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Master's Thesis in Energy and Process Technology

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[EFFECTIVE USE OF NANOTECHNOLOGY IN DESALINATION]

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ABSTRACT

Purified water is very vital for humans and for everyday activities. Water sources available are not able to provide enough required and even the ones present are often polluted by several man made and natural activities. The ocean and sea are very large water sources of water yet contaminated with salts which must be removed for consumption. Emerging research and technology have helped shaped the process of removing this salt from the seawater or brackish water for human use. This process known as desalination has kept improving from time and has helped to obtain pure water from these salt solutions. Regions occupied with desserts on the planet have resorted to the use this process to provide this requisite resource for their inhabitants. Although there are discussions on how expensive this process can be, it is one of the best technologies to help save humans and the planet. There are several inefficiencies with the technology but as time passes there is improvement and additions to help solve the potential water crisis the world faces. As stated earlier, the expensive nature of the process means the need to constantly research and find more innovative ways to make the process more usable by all. Reverse osmosis and inclusion of filter is very common in the process of desalination but in this research work other options have been explored.

This thesis involved the use of nanoscience for the improvement of desalination. The use of boiling and evaporation techniques was also used to helped in the entire desalination process. Seawater, nanofluids made from carbon black nanoparticles and coffee were the main fluids used for experiments and analysis in this research work. The experimental set up was made to transport fluids from on point to another while reducing salinity because of evaporation. The setup consisted of a halogen lamp used as a solar irradiation source and was used for boiling of working fluids. A beaker was placed at specific distances away from the halogen lamp and had a cork which held the tube for transporting 10ml of working fluid to another beaker. The experiments were conducted for each of the different fluids and analysed. The concentration of the working nanofluids used had a concentration range between 0.01% and 0.10%. For the coffee, different concentrations were prepared for each and was measured in g/ml. The main aim of the research, which was to decrease salinity, this was achieved and there were different results for each concentration and fluid sample used. The time for transport of 10ml of fluid from the beaker to close to the irradiation source was also noted for every experiment. Seawater had the longest time for transport of 10ml of working fluid. Nanofluid with concentration of 0.05% had the lowest time taken to transport 10ml of fluid. The different experimental results also resulted in altering the way of preparing the nanofluids. Some experiments had to be conducted with nanofluids formed without sodium dodecyl sulfate (SDS) which was used to stabilize and prevent sedimentation of nanoparticles. The SDS aids in mixing the carbon black nanoparticles when forming the nanofluids. This was done to find the best concentration of nanofluids which can help reduce salinity from 35ppt after the desalination process has been completed. Beer-lambert law was also applied to check if there are any particles present in the fluid after the experiment. This was done by measuring light intensity as it passed through produced fluids. This helped to also indicate fluids that were clean or contaminated with unwanted nanoparticles lighted together with the vapor.

The findings of this research revealed that, evaporation and boiling are viable techniques for reducing salinity and obtaining pure water from salt water. The findings also indicated that nanoparticles help to reduce salinity of a fluid. It was also experimentally observed that, increasing the distance of the fluid from the radiation source affected desalination. For this research, placing the fluid 2cm away from the source was optimal in reducing salt concentration to produce pure water. The average salinity of seawater after experiments was 0.029ppt for a distance 2cm from the radiation. This was a much better result compared to the 0.05ppt when it was placed 4cm and 5cm away from the heat source. The analysis and results suggest that the setup is very suitable for desalination when fluids are placed at the right distance from the heat source and the right volume and concentration of nanofluids are used.

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List of Abbreviations

CB	Carbon Black
CFD	Computational Fluid Dynamics
DASC	Direct Absorption Solar Collector
NF	Nanofluid
NP	Nanoparticles
ppt	Parts per Thousand
SDS	Sodium Dodecyl Sulfate
SS	Solar Still

Nomenclature

a	Heat transfer coefficient	Wm^{-2} K^{-1}]
ΔT	Temperature difference	[K]or[∘C]
ΔT_{max}	Maximum temperature difference	[K]or[∘C]
η_{th}	Thermal efficiency	[−]
μ	Dynamic viscosity	[Pa·s]
ρ	Density	[kg/m^3]
σ	Stefan-Boltzmann's constant = 5.672×10^{-8}	[Wm^{-2}K^{-4}]
ε	Emissivity	[−]
A	Area	[m^2]
d	Length/Distance	[m]
H	Height distance	[m]
I	Radiation intensity	[Wm^{-2}]
K	Extinction coefficient	[m^{-1}]
k	Thermal conductivity	[Wm^{-1}K^{-1}]
m	Mass	[kg]
T	Temperature	[K]or[∘C]
T_0	Initial temperature	[K]or[∘C]

T_1	Final temperature	[K]or[◦C]
t	Time	seconds/minutes
v	Velocity	[ms^{-1}]
z	Length	m

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CHAPTER ONE

INTRODUCTION

1.1Motivation

Purified water is a necessity in the world. Humans depend on it for so many purposes, so news of shortage and contamination always draws the attention of all stakeholders. Water is an essential commodity and is not only needed by humans. The fauna of this planet also requires pure water for survive and this is the reasons taking research in desalination is expedient. Although this resource is supposed to be available to all seven billion presents on the planet, some 1.1 billion people lack access to water. Climate change is listed as a factor for alterations in weather patterns which is also causing droughts and water shortages to even places available water resource. The earth is made of about 70% water but only about 3% of the water is fresh. The sea and ocean are water resources but need to be purified before pure water can be obtained. Getting fresh water from the vast ocean is the reason this research work is based on desalination using nano science and technology. Even though this project focuses on seawater, it is also worth noting that the rivers, aquifers and lakes that provide water are becoming stressed through pollution and population growth.

Desalination is basically the treatment of seawater or brackish water to obtain pure water (Gray et al, 2011). Sea water contains NaCl which is known as common salt. This process involves different technologies and is being improved each time. According to the US Geological Survey, 97% of the earth’s water, which is the sea and ocean, covers about 332,519,000 cubic miles. The context suggests a large volume of water which can be desalinated to get sufficient water to meet global needs. Desalination is a game changer and leveraging on all the breakthroughs it can bring is beneficial to solve water scarcity problems. The desalination process involves equipment and machinery, but this project is done in a laboratory so focuses more on the principles and factors that can be used to improve the process. Fig. 1.1 is an image showing the future global water scarcity.

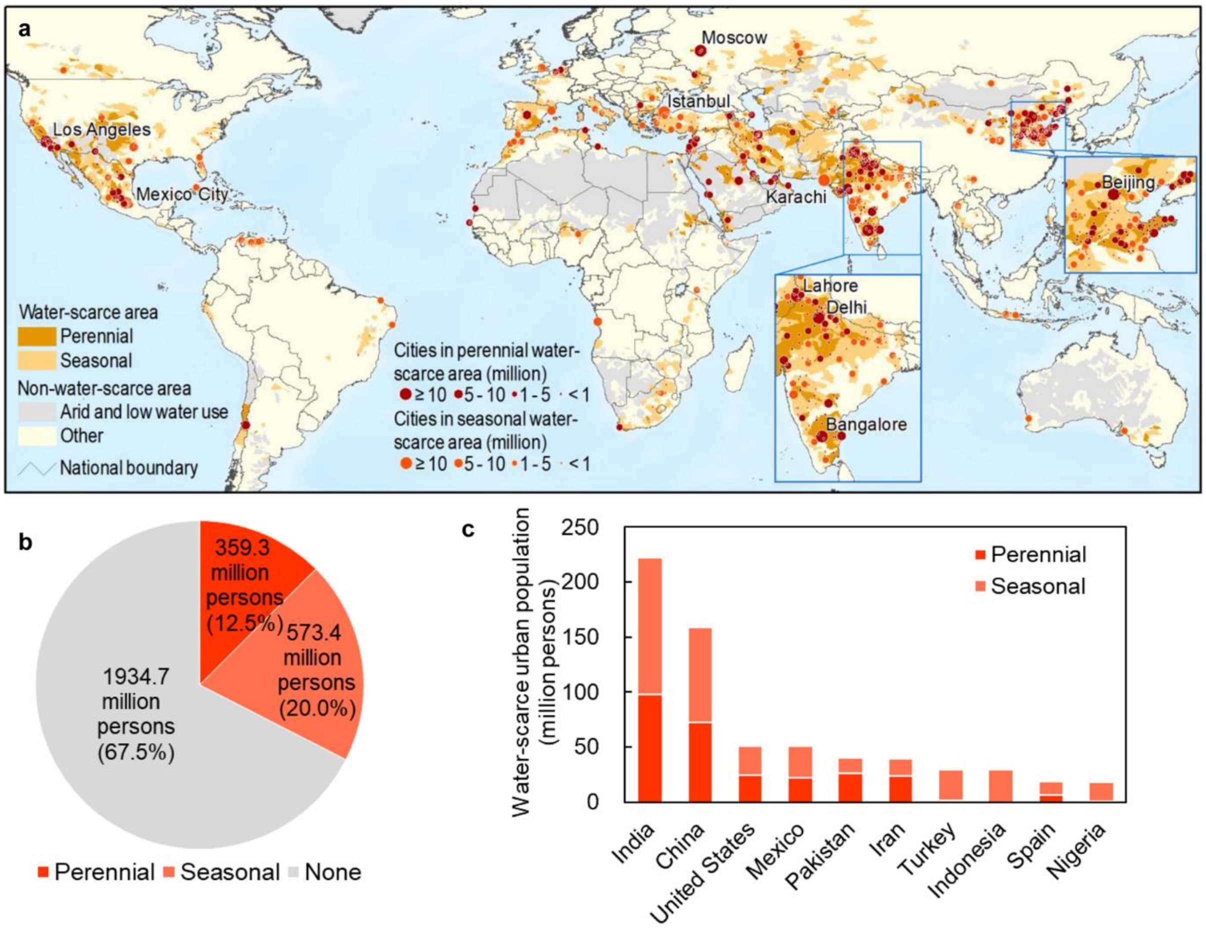

Figure 1.1 Water Scarcity Data

The need for water keeps increasing globally because of the surge in population but the cost of producing clean water keeps increasing as well. The energy and machinery needed for desalination are expensive and hence the need for more technology which can make the process easy, accessible and affordable. There are several desalination techniques, the least intensive and known method is through reverse osmosis. In this process, a semi permeable membrane is used and helps to take away salt from sea water to produce the required fresh water. Theoretically, 1 kWh/m^3 is required to desalinate average seawater through the natural osmosis process (Anon, 2021). In the early 1970s, the required amount of energy needed was about 7.0 to 9.9 kWh/m^3. The advancement in technology and high energy pumps produced have reduced this to 2.5 to 3.5 kWh/m^3. In the USA, it is estimated that the energy required to fly a jumbo jet at good altitude can provide desalinated water to about 300 000 homes. (Anon, 2021).

Desalination also affects the environment because of the fuel needed to power plants and the space it occupies at a particular location. These desalination plants also produce chemical and toxic waste which affects the environment and destroys some wildlife. This negative impact does not however negate the positive impact desalination has on the planet. Several technologies keep coming up, but one popular one this project focused on is the use of nanotechnology and nanophysics to improve this amazing desalination technique.

There are fluid mechanics and heat transfer principles also applied in desalination. A very important one noted in this research work is the convection. This heat transfer method aided in fluid transport, boiling and evaporation of working fluids. The principle is even applied in the use of nanofluids. Nanofluids in this research are liquids produced with carbon black nanoparticles, water and SDS for stabilization. Nanotechnology is basically the use of nano scale measurements to improve technology (Nimesh, 2013). This technology birthed nanofluids and has important use for this research. Nanotechnology is used in almost every field of science now. Carbon black nanoparticles are used mainly for producing nanofluids, a working fluid used for this desalination research. A comparative analysis is going to be needed because that is the only true way to know if the results from the research will be beneficial. Researchers have recently used nanoscience in desalination, but this research is seeking to add on to the already existing findings to make the world a better place and to help solve the earth's water crisis. Coffee was also used as an experimental fluid to help in comparative analysis of the research.

1.2 Objectives

This thesis had specific objectives, and these are listed as follows.

1. To make a functioning laboratory set up for experiments and make use of data it provides. A setup made up of a halogen lamp serving as irradiation source which increases temperature of working fluid for evaporation and transport. A setup that will ensure efficient transport of produced desalinated fluid into another beaker.
2. Examine and compare the time dependence of flow after boiling and evaporation for:

- Water
- Nanofluids
- Coffee

3. Investigate how use of nanofluids and coffee can improve desalination compared to ordinary seawater.
4. Verify if the experimental set-ups are viable for desalination.
5. Investigate if the findings will be beneficial in improving desalination.

CHAPTER TWO
LITERATURE REVIEW

2.1 Desalination

Purified fresh water is a necessity in every community, nation, and ecosystem. The availability of water has not translated to meeting the needs of the world's population, despite covering about 70% of the earth's surface. While fresh water makes up 3% of the water present, the remaining fraction is saline, and ocean based. The accessible amount of fresh water to the entire world population is just about 1% (National Geographic, 2021). This has led to the widespread use of desalination, a technology used to obtain purified water from ocean or saline water.

Desalination is the process of obtaining purified water from saline or seawater. It can also be described as the technique of extracting salt from sea water to get fresh water (Abdel-Fatal and Al Bezedi, 2020). The process is used extensively worldwide for removal of chemicals, natural contaminants, and suspended solids in water. The desalination process also involves processes such as reverse osmosis, membrane filtration and also nanofiltration.

Desalination is also known as the process of removing salts or other minerals from seawater, wastewater effluent and it is for obtaining fresh water for human consumption and industrial use (Anon., 2017). Fresh water is essential even for domestic use, it is a necessity for every household worldwide and hence the constant need for a sufficient quantity to meet its demand. In the industry, fresh water is not only used for operational purposes, but also it is consumed by staff for adequate hydration and to ensure good healthy habits. Desalination is one of the many engineering and technological processes used for obtaining fresh water. The definition of desalination may differ from one another depending on the field in which it is being used, but the main purpose of this process to make available fresh water for consumption.

The desalination process involves the use of several processes and techniques. However, the most known process in desalination is the use of reverse osmosis using semi permeable membranes. Another common step used in desalination is the multistage flash distillation, this can be used together with reverse osmosis or alone (L'Annunziata,2007). The entire desalination process requires a high energy input, this can be electric power tapped from fossil fuels or renewable energy. Sometimes, nuclear power is used as a substitute power source for desalination.

