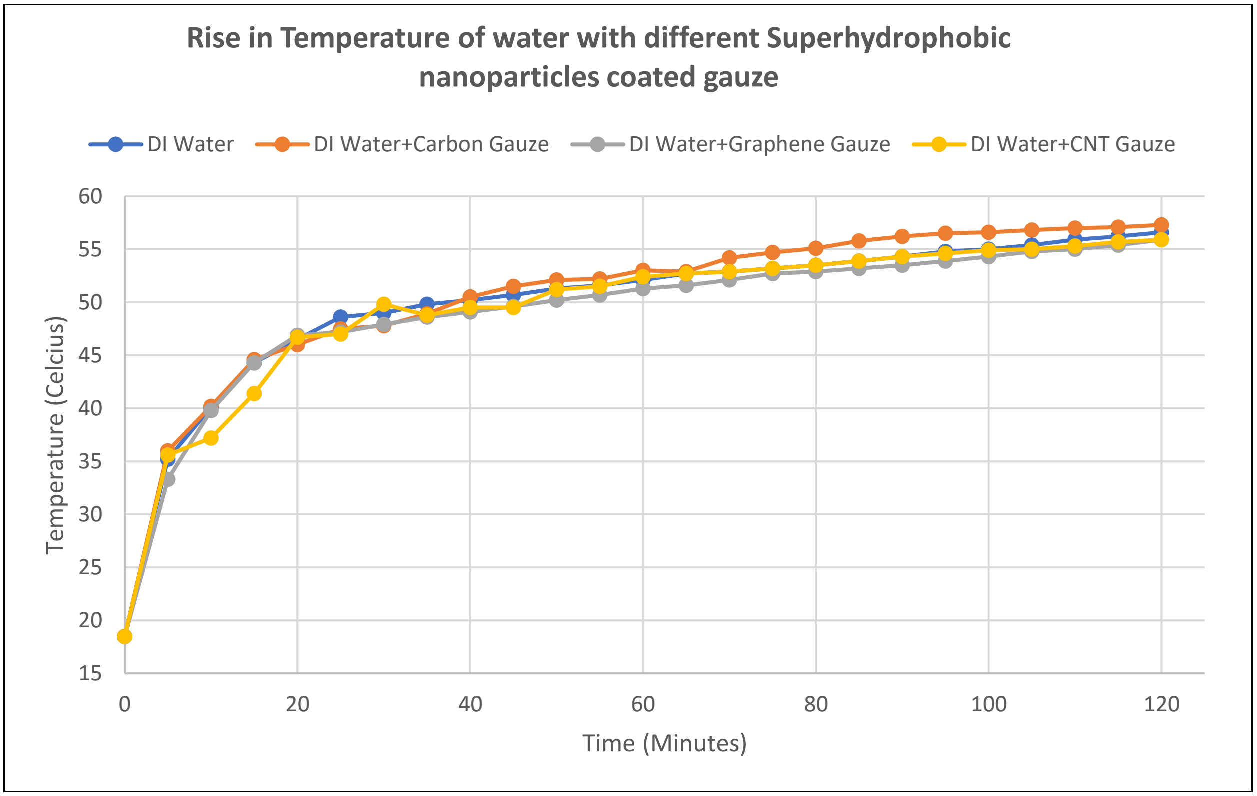
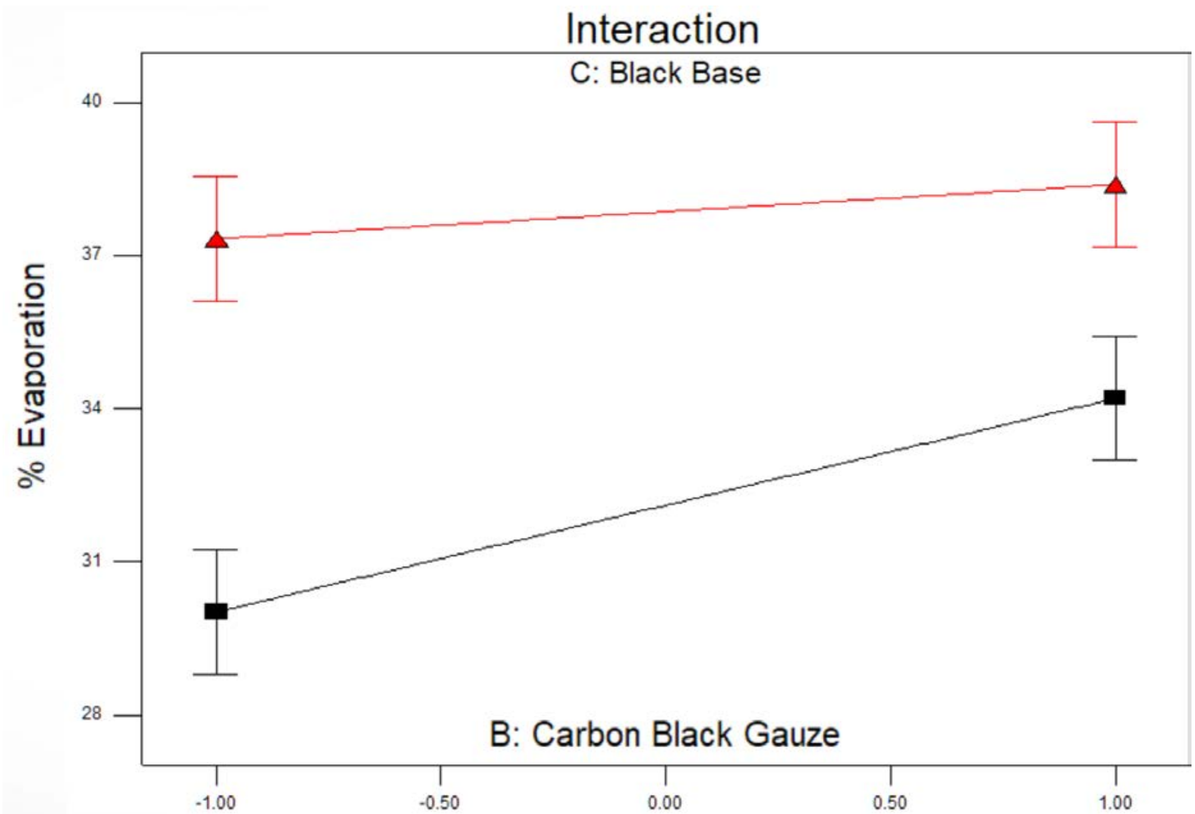