2.1.1 Desalination Techniques

There are various procedures involved in desalination and three major ones are going to be discussed. These processes are necessary for pure water to be obtained from brackish water, sea water or any form of water containing impurities. Filtration, membrane technology and reverse osmosis are the major procedures that act as the backbone of an effective desalination process. Fig. 2.1 depicts all the processes involved in arriving at a successful desalination process.

Although the techniques listed are very popular ways of handling desalination, the use of solar still has also proven to be very viable. The use of silver nanoparticles for double purpose (anti-bacterial and enhancing heat/mass transfer) and exposing water to solar energy has proved to be an effective way of performing desalination (Parsa et. al, 2020). The process is much like the technique used in this research. The difference being the use of carbon black nanoparticles and coffee instead of silver nanoparticles. There is also no anti-bacterial application in this research compared to (Parsa et.al, 2020).

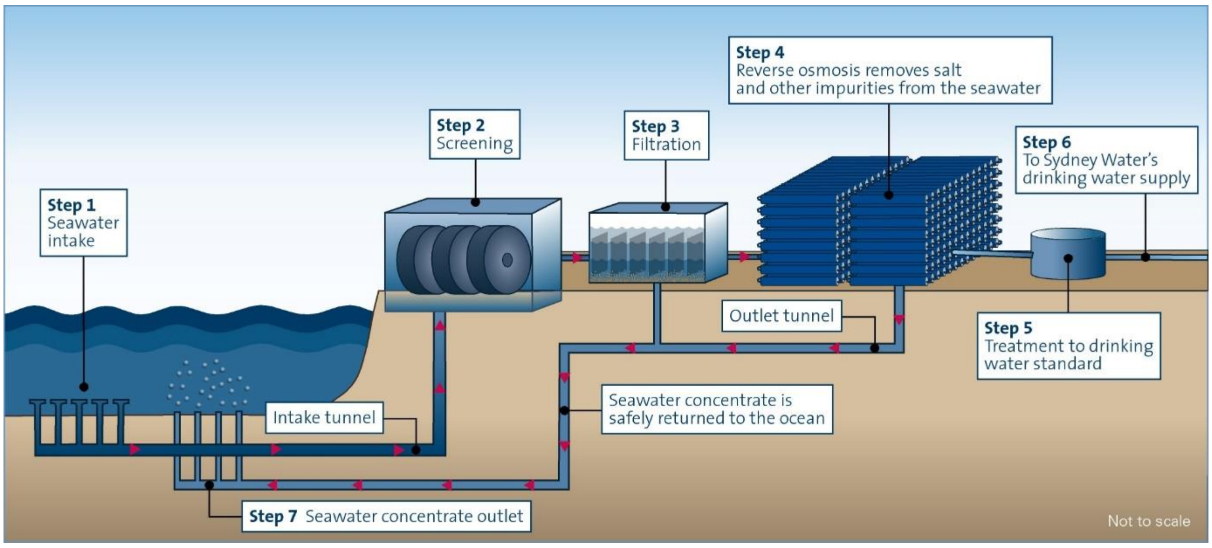

Figure 2.1 (A schematic diagram of the desalination process)

Flitration

As a general term, filtration involves removing large solid debris or sediments from water. In desalination, the use of sand filters is the most common. Although filtration is not the major process in desalination, it must be done with precision and carefulness to ensure membranes are not plugged by large sediments. Sea water or brackish water contains variable loads of sediments and therefore, it usually requires sand filtration supplemented by micro-filtration (Anon, 2021). Depending on the varying sizes of the sediments, pre filtration process is required in the desalination process. The different sizes of sediments will mean different sand filters being used. These sediments need to be removed, to effectively make the sea water or brackish water alone go through the membrane for reverse osmosis. The sediments are usually measured in microns and are larger than the dissolved salts in the water about to be treated. Screen and disc systems are always used in the industry for filtration to make the desalination process successful (Anon, 2021). In (Parsa et. al,2020), the silver nanoparticles act as anti-bacterial agents and aid in the entire desalination process. The result achieved in using silver nanoparticles proved healthier water can be produced without using filters. This also influenced the choice of experimental setup for this research and the use of carbon black nanoparticles.

Sand is a common sediment found when filtering sea water. This has made the use of sand filters very common in the process of desalination. Sand filtration is conventionally applied to the pretreatment of raw seawater in the desalination plant to maintain the seawater quality within the low SDI level (Kawana et al, 2001). The silt density index helps determine the amount of sediment present. A low index indicates that the sea water has an acceptable quality necessary for desalination to proceed. Desalination plants have sand filters which are used for filtration. These plants are very can have very complex systems.

To ensure an efficient filtration process, hybrid filtration technology has grown in desalination. These systems are used for pre-filtration with the main purpose of getting rid of silts or sediments. Hybrid processes combining fiber filter with deep bed filtration process such as fiber filter and sand filter, fiber filter and anthracite and fiber filter and dual media filter are used as pre- treatments to reverse osmosis (Lee et al, 2009).

Roughing filters, which is for coarse media filtration is used commonly when the water to be desalinated contains large amounts of silts and sediments. It is usually utilized in the pretreatment phase to remove organic matter and sediments in the water. A chunk of suspended particles is removed when this type of filter is used. Particles with sizes ranging between 0.5 -40 micrometers can be removed using this type of filter (Kim et al, 2020).

Filtration as discussed is very vital in desalination and plays a major role in the success of desalination. The effectiveness of a filtration process is essential to the engineer handling a desalination plant.

Membranes and Membrane Technology

The sea water or brackish water to be desalinated goes through a semi permeable membrane. This membrane helps to separate the pure water about to be obtained from the sea water. The process where salts and minerals are removed from a solution involving water is known as membrane desalination (Shatila, 2020). The semi permeable membrane allows dissolved solids, suspended particles, and colloids to be left behind for only pure water to be collected as the product. The pressure that propels the salt water to move through the semi permeable membrane is produced by pumps. These pumps generate a pressure that is higher than the osmotic pressure of the sea water. This enables the rejection of dissolved salts and particles from passing through the membrane (Khan et al, 2018). The membranes are semi permeable so that they do not allow every material to pass through. The size of the membrane matters, and membranes have been developed to even have nano pore spaces. There have been several advances made to improve the use of nano-structured pore spaced membranes for desalination. This helps to remove all solids of varying ranges from the solution of water. Membrane desalination is done by a process known as reverse osmosis to generate pure water.

Despite membrane technology, works from (Zakaria et.al,2021) have inspired a new alternative and approach to desalination. The use of solar collectors enhanced by nanofluids are a considerable option for performing desalination. The use of parameters such as temperature and solar intensity has made this alternative possible.

These alternative ideas aided in the experimental procedure and experimental set up for this research (see Section 3.4).

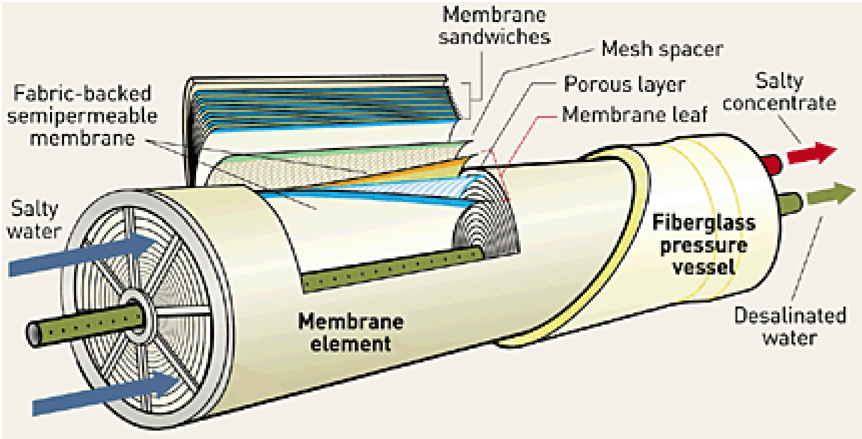

Figure 2.2 A Membrane used in desalination.

Reverse Osmosis

An intrinsic difference exists between filtration and reverse osmosis. The latter involves the use of membranes while the former utilizes sieves. Reverse osmosis allows membranes to permeate solvents and leaves behind unwanted solutes. In filtration, larger sediments are retained by a sieving mechanism and solvents are allowed passage (Ettouney and El-Dessouky, 2002). Reverse osmosis is able to remove dissolved salts and is used for particles that range from 5×10^{-3} μm to 10^{-4} μm (Ettouney and El-Dessouky, 2002). Nano technology is used in both reverse osmosis and filtration and has improved filtration. Particle sizes ranging from 5×10^{-2} μm to 5×10^{-3} μm, can be removed by nanofiltration (Ettouney and El-Dessouky, 2002).
Reverse Osmosis can be described as a membrane process, where the membranes used have the capability of allowing water to pass through while leaving behind organic salts, metals and other solutes (Ettouney and El-Dessouky, 2002). In the petroleum industry, this process can be used for sulphate ions from wastewater. Reverse osmosis has a wide industrial use, the most obvious and largest industry where this process can be applied is in the water treatment and management industry (Zaidi and Saleem, 2022).

2.2 Nanophysics

Nanophysics is the branch of natural science (physics), that deals with structures and objects with dimensions within the nanometer range and handles phenomena that occur in nanoseconds (Catalano, 2016). Nanophysics is governed by the laws of Einstein and Newton and is balanced macroscopic physics and quantum mechanics. Nanophysics is essential for exploiting and relating processes and phenomena that can have their one or two of their material scale reduced to the nanoscale (Catalano, 2016). Nanophysics is a branch of physics that can be applied in engineering, and all other sciences. In the water treatment industry, nanophysics can be used in membrane technology for desalination through the reverse osmosis process.

Theoretical and experimental procedures can be used to determine physical properties of materials using the nanoscale. The evolution of nanophysics can be traced to certain happenings that happened in the mid 1980 that won Noble Peace Prizes each. These were: the discovery quantum Hall effect in a two-dimensional electron gas; the invention of scanning tunnelling microscopy (STM); and the discovery of fullerene as the new.The latter two, within a few years, further led to the remarkable invention of the atomic force microscope (AFM) and, in the early 1990s the extraordinary discovery of carbon nanotubes (CNT), which soon provided the launch pad for the present-day nanotechnology (Catalona 2016, Pg 1). The nanometer is the is 10^{-9}m, and this the billionth of a meter. The nano scale can also be used to represent short durations, a typical example is measurements that are taken in nanoseconds.

Nanophysics has improved and has found large use in other fields such as solar energy. Carbon black nanoparticles have also gained popularity for different applications in nanophysics. These carbon black particles have an advantageous thermo-physical property although they pose some threats to the environment (Alberghini et. al, 2019). In this research, carbon black particles are used as a working fluid for comparative analysis with seawater and coffee. In direct absorption solar collectors, carbon black nanofluids have proven to be good heat transfer fluids (Kosinska et. al, 2022). This idea and finding played a vital role in selection of working fluids for this research.

2.2.1 Nanotechnology

Nanotechnology was first used by a University of Tokyo professor, Norio Taniguchi in 1974. The findings are used to describe the ability of engineering materials to be precisely described by the scale of nanometers (Ramsden, 2016). The engineering materials here characterize design, production, and application of materials. Nanotechnology has now widened the scope to devices and systems rather than just materials. Using nanometer dimensions to control the design and fabrication of systems, devices, and materials is known as nanotechnology (Ramsden, 2016). The importance of nanotechnology therefore is to optimize control and size. This technology has a widespread use in various fields and has helped in desalination processes for water treatment.

2.2.2 Measurements in Nanophysics

The nano scale measurements are done using instruments calibrated to scale. For the three main fundamental quantities, the use of nanophysics is utilized. For length or distance measurements, the nanometer scale is used for all dimensions and calculations. Quantities that are derived from length also use the same nanometer scale for their dimensions and calculations. For measurements of area and volume, the nano scale units are used. Nanometer square and nano meter cubed are used for area and volume units respectively. These units can also be represented by nm^2 and nm^3 respectively, the “n” can also be replaced with 10^{-9}. Instruments for measurements in nanometers are usually industry specific.

Time is a very principal quantity in the field of engineering and all other sciences. In nanophysics the unit of time is nanoseconds. The duration of processes in engineering is very key and no matter how short it may be, it is necessary to note to avoid errors. Stop watches or clocks can be calibrated to measure time in nanoseconds and this is very helpful for projects that are going to be performed using the nanoscale.

2.2.3 Nanofluids

Nanofluids can be simply referred to as fluids that contain nano particles (Mercan, 2020). These fluids are made up of particles that are measured in nanometers. Nanofluids are considered as colloidal suspensions and are known for the enhanced thermal conductivity of these fluids. This property is essential because of the use of this type of fluid in energy generation (Holkar et al, 2018). The future of heat transfer fluids can be attributed to nanofluids, these fluids have a widespread use in heat transfer.

The particles dispersed in nanofluids can be made of one component and this is known as monodispersed. Several other nanofluids can be made with two or three components. The thermal efficiency or magnitude of heat transferred by nanofluids are linked to the type of nanomaterial dispersed in the fluid (Bhanvase and Barai, 2021). The sample of black carbon nanofluids are shown in Fig. 2.3. The use of carbon black nanoparticles was essential in this research. The nanofluids are two phased and the nanoparticles used in preparation are nominally 1-100 nm in size (Nguyen, 2022).

Figure 2.3 CB Nanofluids prepared in a laboratory.

Nanofluids are prepared by simply mixing nanoparticles of a specific material with a base fluid such as water. The concentration of the particles can be altered for experimental or theorical reasons. Concentration imparts the properties of the fluid prepared (Bhanvase and Barai, 2021).

Nanofluids are a preferable fluid for use in solar related desalination because these fluids have excellent thermal properties (Essa et. al, 2020). In solar energy desalination research by (Parsa et. al, 2020), silver nanoparticles were considered because of the good optical properties they possess which is essential for desalination. These nanofluids are produced as solar stills using different substances. Nanofluids can be used for turbidity analysis in desalination and are very critical because helps to determine water quality (Hassan, 2022).

2.2.4 Use of Nanophysics in desalination

In every field, the environmental impact of a substance used is very essential. Although carbon black nanoparticles have been proven to have superior photo-thermal and heat transfer properties, the impact it has on the adverse impact it has on the environment cannot be overlooked. In (Essa et.al, 2020), coffee-based colloids are proposed to replace inorganic metallic nanoparticles that negatively affect the environment. In this research, despite these consequences, carbon black nanofluids and coffee colloids are used for comparative analysis. These nanofluids of different concentrations are used in different experiments and compared with seawater for analysis and to find a suitable system for desalination.

Solar still (SS) is a low cost solar-based desalination system which utilizes solar energy to convert saline water into fresh water (Essa et. al, 2020). The solar still is based on nanophysics and influenced the used of carbon black and coffee as working fluids for this research. The system also affected the experimental setups used for this research as it involved evaporation (see section 3.4).

The research although not focused on solar energy, took a lot of inspiration from the Solar desalination. This is an alternative for producing fresh water for areas where sunshine is abundant throughout the year (Kumar et.al, 2021). The process also involved the use of nanofluid which is adopted in this work. Carbon black is used instead of silver nanoparticles. Also, the use of nanofluid laden reverse-irradiated direct absorption solar collector augmented active solar still is not used. These procedures are all nanophysics techniques applied in solar energy and desalination.

2.3 Coffee

There are several substances which have fluids with high thermal conductivity and have widespread use in heat transfer. Coffee based colloids just like carbon black nano fluids are being applied extensively in heat transfer and energy generation. Coffee is a beverage common to households and usually served as breakfast or even starter for meals. The nutritional value or health benefits is not a subject of matter here, but its application in energy generation, heat transfer and desalination will be discussed.

Coffee based fluids have been used in many solar energy experiments. Coffee based colloids have been used in direct solar absorption and have given positive responses and limitations (Alberghini, 2019). The absorption properties of coffee-based colloids have been compared to classical absorption surfaces for solar technology. The results obtained showed that further investigations can be encouraged for simple, biocompatible, and cheap colloids for direct solar absorption experiments (Alberghini, 2019). The coffee-based colloids have also been compared to carbon black based nanofluids.

Coffee is made up of caffeine, this is the main component of coffee. Using coffee-based colloids for experiments in desalination helps to understand the heat transfer properties of the substance. Coffee based fluids can be compared to other fluids to help gain better understanding of properties being worked on.

2.4 Concentration

In desalination, the water which is going to be treated is in a solution form. This makes it very necessary for the concentration and amount of substance in the solution to be known. Concentration is essential in chemistry, and it is applicable in engineering processes such as desalination. Concentration is crucial because it helps to know the number of sediments going to be handled and how the membrane used in desalination can be handled it. In desalination, different components can make up the sediments that are to be removed. The concentration of sediments or impurities in water is essential before and after desalination. After desalination, the concentration of sediments is very important to the engineer. The equation for concentration for this research expressed in terms of sum of mass of the solute and the sum of the mass of the solvent is

$$\frac{m(solute)}{m(solution)} * 100 = \frac{m(solute)}{m(solute)+msolvent} * 100 = wt\% \quad (2.1)$$

where m represents the mass of the substance.

Concentration is the number of sediments divided by the total volume of the solution. The amount in this context denotes the amount of substance or moles of substance which is denoted by “n” (Fuentes-Aderiu, 2013). The units for volume for the entire system or solution is usually dependent on the quantity involved. The volume can be expressed as milliliters, liters, decimeter cube or even centimeter cube. The amount of substance or moles of substance is also measures in moles. Thus, a typical unit for the concentration of a system or solution can be mol/L or mol/dm3. Sometimes, the content of a substance is confused with the moles of a substance. In biology, concentration of glucose in the blood or spinal fluid can be measured to help in diagnosing diabetes (Fuentes-Aderiu, 2013). Concentration plays a vital role in the chemical engineering industry and its importance cannot be disregarded. Often, people confuse the concentration of a system with its content. The content is the amount of substance divided by the mass of the system (Fuentes-Aderiu, 2013).

2.4.1 Concentrated and Dilute solution

The amount of solute dissolved in a solvent of a solution is known as the concentration (Soult, 2021). A solution where the solute is more than the solvent or a solution with large quantity of solute is known as a concentrated solution. The solute represents the substance that is dissolved, while the solvent is the substance that dissolves the solute. For example, water is the solvent for sea water while dissolved salt is the solute. The solvent for a solution is not always water. Liquids such as Alcohol can be solvents for certain solutes. When the solution or system contains large quantities of solvent than solute, the solution is said to be dilute. In the food and beverage industry, there are certain drinks that come in the concentrated form and to consume at home, a required quantity of water is needed to make it safe to take in.

In desalination, the concentrated salt solution which makes the water unsafe to drink must lose a reasonable amount of salt which is the solute for the water to be considered drinkable. In desalination, the dilution is not being done by adding large amounts of solvent, but by removing large amounts of solutes. This means in dilution; large amounts of solvent are added to reduce the moles of solute per solvent while the amount of solute present remains unchanged. The concentration of a solution is also increased by increasing the amounts of solutes present while maintaining the solvent volume.

Concentration can be divided and grouped in several ways. There are various ways of categorizing percentage and one of the ways is by percentage. These percentage categorizations can be done in terms of mass or volume (Soult, 2021). The solute and solvent percentages can all be determined using this categorization. For smaller concentration of solutes in a solution, the concentration can have units in parts per million or parts per billion. A typical example is finding the concentration of lead ions in water (Soult, 2021). Although concentration units based on moles is essential in chemistry, all these others are units find extensive use in chemistry as well. In dealing with concentration, another useful quantity to understand is molarity. The amount of moles of solute per one liter of solution is known as the molarity (Soult, 2021). Molarity is simply calculated by dividing the moles of solute by volume of the solution, and it is expressed in liter. Therefore, the unit of molarity is mol/l.

2.5 Solubility

Solutes in a solvent can be so concentrated that they no longer dissolve. Depending on the temperature, solutes which are in such a large quantity become insoluble. Solubility can therefore be defined as the maximum amount of substance that will dissolve in a solvent at a particular temperature (Mittal, 2017). The solubility of substances has a very extensive use in the world of science and engineering.

In desalination, the solubility of dissolved salts is an important factor to consider. IUPAC describes solubility as the analytical composition of a saturated solution expressed as a proportion of solute which is dissolved in a solvent. Solubility occurs under dynamic equilibrium and the units of solubility can be stated in molality, mole ratio and concentration (Viswanathan et al, 2017).

As temperature rises, most substances are known to become more soluble (Mittal, 2017). In the sea water the sodium chloride present is soluble in the water which is the solvent. This information is useful in desalination to help in obtaining pure water from sea water. There are other insoluble sediments in water during desalination but are usually removed prior to the actual desalination process. Also, solubility depends strongly on the presence of other molecules and ions in the solvent (Viswanathan, 2017). Low solubility is expressed in terms of solubility constant for saturated solution of ionic compounds (Viswanathan, 2017).

2.6 Water

In the discussion of desalination, water is the most important topic. Water is a chemical compound made of hydrogen and oxygen. Water can exist in so many different phases and forms. Water can exist in the gaseous phase as vapor and water can also exist in the solid state as ice. Water must exist in the liquid phase for desalination to take place. There are also several properties of water that exist. These properties range from their chemical to physical. Water has some optical properties also. In desalination, one very important property of water to consider is the ability to the flow through spaces and change shape and size in its liquid state. The various properties of water will be explored.

2.6.1 Physical Properties of Water

A few of the physical properties of water are going to be listed below. Some of the physical properties of water include the density of the water, the melting point of the water, the boiling point of the water, odor of the water and the heat capacity of the water. Water also has adhesive and cohesive properties. The properties are all important for engineers that are handling desalination projects and we will be talked about in detail.

Odor, Color, and taste

Most substances, no matter the state they exist in, can be identified by color or smell. For water, this is not the case. Water has no smell or color (Shmeis, 2018). Water has no taste, when any chemical or foreign substance is added to water and it becomes tasty, it ceases to be water. The appearance for water gives room for determining physical properties of water.

Turbidity

Although water has no color, water bodies can be classed as clear based on the sediments or impurities present in the water. Water clarity measurement is known as turbidity. Clay, silt, fine sand particles, inorganic materials and plankton present in water can disguise the appearance of water. These substance account for making water very turbid and in turn affect the appearance of water. When the turbot of water is very low, it means the water is very clear. When water appears not to be clear, it then means the turbidity of the water is very high. Turbidity is measured in turbidity units (Shames, 2018).

Density

Density is described as the mass per unit volume. Water has density and it varies at each phase water exists in. The solid form of water is less than the liquid form of water. This is the reason why ice floats on the surface of liquid water. The density of water also varies at different temperatures. The value of water density at 100 C is 0.9854g/mL and is 0.9971g/mL at 25 C (Shmeis, 2018)

Viscosity

The property of water is very in fluid mechanics. The ability of water to flow is also essential in desalination. Viscosity is expressed in terms of shear stress per shear rate and is measured in centi poise (cP) or Pascal per second (Pa. S). There are units of viscosity, but for water at 100 C, the viscosity is 0.28cP. Viscosity is also a property that is temperature dependent (Shmeis, 2018). Dynamic viscosity is measured by shear stress per shear rate and is denoted in Eq. 2.2.

$$\eta = \frac{shear\ stress}{shear\ rate} = \frac{\tau}{\gamma} \qquad (2.2)$$

The equation for dynamic viscosity can also be represented using Isaac Newton's law as represented in Eq. 2.3.

$$\frac{F}{A} = \eta \frac{dv}{dx} \qquad (2.3)$$

Where *F* is the force, *A* is the area and *dv/dx* is the velocity gradient.

Melting Point and Boiling Points of Water

The ambient temperature can affect the physical properties of water. Above or beneath a certain temperature, the melting or boiling of water may occur. At at a pressure of 1atm, water boils at 100 C (Shmeis, 2018).

2.6.2 Chemical and Optical Properties of Water

The chemistry of water is essential to very engineer just as its physical properties. Water also has optical properties. The properties of water are important in desalination to know whether the water that has been treated is consumable. Water is used in various fields and has to meet the required standards to avoid problems. The optical property of water tells reveal how it will behave under electromagnetic radiation. For the chemical properties, it helps notify when foreign chemicals are present in the water.

Salinity

This property of water is defined as the concentration of inorganic salt present in the water. It is measured in parts per thousand or grams of salt per kilogram of water (Lagerloef, 2001). This property has helped oceanographers to determine the salt concentration of seawater. A practical salinity scale helps derive salinity by temperature, pressure, thermal conductivity and a set of empirical equations (Lagerloef, 2001). The standard salinity of sea water has a range of values depending on several factors. The values range from 35g/L to 45g/L (Lagerloef,2001).

pH

The ph scale measure the acidity or how basic a substance is. The pH scale has a range of numbers from one to fourteen. On the scale, the numbers which range from one to six show that a substance is acidic, while the numbers that range from eight to fourteen show that the substance is basic. For neutral substances, that is non-acidic or non-basic substances, have a value of seven on the pH scale. Water has a pH of seven and is therefore a neutral substance (Anon, 2022).

Chemical Composition

Water is a compound that is made up of two hydrogen atoms and one oxygen atom. A drop of water contains a billion hydrogen and oxygen atoms. Each of the hydrogen atoms are bonded to the oxygen atoms by a single bond. The chemical formula of water is H2O. The hydrogen bonds in the water makes also make water polar (Anon, 2022).

Cohesion and Adhesion

There's a constant breaking and reforming of hydrogen bonds between water molecules. Adhesion is the ability of water to stick to surfaces while cohesion is the ability of water of water molecules to stick together.

Strong adhesion is because of waters polarity. Adhesive forces are generally stronger than cohesive forces. The strong adhesion and cohesion of water causes capillarity to occur (Kontogeorgis and Kiil, 2016)

Refractive Index of Water

This optical property of water is very important in the field of physics. The refractive index is the ratio of light velocity of specified wavelength in air to the velocity of another substance being assessed (Wypych and Petreas, 2019). For measurement purposes, it can be defined as the ratio of the sine of the angle of incidence to the sine of the angle of refraction (Wypych and Petreas, 2019). For water, the ratio of the sines of the incident and refractive angles of light in water is equal to the ratio of light velocity to the velocity of light in vacuum (Wypych and Petreas, 2019). The equalities in these equations can be known as the Snell´s law.

2.6.3 Seawater

The earth is made up of about 71% percent of water and the ocean covers about 96.5 % of the planet's water (Anon, 2019). The earth's water can are also present as ice, glacier and exist in the air as water vapor. Although this much water exist on the planet, not all these waters are consumable for humans. Plants and animals also require water for nutrition. For humans, water is not only present for nutritional purposes, but also required in the health sector and even for industrial use. Water must meet certain requirements for whatever specific use it has. Although several water bodies exist, not all these natural resources provide the water needed for daily use. The ocean and sea are very large, but the chemical content of these bodies make the bodies not meet the pure water needs of humans. The global demand for pure water keeps increasing and this has led to scientists removing the sodium chloride content of the sea to provide pure water for domestic use and industrial use.

The sea contains excess amounts of salt is this product is not desirable. Seawater is a large volume of water which has a salt concentration which varies in parts per thousand. The range of seawater concentration is between 35g/l to 45g/l. The same measurement can be done in different units, and this can make the range from 35 parts per thousand to 45 parts per thousand (Lagerloef, 2001). This concentration of salt does not make sea water to be drinkable and hence the introduction of technology like desalination to produce pure water. For experimental and scientific purposes, samples of seawater can be produced because of the known concentration. Fig. 2.4 is a sample of one liter of seawater prepared in a university of Bergen laboratory.

Figure 2.4 A sample of laboratory prepared seawater (35ppt)

The sea is generally known to be smaller than the ocean and it is located where the land and ocean meet (Anon, 2019). The ocean is referred to as the deep sea. Seawater is a part of the 96% saline water present on the planet. The planet's fresh water is minutes compared to the volume of seawater and ocean. The sea is habitat to lots of aquatic organisms and offers a mode of transport for humans as well. Sea water is also beneficial to humans because it is a source of salt which gives taste to food. The volume of sea water and ocean is measured to be 1338 000 000 cubic kilometers (Anon, 2019).