Figure 79. Comparison of rising in temperature of DI water with carbon black and graphene nanoparticles along with rubber black base

4.2.5.4. Statistical Analysis

- **Model Graph for Percentage Evaporation of Carbon Black Gauze with Black Base in Water**

According to the figure 80, which shows the model graph for the percentage evaporation of carbon black gauze with black base in water, in which the black line indicates the evaporation of water with and without carbon black gauze and the red line indicates the evaporation of water with black base and black base plus carbon black. According to the graph, the slope of black line is more than that of red line, which indicates that the floatation of the carbon black gauze on water would enhance the evaporation of water more than the combination of carbon black gauze and black base together in water. This also show that the carbon black gauze is much effective in enhancing the rate of evaporation of water.



Design-Expert® Software

% Evaporation

■ C- -1.000
▲ C+ 1.000

X1 = B: Carbon Black Gauze
X2 = C: Black Base

Actual Factor
A: Salt = 0.00

- R^2 value for test with gauze: **0.9805**
- P value for model: **0.0067**

Figure 80. Model graph for the percentage evaporation of carbon black gauze with black base in water

As compared to other research nanofluids are prepared by dispersing the nanoparticles with fluid medium in which its thermos-physical properties play a significant role in the heat transfer. M.H.U. Bhuiyan et al. used similar method to determine the effect of nanoparticles and their size on surface tension [25]. In this research work we used the carbon black and graphene nanoparticles combining with water, salt water and DI water which gave the 6.11mg/h.cm^2 for water, 7.79 mg/h.cm^2 for salt water and 9.07mg/h.cm^2 for DI water. However, Wenbin Zhang el at. used Calcium titanite particles in silicon oil to enhance the evaporation rate which gave the evaporation of 1.33 mg/h.cm^2 [18] and Stephen U.S. Choi el at. used metallic nanoparticles in heat transfer [12].

To prepare the floatable nanoparticles gauze, ultra-ever dry superhydrophobic liquid was used along with the carbon black, graphene and CNT nanoparticles by curing it to 75^{0}C to make it float on water. Whereas, Yiming Liu et al. used the used PDMS carbon black and hexane solution along with sonication and 80^{0}C curing to obtain a floatable nanoparticle gauze [40].