2.6.4 Brackish Water

A mix of fresh water and sea water and has a lower salinity. Also, the salinity of brackish water depends on the origin. Brackish water is diluted and has a lesser concentration of salts than sea water (Vargel, 2004). Brackish water may also form from geothermal processes (Vargel, 2004). Brackish water that has been formed by a geothermal process comes out heavily loaded with metallic chlorides and sulfides. Sodium chloride, magnesium chloride, hydrogen sulfide and iron sulfide are all salts present in brackish water formed from a geothermal process (Vargel, 2004). Brackish water then be simply defined as sea water that has been diluted by fresh water from a river.

Brackish water possesses a serious threat to aluminum alloys and is unwelcome in the aluminum alloy world. However, this water can be treated and made desirable for industrial and domestic use. Brackish water like seawater is also a habitat to aquatic organisms. Desalination techniques can purify brackish water for human and industrial use. For desalination purposes, brackish water and sea water can be named as the raw materials needed and the purified water produced is the product. Brackish water and sea water are abundant on the planet and still do not meet the requirements for humans. Desalination techniques are hopeful for producing enough fresh or purified water for human sufficiency. For the volume of brackish water present, turning less than 70% to pure water will do a lot for humans.

Ions present in water.

There are other ions found in abundance in water other than the oxygen and hydrogen atoms present. The most abundant cations present in water are calcium, magnesium, sodium, and calcium. Bicarbonates, sulphates, and chlorides are the most abundant anions present in water as well. These constituents govern the quality of the water (Anon, 2018). These ions present can make the water hard or soft by affecting its ability to lather with soap.

2.7 Temperature

Temperature is the degree of hotness or coldness of a body and depicts the average kinetic energy of the particles present (Helmenstine, 2023). This parameter is very important in daily living and can be measured using a thermometer. The heat energy of a body is also measured because of temperature difference that can be measured. Objects with the same temperature have no heat flow in them. The measurement of temperature can be done using different techniques and devices. Temperature is an intensive property and does not depend on the volume of a substance or object (Helmenstine, 2023). Temperature measurement is very necessary ion desalination and helps engineers to ensure safe flow of fluids using different fluid mechanic techniques. Table 2.1 represents the various temperature scales and units and how they are related (Nesbitt, 2007).

Kelvin* scale**	**Celsius scale**	**Rankine scale**	**Fahrenheit** scale**	**Physical relationship**	
Relative temperature value	0 K	− 273.15 °C	0°R	− 459.67 °F	Absolute zero
	273.15 K	0 °C	491.67 °R	32 °F	Melting point of ice*
	273.16 K	0.01 °C	491.688 °R	32.018 °F	Triple point of water*
	373.15 K	100 °C	671.67 °R	212 °F	Boiling point of water*
Relative temperature intervals (diffs)	1 K 0.55556 K	1 °C 0.55556 °C	1.8 °R 1 °R	1.8 °F 1 °F	

Table 2.1 Temperature Measurement Scales and the relations between these scales

For defined conditions

Value in °C =11.8 (value in °F −32) = (value in K −273.15)

Value in K =59x (value in °R)

2.7.1 Measurement of Temperature

Temperature is measured in different units. The hotness or coldness of a body can be measured in degrees Celsius, degrees Fahrenheit or Kelvin (Helmenstine, 2023). The Kelvin scale measures absolute values of temperature, and its zero value is absolute. Celsius and Fahrenheit are measured in degrees but not on the Kelvin scale. All these units can be measured or read using a device known as the thermometer. There are different types of thermometers which are made based on different principles in physics. The thermometer is not only important to the engineer, but to everyone that has a life. In summer and winter, temperature measurements help to adjust air conditions and heaters to recommendable values, so the present weather conditions do not make living unbearable.

Thermometers are available based on different principles. The most common thermometer is the liquid in glass thermometer which is based on the principles of expansion and contraction of liquids. In such thermometers, a tube containing a liquid will rise or fall based on their temperature measured (Helmenstine, 2023). These tubes are calibrated numerically for accuracy and precision. Sometimes, people often confuse temperature with heat.

2.7.2Types of Thermometers

Thermometers are devices used to measure temperature. The production of these devices depends on different principles in physics. These days, digital thermometers that utilize sensors are becoming very common in the world. Although they are digital, these thermometers also apply principles of physics to function. Thermometers are installed in many household devices for temperature regulation. Offices also regulate room temperature on air-conditioners and heaters because of the physics that helps to manufacture these items to include thermometers. The different types of principles of physics and the type of thermometers that are produced when used are discussed subsequently.

Liquid in Glass Thermometers

This type of thermometer is the most popular type of thermometer used to measure body temperature across the world (Ostadfar, 2016). The principle behind this type of thermometer is the volume of expansion of fluids with temperature. The thermometer has a reservoir that contains fluids, mainly alcohol or mercury. It contains a tube with a small diameter in which the fluid rises or falls. The tube is scaled or calibrated, and measures temperature based on volume expansion, that is, the rise and fall of liquid in the tube (Ostadfar, 2016). The disadvantage of using liquid in glass thermometers is that it can easily be broken and cannot measure very high and low temperatures. The choice of liquid being mercury and alcohol is because of the ability to conduct heat very well, and the fact that these liquids do not wet glass. Another advantage of using mercury is that it is very clear and visible to read.

Resistance Thermometer

This type of pf resistor is built based on the principle that electric resistance varies with temperature. The thermometric substance used in this type of thermometer is resistance wire. The higher the temperature, the higher the resistance of the electric wire. These types of thermometers can measure very low or very high temperatures. They can be used in transducers to measure temperature based on resistivity as well (Sinclair, 2001).

Gas Thermometer

Gas Thermometer is built on the principle that, at constant volume, the pressure of gas increases linearly with temperature. Hydrogen or helium gas is used for these types of thermometers in a bulb attached to a manometer. The thermometric substance used in this type of thermometers is the gas which is the hydrogen and helium (Anon, 2022)

Thermocouple

The thermocouple is built on the principle that there is a temperature difference that occurs at a junction where two different metals having different electric potentials or current meet. These metals can be copper and constantan. These types of thermometers are also referred to as thermoelectric thermometers. It is derived from a term in physics known as the thermoelectric effect. It is the phenomena where there is direct conversion of temperature changes to electric voltage and the opposite (Benseba, 2013).

Fig. 2.5 and Fig. 2.6 are images of temperature measuring devices or thermometers used in a laboratory at the physics department of University of Bergen, Norway.

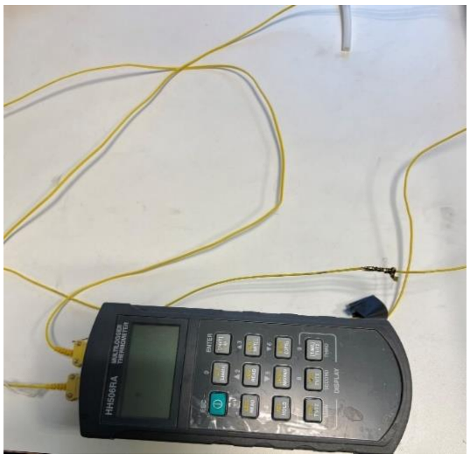

Figure 2.5 Thermocouple Thermometer

Figure 2.6 Digital Temperature Gun

2.7.2 Seawater Temperature

To desalination, knowing the temperate of the sea and ocean is expedient. This helps in laboratory analysis and experiments which are translated to the field to produce pure water from seawater. The temperature of the sea is not only essential in desalination, but also it must be known for climate change research purposes and for protection of the habitat of marine life. The temperature of the sea varies from region to region on the earth. The average temperature of the sea is about 20°C but it ranges from more than 30 C in warmer areas and can be less than 0 C in high latitudes (Anon, 2014).

2.8 Boiling Point

This is the temperature at which the vapor pressure of a substance becomes equal to the atmospheric pressure (Schmitz, 2018). Heating of different substances will cause the substances to boil at different temperatures. Every substance has a different temperature it boils at, and this means boiling is affected by many physical and chemical factors. A substance will change from the liquid state to the gaseous state at boiling point. Boiling point can also be defined as the temperature at which the liquid and vapor or gaseous state of a substance can co-exist in equilibrium (Speight, 2020).

When a substance is being heated and vapor pressure of the liquid becomes equal to the atmospheric pressure of the surrounding, the further temperature rise caused by heating only causes a latent heat of vaporization. This latent heat of vaporization causes the liquid to change into the gaseous state (Speight, 2020). Boiling does not occur only at the surface of a liquid but throughout a liquid.

2.9 Freezing Point

Freezing temperatures varies for many different substances. The temperature where a substance will begin to get cooled and become solid is very beneficial to every scientist. Freezing point can be defined as the temperature at which the vapor pressure of a substance becomes equal to that of a solid crystal (Berk, 2009). Freezing is a phase transition from liquid to solid. The presence of foreign substances may alter the freezing point of a liquid. Freezing has many uses in the field of science. Freezing is used in food processing, medicine storage, and many other fields of engineering.

Water freezes at 0 C or 32 F but this temperature can be affected by the introduction of substances such as salts in the water (Berk,2009). The freezing point of water can now also be defined as the temperature at which water begins to freeze. Different liquids have dissimilar freezing points, and the freezing points of these fluids can also be altered. Addition of salts to water lowers the freezing point of water and this can explain why sea water does not freeze at 0 C or 332 F (Berk, 2009).

2.10 Evaporation

The phase change from liquid to gaseous state or vapor is known as evaporation (Marshall, 2014). The energy needed for this phase change comes from heat. For phase separation of solutions, evaporation is defined as the removal of water or a solvent from a solution through heating (Marshall, 2014). Evaporation is based on heat transfer theories and is essential in the study of boiling and condensation. Evaporation is very beneficial to our ecosystem; it plays a major role in the water cycle which helps in rainfall. In desalination, evaporation is also important for the water to be separated from the sea water solution.

2.11. Conductivity

This parameter is the measure of the ability of a material or substance to allow electric current flow through it when a potential difference is applied (Silla and Wypych, 2019). Conductivity canals be simply defined as the opposite of electrical resistivity. It is measured in micro-Siemens per centimeter (µS/cm). Materials that have high conductivity are known as conductors and materials that have low conductivity are insulators (Silla and Wypych, 2019). For solutions such as sea water or brackish water, the conductivity occurs as a result of the mobile ions. The formula for measuring conductivity when the surface resistance is known is 1/Rs (Sharaf, 2020).

Conductivity is temperature dependent and increases with increasing temperature. For aqueous solutions such as sea water, another factor that affects conductivity is the concentration of the solution (Sharaf, 2020). This means, at higher temperatures and large quantities of salt present in a solution the conductivity will also be high or large. Conductivity can be related to salinity, and this has enabled researchers to determine the average concentration of sea water.

2.12 Salts and Ions Present in Water

Aside from the Sodium Chloride (NaCl) present in seawater, there are other ions that may be present in water. These ions can give water a property which on the ability of the water to lather with soap. These ions are

present in a minimal amount and are not harmful to consumers. Salt is not required in pure water and hence the reason it must be completely avoided. The various ions and sodium chloride are going to be discussed in subsequent. The percentage of these ions present in sea water can be verified although it is not a subject of matter in this research. There are various experiments which give information about ions present in water.
These inorganic substances found in sea water affect the conductivity of the water. There are some organic materials that get dissolved in sea water. These organic particulates can be dissolved as amino acids or carbohydrates. Phosphorus and nitrogen are also notable ions found in sea water because of the role they play in the entire ecology of the ocean. These ions help in the growth of organisms that live in the sea and the ocean. The ions present in sea water add to the weight of the water. The volume or number of salts present in the sea varies because of evaporation and precipitation in different regions (Anon, 2023).

2.12.1 Sodium Chloride (NaCl)

In inorganic chemistry, sodium chloride can be described as a halide (House, 2020). This type of salt is not only found in seawater, but it can also be found in salt beds and salt brines all over the world. Sodium chloride is also described as salt and therefore has a pH of 7. Salts are formed from neutralization reaction and are usually neither acidic nor basic (House, 2020). This salt or halide is a compound which is made of Na^+ and Cl^- ions. Sodium chloride is also the general name for what is referred to as common salt. Although NaCl is essential and is abundant in the world, the water crisis and constant need for water makes it undesirable in seawater. This is a reason for investments in desalination to obtain pure water from this sodium chloride contaminated water. The molecular structure of NaCl is shown in Fig. 2.7.

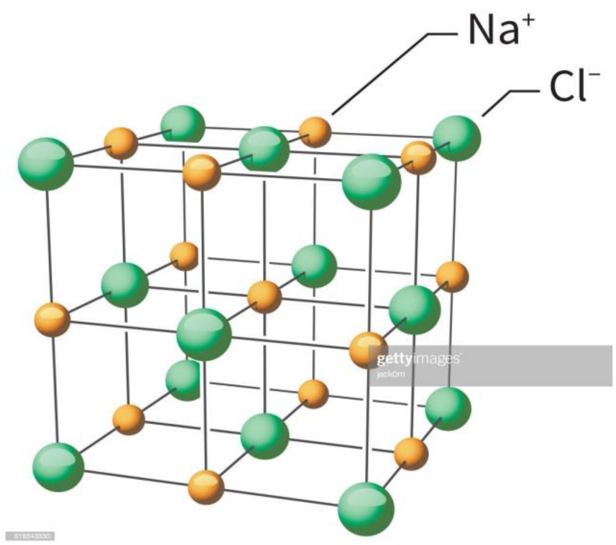

Fig. 2.7 An illustration of the molecular structure of a common salt crystal cube (Source; Anon, 2023).

Sodium chloride as one an important halide is one of the most abundant inorganic chemicals on earth (House, 2020). It is mined in several places for different reasons. In desalination is undesirable and must gotten rid of. Water containing sodium chloride has a higher salinity and conducts electricity very well and hence the reason conductivity can be related to salinity. This means sea water has a higher salinity and conductivity than fresh water and brackish water. The mobile ions in the sodium chloride compound make it a good conductor.

2.13 Heat Transfer

The temperature difference between different points is responsible for heat transfer. For horizontal and vertical tubes, heat transfer is affected by gravity and hence temperature difference between different points (Brunner, 2014). Temperature difference is directly proportional to the heat flow (Brunner, 2014). The temperature difference will also keep decreasing as mass increases. This concept is used in many fields of engineering including desalination. Heat flow is measured in the ocean and useful geo-scientist for many research purposes. Also, another important factor that affects heat transfer is the material for transmitting the heat. There are materials that can transfer heat from one point to another easily, and there are others that cannot do it very well. Metals are examples of materials that are good conductors of heat. Heat can also be transferred without a medium through electromagnetic waves or photons.
Nanofluids containing nanoparticles have shown an improved efficiency for heat transfer (Benseba, 2013). There are also different means by which heat is transferred and each uses these equations differently. Heat can be transferred through conduction, convection and radiation.

2.13.1 Conduction

The transfer of heat through matter without bulk transfer of the matter is known as conduction (Shahidian et al,2020). This mode of heat transfer occurs in solids, liquids and gases. Conduction can also be explained as the transfer of energy from a more energetic to less energetic particles of a substance because of interaction between the particles (Shahidian et al, 2020). For solids, conduction occurs because of lattice vibrations while in liquids and gases it occurs because of collision and diffusions of molecules during random motion (Balmer, 2011). Heat conduction is used in different areas and aspects of our lives. Heat conduction is used in heating homes, for cooking, the principle for making pressing irons, welding of two metals and so many others.

The pipes and tubes used in desalination also employ conduction principles for an efficient process. The liquid which is going to be desalinated is matter and therefore conduction occurs when heat is being transfer from one point of the fluid to the other. The heat transfer process also depends on different factors. Material property, temperature gradient, cross section of material involves, and path length are also factors that have an influence of the conduction process (Balmer,2011). Temperature flows from the hottest to the coldest region in conduction. Materials that do not conduct heat very well are known as insulators.

The flow of thermal energy from one point to the other through conduction can occur in either aa steady state or an unsteady state. Steady state conduction exists when the temperature at all points of a substance is constant with time (Balmer, 2011). A typical example of this type of conduction is the flow of heat through a uniform wall. Periodic and transient conduction are the two types of unsteady conductions. In the desalination process, unsteady state conduction can be encountered when seawater is pumped for purification. In food processing, air-conditioning and heat treatment of metals, unsteady state conduction is encountered.

The application of mathematical equations and formulae has made application of heat conduction easier for engineers. Scientists developed relations between different parameters to help solve heat conduction problems. Fourier´s law and equation is the used for heat conduction calculations. *"**Fourier's law is also known as the law of heat conduction, it mainly states that the heat transfer rate through a material is considered to be proportional to the negative gradient present in the temperature, as well as to the area, which is at right angles to the gradient, through which the heat flows. This law has two equivalent forms- integral form and differential form. This law is in an empirical relationship that is based on observation".*** The basic equation for conduction of heat as stated by Fourier is.

$$Q_{cond} = - k_t A (dT/dx) \quad (2.4)$$

Q_{cond} is the conduction heat transfer rate, kt is the thermal conductivity of the material, A is the cross-sectional area normal to the heat transfer direction, and dT/dx is the temperature gradient in the direction of heat transfer. The algebraic sign of this equation is such that a positive Q_{cond} always corresponds to heat transfer in the positive x direction, and a negative Q_{cond} always corresponds to heat transfer in a negative x direction. Since this is not the same sign convention adopted earlier in this text, the sign of the values calculated from Fourier's law may have to be altered to produce a positive when it enters a system and a negative when it leaves a system (Balmer, 2011).

2.13.2 Convection

The transfer of heat through two bodies by movement of currents through fluids is known as convention (Sokolova, 2019). The seawater used in desalination is a fluid and when it is heated up, convection occurs. Convection is a very efficient means of heat transfer in desalination and helps to successfully carry out the process. Another advantage of convection in desalination is that it maintains a steep temperature gradient between the body and surrounding fluid. This makes convection very efficient and effective. Heat transfer by convection goes along with actual material flow which is not the same in heat conduction (Muller, 2019).

In convection, the initial heat transfer occurs as a result of conduction and then the bulk movement of fluid which causes the convection follows. Convection forces occur naturally or can be forced. When a fluid is heated as in the case for desalination, the parts of the fluid which faces the heat source expands thermally. This hotter part gets less dense while the other colder region is much denser. The less dense part of the fluid moves and is replaced by the cooler one in a repeated cycle due to buoyancy. This mechanism accounts for convection in fluids (Anon, 2022). Convection is affected by factors such as viscosity, thermal conductivity and density. Convection is related to Newton's law of cooling and can be calculated using the formula stated below.

$$P = dQ/ut = hA(T\text{-}Tu) \qquad (2.5)$$

$P = dQ/dt$

- is the rate at which heat is transferred
- h is the convection heat-transfer coefficient
- A is the exposed surface area
- T is the temperature of the immersed object
- T_o is the temperature of the fluid which is under convection.

2.13.3 Radiation

The last type of heat transfer to be discussed is thermal radiation. Radiation is the emission of electromagnetic waves from all matter at nonzero temperature, in the wavelength range of 0.1um to 100um (Meseguer et al, 2012). It is known as thermal radiation because the cause and effect are thermal matter (Meseguer et al, 2012). Radiation occurs in almost all matter and a body has a very high temperature like an overheating oven emitting radiation. Every substance that has a temperature above 0 K emits radiation (Ting, 2022). Liquids, solids and gases transmit or emit radiation. Thermal radiation enables bodies with varying temperatures to emit radiation. The electromagnetic spectrum is shown in Fig. 2.8.

The energy transfer is carried in the form of electromagnetic waves called photons. These photons have both particle and wave characteristics, and their energy is given by h_v, where h corresponds to Planck's constant and ν denotes its frequency. Gamma rays, X-rays, ultraviolet light, infrared light, and radio waves are all categorized by their radiation frequency. However, visible light is only a small portion of the electromagnetic spectrum. Stefan-Boltzmann's law makes it known that the rate of heat that leaves an object depends on the absolute temperature of the object itself *T* and the surface area *A* (Young, 2015). The emitted heat is represented by Stefan-Boltzmann's law as

$$q_r = \varepsilon\sigma AT^4 \qquad (2.6)$$

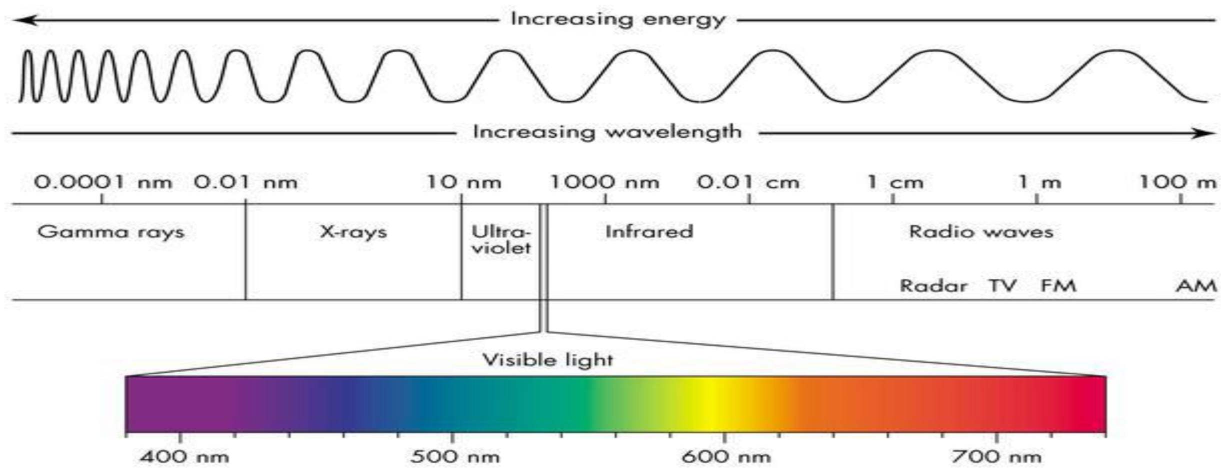

Figure 2.8 The electromagnetic spectrum which is made up of different types of radiation. The most energetic radiation with high frequency and shorter wavelength lies to the left.

Here q_r is the radiative heat flow rate, ε is the emissivity, *A* is the surface area, and *T* is the absolute temperature of the surface. σ correspond to the Stefan-Boltzmann's constant and is equal to 5.672×10−8 $W/m^2 K^4$.

2.13.4 Absorption

A fluid's capacity to absorb solar radiation is considered as a necessary requirement for photothermal conversion of the solar energy available. Therefore, absorption properties of the working fluids used in this research are directly affected the efficiency of our system and are therefore subject to enhancement. When assuming that the working fluid is one-dimensional, the maximal radiation intensity, Io [power/area], occurs at the surface where $z = 0$ (Table 4.4). In this research, the Beer-Lambert law is used to check for the presence of particles in working fluid samples after desalination. The Beer-Lambert law provides decaying radiation intensity associated with the propagation length, z, within the fluid as

$$I = I_0 \exp[-Kz] \qquad (2.7)$$

where *I* and I_0 are the light intensity of the outgoing and incoming radiation, respectively, *z* is the length of the radiation in the medium while *K* denotes the extinction coefficient. The latter is a quantitative characteristic of the light absorbance ability of the medium in question. By rearranging Beer-Lambert's law, the absorbed energy in a volumetric absorber is expressed as

$$E_{abs} = I_0 - I = I_0 [1 - \exp(-Kz)] \qquad (2.8)$$

As previously stated in Section 2.13.3, a body of absolute temperature T higher than absolute zero emits energy in the form of thermal radiation. Moreover, the surroundings of the body with temperature T_s will also be radiating, leaving the body to absorb some of this radiation. The incident of thermal equilibrium occurs when the temperature of the body and the surroundings are equal, $T = T_s$, and the rates of radiation and absorption are also equal. Hence, the rate of absorption can be expressed with Stefan-Boltzmann law (Eq. (2.6)). The net heat exchange between the body at temperature T and its surroundings at temperature T_s is therefore given by:

$$q_r, net = \sigma\varepsilon A\,(T^4 - T_s^4). \qquad (2.9)$$

The net radiative heat transfer is out from the body to the surroundings for positive values of *qr,net* (Nguyeng, 2022). An idealized black body in thermal equilibrium emits the same amount of energy that is absorbed, according to Kirchhoff's radiation law. Hence, $\alpha = \varepsilon$, and the radiative loss for a volumetric absorber is calculated as

$$E_v = [1 - exp(-Kz)]\ \sigma T_v^4, \qquad (2.10)$$

where the emissive power is denoted E_v and the working fluid temperature is T_v. The relation shows a proportionality between emissive power and the extinction coefficient.

2.14 Fluid Mechanics

Fluid mechanics is the branch within physics and engineering science that governs the behavior of fluids is called fluid mechanics. Ample knowledge of fluid mechanics is essential for investigating the fluid movement within systems as well as the analysis of heat flow and fluid transfer (Warren, 2005). In this research fluid flow through a pipe is essential and fluid mechanics helps in understanding how these movements through the pipes occur.

2.14.1 Basic Equations of Fluid Flow Bernoulli's Equation

Bernoulli's equation relates the kinetic energy of a unit mass of fluid, the work done by external forces, and the potential energy of a unit mass of fluid in a mechanical energy balance. Additionally, the loss of mechanical energy in the system due to fluid friction must be taken into consideration. Any conversion of mechanical energy to heat in a fluid flow is considered as fluid friction, and the disappearance of mechanical energy is equal to the heat generated, according to energy conservation principles (Nguyeng, 2022).

For fluid flow estimation in fluid mechanics, Bernoulli's equation has been simplified and is used to calculate the theoretical velocity in the pipe. There are some assumptions that are made for calculations and are stated as follows:

- Assume that the flow is laminar, that is, $\alpha_a = \alpha_b = 2$, and that the pressure is atmospheric, resulting in $P_a = P_b$.
- For station *a*, which is at the top of the inlet reservoir, the average velocity V_a equal zero.
- The height z_b is the level of the outlet of the pipe system, which is set at zero elevation. Further on, the height of the fluid near the inlet, z_a, is denoted as H for simplification.

CHAPTER THREE

METHODS

3.1 Study Design

This research work involved comparative analysis of different fluids and how the fluids improve desalination. Nanofluids of different concentrations, sea water and pure water are analyzed differently in this work. The study involved preparing nanofluids using carbon black particles and preparing dark coffee of different concentrations. The pure water was obtained from running tap and the sea water was prepared in the laboratory using NaCl and pure water. The different nanofluids prepared in the laboratory have water as base fluid and different masses or volume of carbon black were used. Water was also the base fluid used for coffee.

Two experimental set ups were used in this research work. The first set up had no pump but also used a beaker to collect the experimental fluid. The fluids were held with a lamp as heat source, and they evaporated and condensed into another bigger glass beaker. This first set up investigated the average time needed for transport of experimental fluids after being boiled, evaporated, and condensed. These results were compared and noted. The temperatures were noted but the focus was the time taken to fill 10mm of the bigger glass beaker. This first set up was also used for desalination to separate purified water from the laboratory prepared sea water. The second set up was mainly put up for desalination and had a pump and round bottom flask with two openings. The water obtained from the desalination experiment was collected and the concentrations of these fluids had to be measured and analyzed.

For the experiment to be to be conducted repeatedly and at any time, measurement of distances and fluid volumes were noted. These reliable experimental set ups included a lamp as a heat source and a test tube attached to a clamp. Temperature measuring devices were also used to measure temperature and a tape measure was used to note distances. The conductivity meter was also used for measuring salinity after desalination which helped to know the concentration of the water produced. Tab. 3.1 shows a list of the laboratory devices used for the experiments and their manufacturers.

Equipment	Usage	Manufacturer
Bransonic Ultrasonic Cleaner BRANSON 3510E-DTH	Extra mixing of NF and SDS in an ultrasonic bath. Duration: 1hr	Branson Ultrasonics Corporations
Magnetic Stirrer VWR VMS-C4 ADVANCED	Mixing of NF and SDS. Duration:20mins	VWR Collection
Precision Scale SARTORIUS EXTEND	Weighing of substances	Sartorius

Conductivity Meter FISHERBRAND	Measuring conductivity of fluids	Traceable
Stop Watch	Measuring time	Apple
Halogen Flood WITHOUT MOTION SENSOR	Used as a heat source for boiling fluids.	RS PRO

Table 3.1 List of Laboratory Equipments

3.2 Formation of Nanofluids in The Lab

Black carbon nanoparticles ENSACO™ 350G from Timcal with a bulk density of 2 250 kg/m^3 were used in preparation for nanofluids used in this research work. The particles are nano-sized, that is the inverse of a billion. These particles are very light weight and decolorize water when a little amount is added. The particles sediment and hence the reason mixing devices are used. The nanofluids used for this research purpose are black in color and were prepared in different concentrations but through the same procedure. The preparation for a particular concentration of nano fluid can take up to ninety minutes. The nanoparticles are very light in weight and exist in powder form so must be handled with care.