According to all the above results, the concentration of 0.1% gave better results when test with carbon black and graphene. In next step, the same nanoparticles were tested to see which one give the better result, and carbon black proved out to be more effective nanoparticle with 0.1% concentration in enhancing the rate of evaporation of water. In later stage, the nanoparticle which gave better result i.e. is carbon black was used to fabricate the floatable gauze to make the selective hearting of water surface and enhancing the rate of evaporation of water. But, the amount of evaporation obtained from floatable superhydrophobic carbon black nanoparticle is less than that of the evaporation rate obtained from suspending the carbon black nanoparticles in water. It also showed that, the carbon black works better with the salt water which can be used for the desalination process to obtain the fresh water out of sea water. The black base also makes a difference in enhancing the evaporation and the combination of black base with the carbon black both together can give more improvement in evaporation rate of water.

CHAPTER 5

CONCLUSION

According to this research study, which concludes that nanoparticle played a significant role in enhancing the rate of evaporation and increasing the temperature of nanofluid. The dispersion of nanoparticles in water can vary help in selective heating of the water surface, due to good transmission of heat absorbed from the radiations. The change in concentration of nanoparticles in water also showed variation in results. Experiments showed that the concentration of nanoparticles with 0.1% showed better results of evaporation for regular tap water, salt water, and DI water as compared to other concentrations.

When the different types of nanoparticles were tested under IR light for better evaporation rate, the carbon black nanoparticles showed better results as compared to graphene and CNT. The rate of evaporation even enhanced more when carbon black was combined with a black rubber base, which gave an improvement of 17.98% for tap water, 18.78% for salt water, 16.05% for DI water as compared to water. The carbon black gave better evaporation rate for salt water, which shows that this process can be used for desalination process as carbon black is more effective with the salt water.

By using the nanoparticles which gave the maximum evaporation for water, a floatable superhydrophobic gauze was fabricated using carbon black nanoparticles and ultra-ever dry superhydrophobic liquid by spraying technique. The fabricated gauze showed the superhydrophobic properties and floated on the air water interface. When the floatable gauze of carbon black combined with black rubber base was tested under IR light, it gave the evaporation of 14.09% for tap water, 13.16% for salt water and 12.41% for DI water. The statistical analysis done by 2k factorial method by comparing different test showed how effectively carbon black absorbs the radiation and helps in transmitting the heat to enhancing the evaporation rate.

The combination of nanoparticles with water showed a significant change in the temperature due to which the enhancement in the rate of evaporation was observed. The method used in this research can be effectively used to enhance the phase transition of water from liquid to vapor to separate the salt from sea water. More studies can be done to find out how the size of the nanoparticles can alter the rate of evaporation of water and which the method which suits the best to enhance the rate of evaporation.

CHAPTER 6

FUTURE WORK

In this research we used the nanoparticles to enchance the evaporation rate. Similar test can be done by altering physical properties and using different materails. As the technology is flourishing, there are various research studies going on to determine how to obtain the fresh water from the saline water and how the rate of evaporation can be enhanced to obtain the fresh water at the faster and economical way. Getting clean and fresh water has come to a great concern of the world which can be easily solved by the improving the rate of evaporation of salt water and thus obtain the fresh water out of saline water. Further, the research can be done by considering the following aspects,

- Varying the physical properties of the nanoparticles like, using the different size of carbon black nanoparticles, as the particles with smaller size have more surface area and help in better absorption of heat radiation and transmitting it to the water.
- Using different materials made out of carbon like carbon composites, carbon fibers, carbon film, carbon plastic, carbon fabrics, etc. as the above research showed that carbon is more effective as compared to other materials.
- Experimenting with different surface area of water exposed to the radiation, as more exposure to radiation will absorb more heat and lead in better evaporaiton rate.
- Quantity of water also plays an important role, as water bodies with more depth can store more heat, which leads in longer evaporation as compared to the shallow water bodies.
- The concentration of salt in sea water around the world is not same it varies with the location, different experiments can be done by varing the concentrations of salt in water.

- In this research, we used infrared light as the source of radiation, the next study can be donn by experimenting under Sunlight instead of using the infrared light as the source of radiation.
- Using black base widely affects the evaporation rate, due to which the black base of different materials can be used, as well as the height of the black base from the top surface of the water can also be altered to see the variation in evaporation rate of water.

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