For any concentration of nano fluid going to be formed, the mass of nanoparticles is weighed, and the volume of water is also measured. The volume of water used in this research work was 200 ml and the corresponding mass was based on the agreed concentration. For 0.01% concentration, the mass of nanoparticles used is 0.02 g. The amount of SDS used must be the same as the number of nanoparticles used for a particular concentration. The water and nanoparticles are mixed in a mixer which uses magnetic principle. The mixing only begins when magnetic ice is placed in the mixture of water and nanoparticles. The mixing is done for about 20mins and then then move to another device for ultrasonic bathing. This process takes place for 60mins, and the black color of the desired nano fluid is obtained. The relation mentioned for the 0.01% concentration means for 0.03%, the mass of nano particles to be used is 0.06 g and the SDS must also be 0.06 g. The relation helps to prepare the fluids in the lab easily.

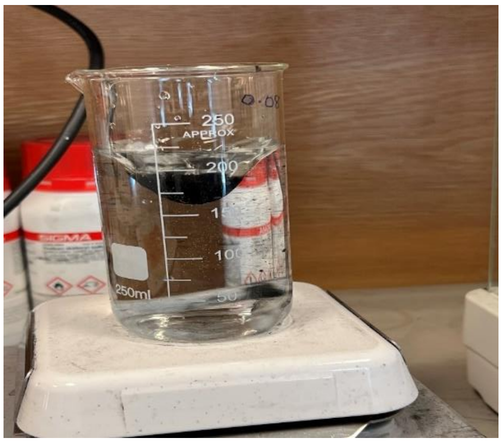

Figure 3.1 Nanoparticles being mixed up for thorough mixing with water (Magnetic Stirrer VWR VMS-C4 ADVANCED)

3.3 Formation of Seawater

The concentration of seawater is already known to be 35 ppt and so can be easily prepared in the laboratory. The water is readily available in the laboratory and the NaCl, also known as common salt, can be gotten easily. To prepare sea water in the laboratory, clean volumetric flask is required. The resulting mixture will have a concentration of 35 ppt and sea water for experiments has been made available. The device used for measuring the salt is displayed in Fig. 3.2.

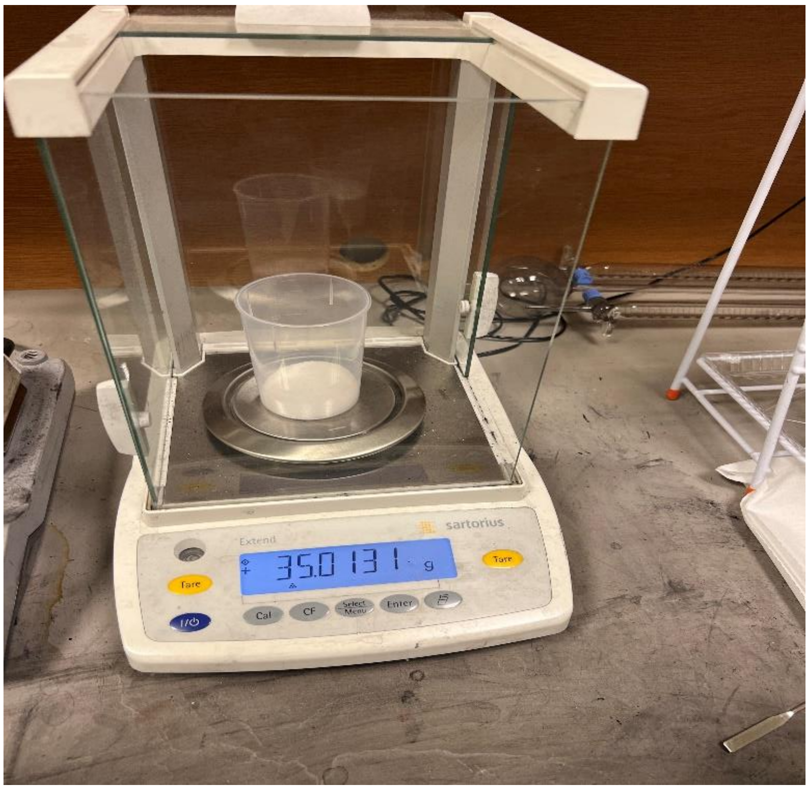

Figure 3.2 A Digital Scale for Weighing Salt (Precision Scale SARTORIUS EXTEND)

3.4 Experimental Set up and uses.

Two different set ups were used for conducting experiments for desalination in this research. The set ups are designed to be able to heat the fluid in a beaker and transfer it to another beaker. The set up was designed in the University of Bergen laboratory and can be set up again for repetition and confirmation. For this research work, the fluid had to be heated so both setups had a heat source. The experiments were conducted with precision and accuracy and so the required devices were used for every measurement. Some of the devices used for the experiments included a level, tape measure, digital thermometer gun, conductivity meter, ultrasonic bath device, digital weighing scale and various volumetric glass beakers.

3.4.1 Experimental Setup Which Involves No Pump

The first set up was used for desalination as mentioned and used to test how long it takes for different fluids to be transported. The transportation in context of this research was movement of fluid from a heated fluid in a beaker to another beaker. For easy analysis and drawing conclusions, the transported fluid had to fill 10ml of the second beaker for experiment. The duration of this transport was taken using a stopwatch and a thermocouple or thermometer used to measure temperature. The first set up had a very simple design and took a shorter duration to fill 10ml of the beaker compared to the second experimental set up. The first set up had a heat source and fluid to be heated was placed several centimeters away from it. The fluid to be heated was placed in a beaker and filled. In order to hold the fluid in the beaker, a clamp was used to hold the beaker close to the heat source. The beaker was covered with a cork and a tube penetrated the cork to allow the fluid flow to the other beaker. The rises and fluid flowed through to the tube to the second beaker when it had been heated to a certain temperature. This occurred beyond the boiling point of all the fluids used for each experiment. To avoid error in measurements, the lamp which served as a heat source had to be cooled before performing another experiment. For this same set up, when sea water was used, and the resulting water was obtained it had to be transferred to another beaker for salinity to be measured. Important devices such as stopwatch, thermometer and salinity meters were not attached to the set up but were used in isolation. Fig. 3.3 and Fig. 3.4 are visual representations of the simple set up used for desalination experiments.

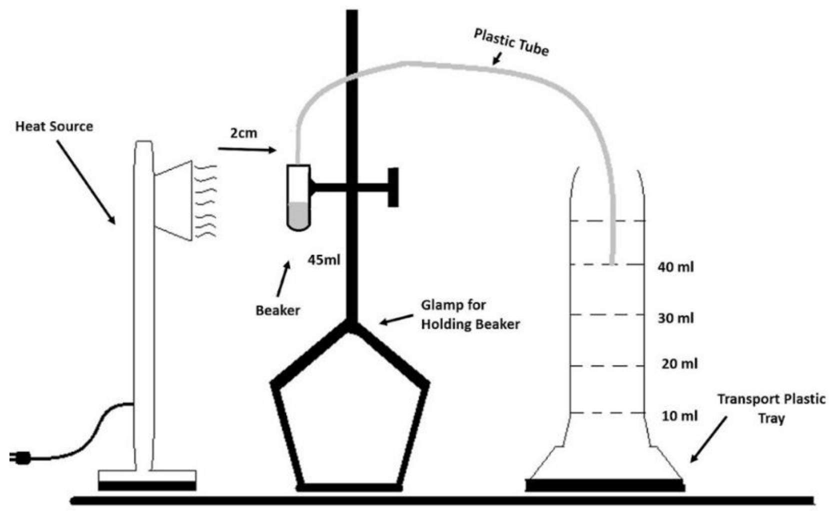

Fig. 3.3 A graphical representation of the setup for conducting the desalination experiment using boiling and evaporation (not drawn to scale).

Figure 3.4 An image of the experimental setup for performing desalination using boiling and evaporation.

3.4.2 Experimental Setup Involving a Pump

The second experimental set up was used mainly for desalination and included only a LAMDDA PRECIFLOW pump and round bottom flask which had two openings. The set also had thermometers and salinity meter isolated from it. Temperature and time measurements were taken manually. In this second set up, the sweater was pumped and transferred to the round bottom flask. The water in the round bottom flask was heated and upon boiling and evaporation it rises and flows into a beaker. The same 10 ml standard was used for this beaker. The resulting liquid was taken, and the salinity was measured. It is worth noting that, the salinity meter used in the laboratory measured conductivity in µS/cm which was later converted to ppt using an online calculator. The second set up is represented in Fig. 3.5 and Fig. 3.6.

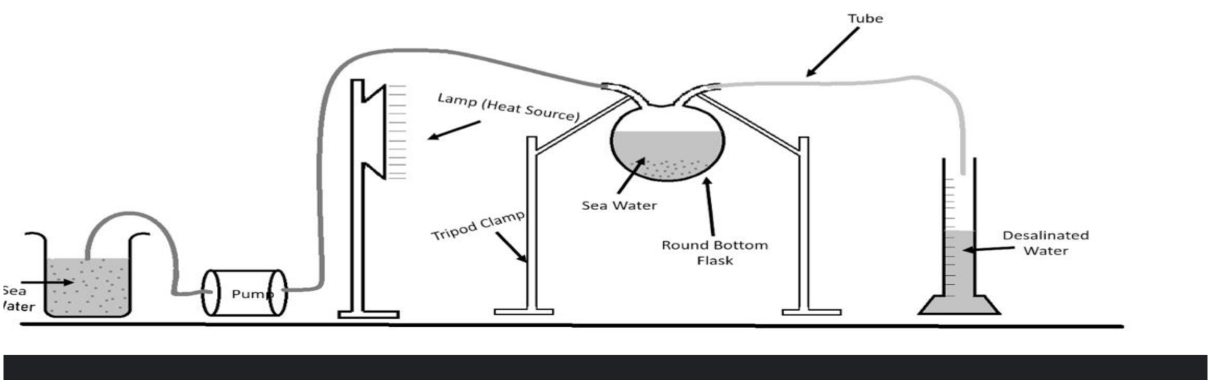

Fig. 3.5 Experimental setup for desalination using boiling and evaporation which included a pump and round bottom flask (not drawn to scale)

Figure 3.6 Image of experimental setup for desalination using boiling and evaporation which included a pump and round bottom flask.

3.4.3 Lamp and Beaker Positions for Experimental Setups

To ensure this experiment was carried out in a very accurate error free manner, the positions of the lamp and the location of the beaker had to be noted carefully. The best way to achieve this was getting the dimensions of the lamp and beakers. To ensure easy repetition and good analysis, the beaker was always placed in a central position to the lamp no matter the distance the beaker was away from the lamp. The Dimensions and positioning is portrayed in Fig. 3.7.

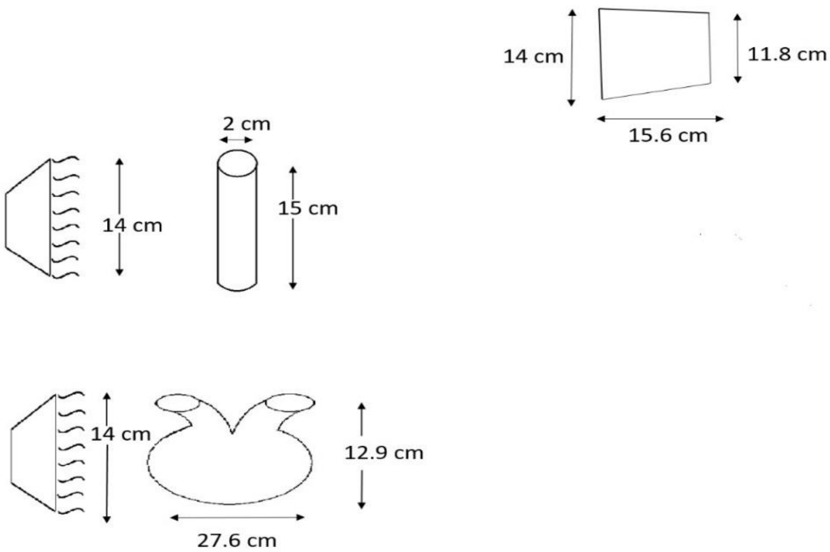

Fig. 3.7 Dimensions of lamp, beaker and round bottom flask used for experimental setup.

3.5 Experimental Data

The different experiments conducted give available data tone analyzed and investigated. For this research purpose, the data obtained from experiments were put in table and graphs and are given unique titles. The tables listed in this chapter four give an overview of how results are grouped and are not all the data obtained from the whole research work.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Overview

The chapter focuses on the experiments conducted and how the data obtained are analysed. The main fluids for this research which are water, nanofluids and coffee have been different set of data that has to be examined. The main objective which is to investigate desalination methods is key in the analysis although there are different results that are discussed for the same goal. The preparation of nanofluids is discussed and the seawater concentration is noted. The seawater concentration is also used for making nanofluids which have the same concentration for easy analysis. This means, nanofluids are mixed with salt to also have a concentration of 35 ppt.

While conducting experiments and noting down results for investigation, some other calculations are also noteworthy. The amount of fluid to be put in a beaker for each experiment is taken notice of the distance from light source and beaker and the temperature at which boiling begins for each fluid. Another important parameter that is of essence in this investigation is the time it takes to complete the experiment. To producing pure water from sea water, the conductivity meter is introduced. The meter used for the experiments measures conductivity which is then converted to concentration in ppt. Since the same concentration is used for the seawater and nanofluids, the results can be compared and examined. The values and results from the two experimental set ups are compared to find out a more reliable way of performing desalination. The observations made during the desalination experiments for nanofluids made it necessary to prepare some of the nanofluids without SDS for comparatively investigations. The data obtained from every experiment is for the purpose of desalination and how it can improve the process to obtained purified water. The research work is similar using solar thermal collectors enhanced by nanofluids for water desalination by (Zakaria et.al, 2021). The involvement of evaporation and carbon black nanofluids make these works similar.

4.2 Experimental Set-up and Experiments

When the research began, definite distances and volumes were not agreed on. The inception of the experiments led to consideration of lengths and volumes to be used for each experiment. To know the working fluids had the same amount of desalinated fluid after every experiment, 10ml was decided upon. Also, to ensure safety and avoid accidents, the beaker containing fluids to were handled with a very thick plastic insulating material. The cork which supported the pipe for fluid transfer was fitted well on the beaker to avoid escape of vapor and fluid (see Fig 3.3).

The second set up which included a pump had the fluid bearing beaker replaced with a double opening round bottom flask. The flask received water from the pump through a tube and the desalinated fluid also flowed out through another tube in the other opening. The disadvantage with the second set up was, one the fluid reaches a certain volume, the pump had to be put off avoiding a spillage.

4.2.1 Preparation of Working Fluids

All fluids used for this research were prepared in the University laboratory. The sea water was prepared using common salt (NaCl) and pure water. This was easy to prepare because review literature had already made known the concentration of sea water. The nanofluids were prepared using the methods described in the previous chapter. This consisted of tap water, black carbon nanoparticles and SDS. The particles had to be mixed by a very thorough process which included ultra sonic bathing. The coffee was also prepared using taped water and with the coffee making machine (see Section 3.2). For making of the nanofluids, a similar method used by (Kosinska et. al, 2022) and (Nguyeng, 2022) was used.

4.3 Duration of 10 ml fluid evaporation from one beaker to another to another

Before the actual desalination experiments began, the set up was tested to know how fluids will move. A sample fluid was placed in a beaker close to the radiation source which is a halogen lamp. In (Zakaria et.al, 2021), a solar water is used for heating and is tilted at an angle of 30°. A tube is placed in a cork covering this water and connected to another beaker. For easy analysis, 45ml of fluid is placed in the beaker for each sample. The beaker is made of glass and so is very transparent. Several glass volumes are available for volume measurement so makes it not difficult to measure. The tube which transported the fluids is made of plastic and had the ability to withstand the heated fluids with getting destroyed or deformed. The tube is easily adjustable and so makes moving it effortless. The glass beaker for this experiment was placed 2cm away from the heat source for each experiment. The results produced by each experiment is noted down in tables and these data are used for the graphs. Several experiments were carried out each for this for every reason for accurate and precise results. The experiments for the fluids were carried out five times and the average were taken to make a plot for the dependence on the flow by evaporation and boiling with time.

The time taken for these fluids to flow from the beaker closer to the heat source to the other beaker is the most paramount parameter. The amount of time taken is necessary as it helps prepare for the next experiments. Fig. 4.1 and Fig. 4.2 are graphical representations of the results obtained. The results in the Fig.4.1 and 4.2 also confirm that, adding nanofluids to a fluid can the heat efficiency by increasing the thermal conductivity (Zakaria et. al, 2020). The increasing thermal efficiency is responsible of reducing the time needed to transport 10 ml of fluid.

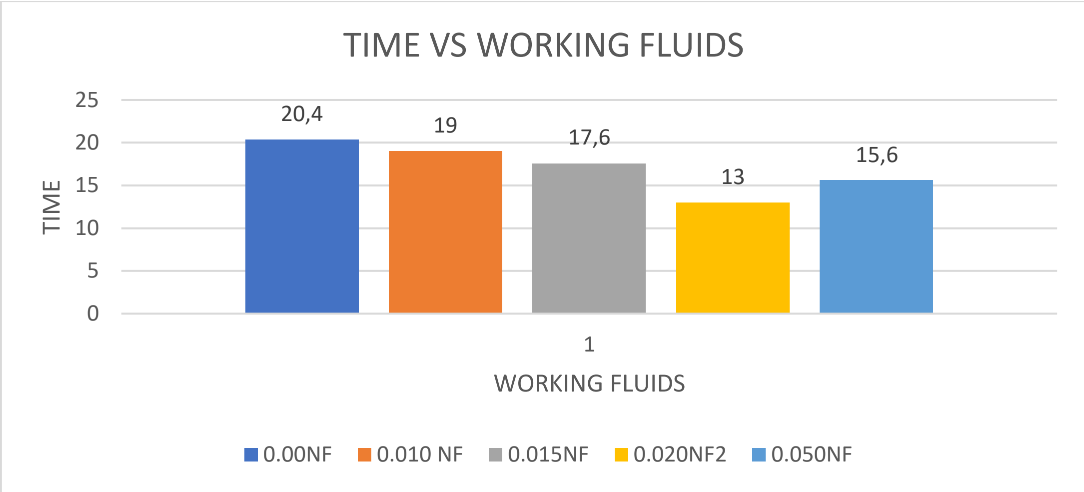

Figure 4.1 The time taken for 10ml fluid to be evaporated from and condensed into beaker.

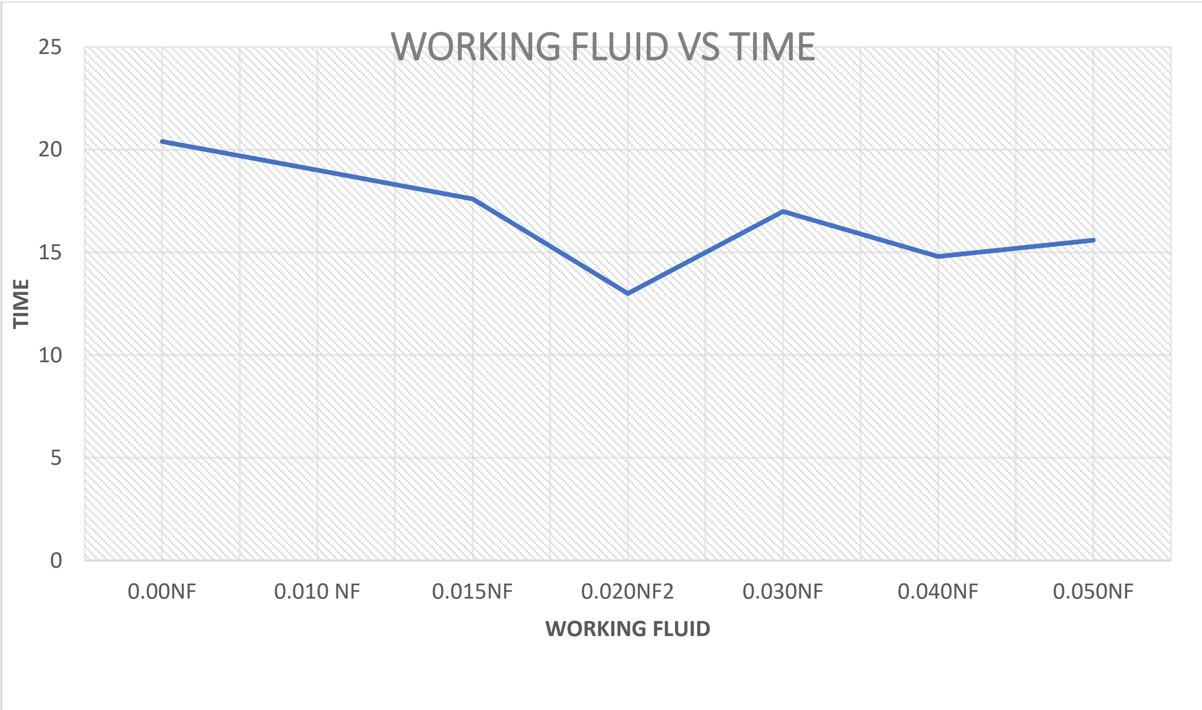

Figure 4.2 The time taken for 10ml fluid to be evaporated from and condensed into beaker.

The resulting graph suggests that, as the concentration of nano fluid increases, the time taken to flow from one beaker to the other decreases. The 0.00% in the graph represents water since it is being assumed that it is a nanofluid for easy investigations. This also suggests that the darker the fluids get the greater the ability the fluid must conduct heat which aids in the transportation of the fluid. The result for coffee is shown in the Table 4.1 below suggesting that coffee also conducts heats better that water and less concentrated nanofluids. The maximum concentration for this experiment was 0.050% although higher concentrations can be experimented with. The result for these experiments gives the idea for what to expect when these fluids are used for the main desalination experiments. The temperature measurements taken were also of essence as it helped to make sure the beakers and heat source had a particular starting temperature for each experiment. The 10ml volume requirement for complete transport was taken note of with the aid of the volumetric glasses.

Fluid Type	t (mins)
Coffee	15
Coffee	16
Coffee	17
Coffee	16
Coffee	17
Average Time	16

Table 4.1 Average time taken for coffee to be evaporated to fill up to 10ml.

A necessary precaution that had to be taken for this experiment was using an insulation material to handle beakers after heating to avoid burns. The high temperatures lamp used for heating also produced very bright light which could affect the eyes so the use of googles was need. To avoid stains from coffee and carbon black nanofluids, wearing a laboratory coat was also very necessary. Parallax error was also avoided by proper reading of volume measurements on glass beakers.

4.3 Using Boiling and Evaporation for Desalination of Seawater

Two different set-ups are used for seawater desalination in this research. The set ups are showed in the previous chapter (Fig. 3.3 and Fig. 3.4). The inclusion of a pump and double opening round bottom flask makes the difference in the two set ups. Although the two set ups vary a little, they are based on the same principles. The heating of the fluids caused the fluids to rise through the tube to the volume measuring glass to allow the salinity of the resulting water to be measured. The salinity of seawater is 35ppt, the water produced is therefore expected to have a much lower salinity to prove the effectiveness of the experiments and the experiments and set ups. In (Essa et. al, 2020), solar still is used for the desalination using solar energy as well. In this research the halogen lamp which is the main radiation is used and the seawater. The salinity is then required to be reduced by evaporation just like in the used of solar still.

For the first set up without the pump, the positive thing about it is the short time is takes for the fluid to be desalinated. Compared to the data gathered from the experiments, the set-up which includes a pump took a longer time for the entire process to be complete. The temperature at which boiling began in each of these two set ups were all greater than a 100 C. The transport of the fluid from the beaker close to the heat source to the one volume measuring beaker happened by evaporated fluid rising through the tube and condensing in the volume measuring beaker. The boiling of the fluid also aided in rising of the fluids from the beaker through the tube to the volume measuring beaker. For time’s sake and for consistency, the volume of fluid needed in the volumetric beaker was 10ml per experiment. When the 10ml is gotten, then the fluid is then taken away for salinity to be measured to check if indeed desalination has occurred.

4.3.1 Salinity measurement

The conductivity meter used in this experiment helps to know what actual happens. It measures conductivity in mS/cm or µS/cm which is later converted to ppt. The device works on a principle which assumes a temperature of 25°C/77F. The device is a very simple one which is inserted in the fluid and then conductivity reading is read in mS/cm or µS/cm which is then converted to ppt for the purpose of this research. Several experiments were carried out using the two set ups for the seawater and the average salinity was noted. For the set-up which included a pump, though it had a longer procedure for the whole process, the results obtained gave the best average salinity. The average salinity for the set-up which included no pump was 0.029ppt which is much higher than the set-up which includes a pump which is 0.019. Table 4.2 and 4.3 are tables representing the data and results from the experiments carried out. The results showed like in the previous works done by (Guo et. al, 2022), the setups had a good water desalination performance. Despite the exclusion of P-SVTD used in (Guo et. al, 2022), the desalination performance by the experimental setups was impressive.

Fluid Type	**Salinity** (µS)
Seawater	0.029
Seawater	0.031
Seawater	0.026
Seawater	0.029
Seawater	0.032
Seawater	0.029

Table 4.2 Average salinity of seawater after desalination using the set up without a pump.

Fluid Type	**Salinity** (µS)
Seawater	0.019
Seawater	0.018
Seawater	0.019
Seawater	0.018
Seawater	0.019
Seawater	0.019

Table 4.3 Average Salinity of seawater after desalination using the set up with a pump.

4.4 Using CB Nanofluids for Desalination

Nanofluids with 35 ppt salt concentration were formed and experimented with to know how they can improve desalination. The fluids were easy to be prepare because the seawater concentration is known and can be applied in this experiment. Different concentration of nanofluids were prepared for the sake of this experiments. However, the set-up which did not include the pump was the only one used for desalination which was made up of CB nanofluids. The same 35ppt concentration of salt was used for each CB nano fluid so it acted like seawater. This was also to make it easy for analysis and comparisons. The concentration varied from 0.010% to 0.100% and each gave a peculiar result because of the different of nanoparticles each of them contained. For the set up used for this experiment, the duration for each concentration takes a shorter duration to complete the entire desalination process compared to water. Seawater comparatively takes a longer time as shown in previous results. The use of carbon black nanofluids for this research played a similar role like silver nanoparticles in (Parsa et. al, 2020). The major difference was in this case, there was no need for bacterial removal for carbon black to act as an anti-bacterial agent. The carbon black nanoparticles improve thermal efficiency and help to produce much less saline water for consumption.

Although the salt completely dissolved in the CB nanofluids, some slight changes occurred during heating for some of the concentrations. The dissolution properties of salt and nanoparticles start to change when the heating of the fluids for some concentrations are heated. It is observed that, the very low concentrations, 0.01%-0.04% had nanoparticles dissociating from the fluid when heating begun. Fluids of this concentration took a longer time for the desalination process to complete and yield some positive results.

A trend was realised when the concentration was increased to between 0.050% to 0.100%. The nanofluid mix with salt to behave like seawater did not dissociate when it was heated. Another thing worth noting was the fact that, the duration for desalination for these concentrations were short compared to the lower concentrations. Figure 4.3 is a graphical representation of the trends that were noted and results that were obtained.

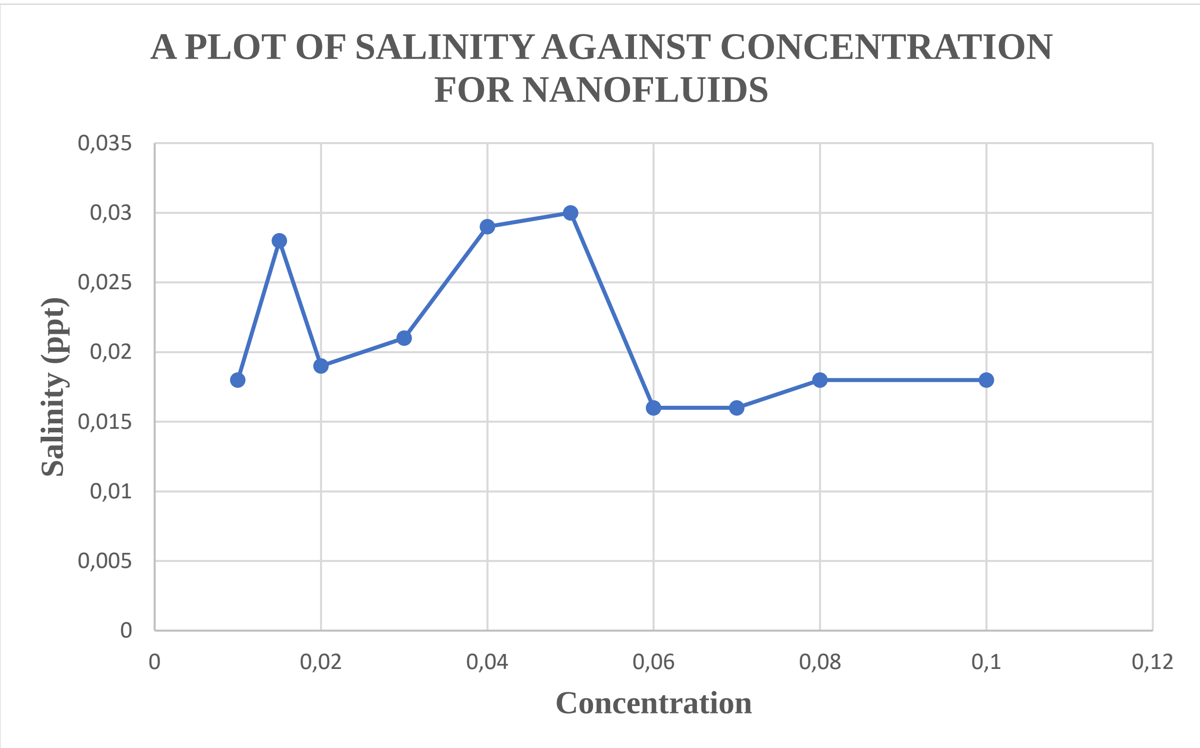

Figure 4.3 Salinity of nanofluids after desalination

The graphs and information presented above shows that, the salinity after the desalination process for all fluids in these experiments decreased drastically. The initial 35ppt concentration was reduced to less than 1ppt for each concentration of the CB nanofluids. The results show that evaporation and boiling do help in providing less saline fluid. This also means majority of salt has been removed from the fluid which is the aim of the experiment.

The trend for the salinity of nanofluids formed with SDS also shows that, beyond 0.05% concentration nanoparticles present in seawater desalination can be improved to obtained seawater. Specific volume requirements of seawater must be noted was well.

4.4.1 CB Nanofluids formed without SDS used for Desalination.

Based on results obtained from the section above, the decision to conduct experiments with nanofluids which are formed without SDS was considered. From the previous sections, CB nanofluids are known to be formed using SDS. When the nanofluids experiments were conducted for desalination, the lower concentrations segregated when salt was added and heated. This led to the introduction of producing nanofluids without SDS for this research. For this reason, new batches of nanofluids had to be prepared. The same procedure and method were used but this time without SDS. This was done to make a conclusion on why the dissociation occurs and to know if the separation will occur when the nanofluid is formed with the SDS. The concentrations which were used for this set of experiments ranged from 0.01% to 0.050%. The experiments involved the use of the set up one which included no pump. The conductivity was also measured using the salinity meter and converted to ppt using a calculator. Fig. 4.4 is a graph representing the results that were obtained.

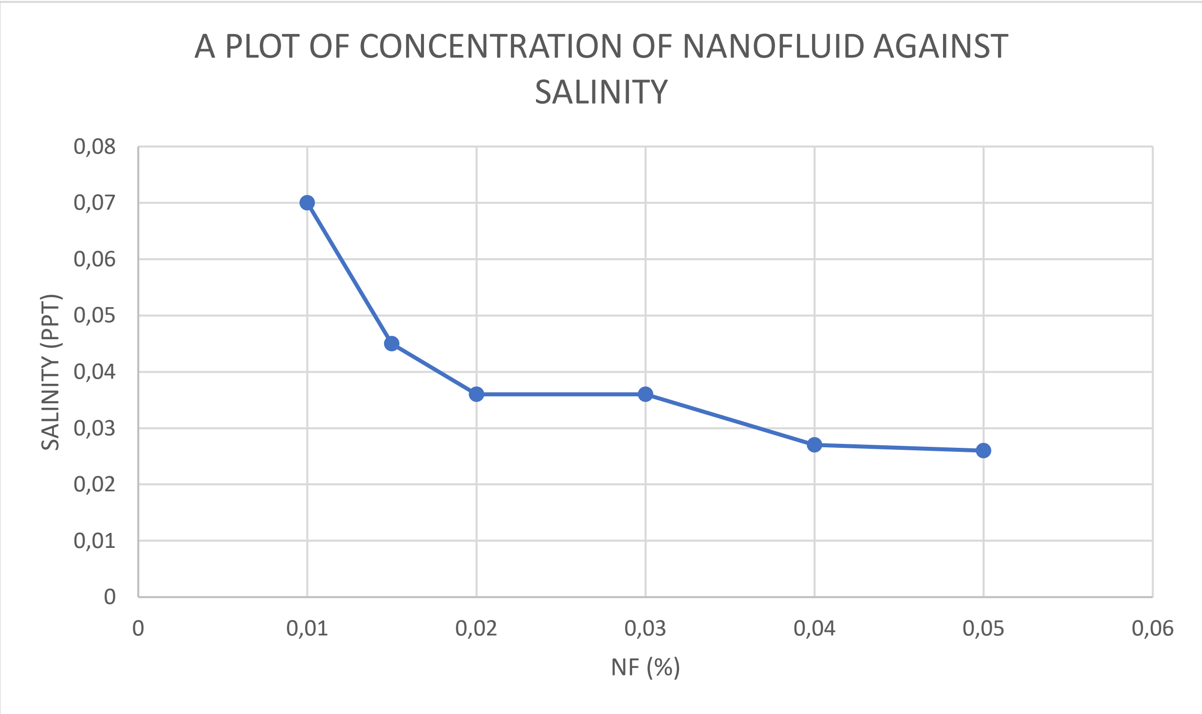

Fig. 4.4 Salinity of nanofluids formed without SDS after desalination using experimental setup.

Compared to the nanofluids formed with SDS, when the concentration of nanofluids formed without SDS increases the salinity decreases. This is not the same for the former which shows an irregular trend and begins to decline and plateau beyond 0.060% concentration. The graphical representation above also shows that, for nanofluids formed without SDS, desalination can improve when nanoparticles are added to specific amounts of seawater to obtained pure water. A well calculated volume of nanoparticles amount to specific volume of sea water can produce the desired pure water for consumption.

The results also show that, overall salinity measurements after experiments mean nanofluids formed with SDS gave the lowest salinities. This implies that, nanofluids formed with SDS will be the best when used for desalination.

4.4.2 Results for Using Coffee for Desalination

Coffee being one of the main fluids used in this research work was exploited for the purpose of desalination. Different concentrations of coffee were prepared, and the salt concentration of seawater was used for these concentrations. This was to ensure the coffee behaved like the seawater. The salinity after desalination was noted to see how much salt is still present. The coffee already had its own salinity and so the addition of salt increased it than that of the ordinary sea water and CB nanofluids. In (Essa et. al, 2020), coffee colloids proved to be viable replacement for carbon black nanofluids. The coffee was used as solar still and had an advantage of being eco-friendly.

For the coffee, the concentration of coffee used for the experiments ranged from 0.05 g/ml to 0.10 g/ml. The salt concentration remained 35 ppt as already stated. Several experiments were conducted for each experiment, and each gave different results. The average time for desalination of this coffee was 14mins which is a much shorter duration that that of the seawater and other lower concentrations of nanofluids. The results given by the coffee were noted and it was observed that, the lower the concentration of coffee in g/ml the lower the salt present after desalination. Hence, the coffee with concentration 0.05 g/ml gave the best desalination result. The salt concentration after the process was reduced to 0.014 ppt. As the concentration of coffee increased, the salt concentration after desalination also increased. Fig.4.5 is a graph that represents the results obtained.

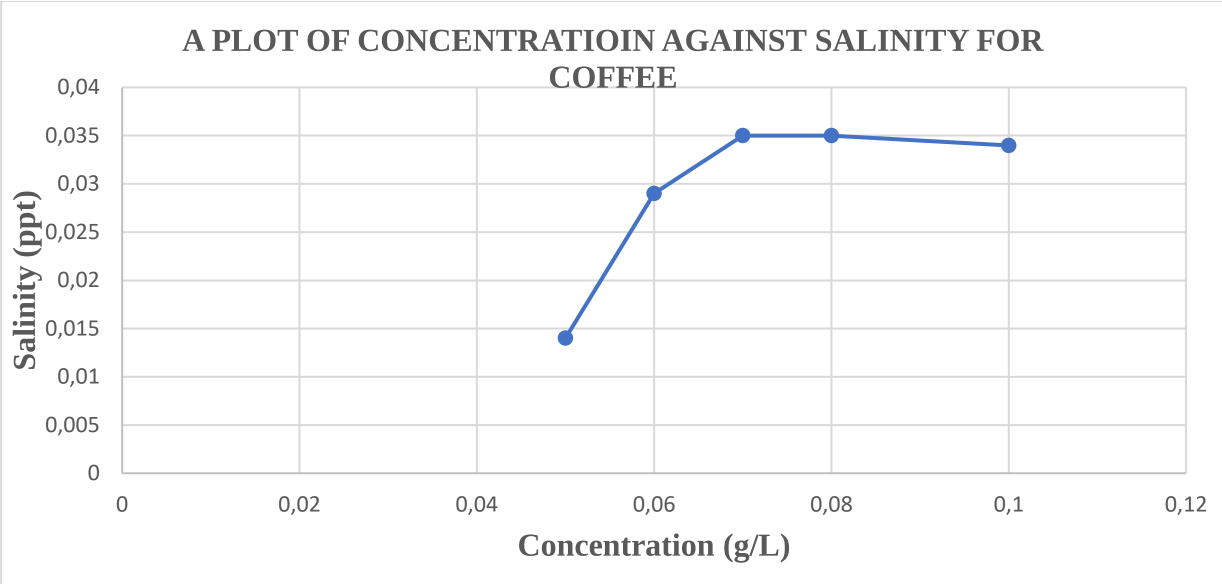

Figure 4.5 Salinity of coffee after desalination

It is observed that, the ppt after desalination for the concentration of 0.07, 0.08 and 0.10 g/ml almost plateaued. The average concentration of these fluids is 0.035 ppt which is greater than the 0.05 g/ml concentration. It is also worth noting that, the average salinity for all the coffee concentrations is greater than that of nanofluids and actual sea water. The means, although coffee yield some great results, it will not be so desirable for desalination compared to CB nanofluids.

4.5 Checking the effect of light on desalination by increasing distance (4 cm and 5 cm)

For accuracy and a more efficient outcome for desalination, the research involved exploring the effect of light on desalination. The method for the exploit was to increase the distance further away from the light source. The fluid in the beaker close to the light source was moved at several distances in this section. The conventional distance for majority of experiments in this research was 2 cm but for the purpose of this section, it was moved further away. The two main distances exposed for this test was 4cm and 5 cm. The same variables and experimental setup were used. The desired outcome was to know if desalination will improve or be better than the 2 cm.

Although it was about checking the effect of light, the main parameter considered was the distance and this was very essential to measure accurately. The tape measure used for the conventional 2 cm was used for this 4cm and 5cm experiments. The set up which had no pump was used for this experiment and the results were noted. The salinity after desalination was the main goal and so the results of salinity was noted for these experiments. One observation made for this experiment compared to the traditional 2 cm experiments was, the average duration for each experiment was longer. It took longer periods to complete experiments compared to the 2 cm experiments.

This experiment was carried for only seawater and the CB nanofluids formed without SDS and so the concentration range was 0.00%-0.050%. The 0.00% stated represents water because it contains no carbon black nanoparticles. The various experiments were carried out and the results are shown as follows in the graphs in Fig 4.6 and 4.7.

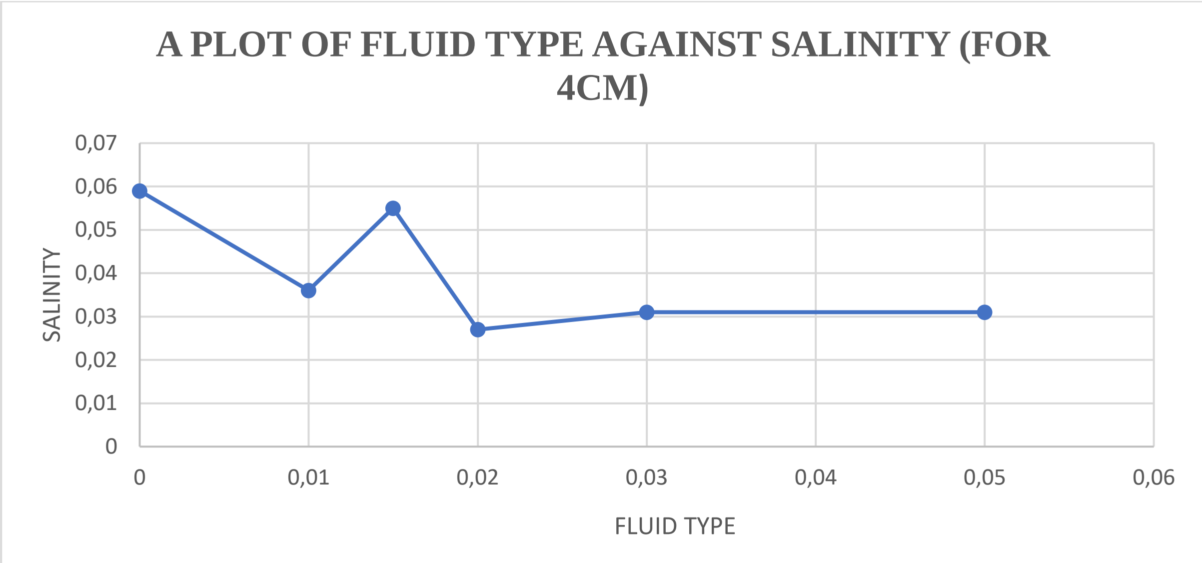

Fig 4.6 Salinity of fluids after being placed 4cm away from heat source to check if light affects desalination.

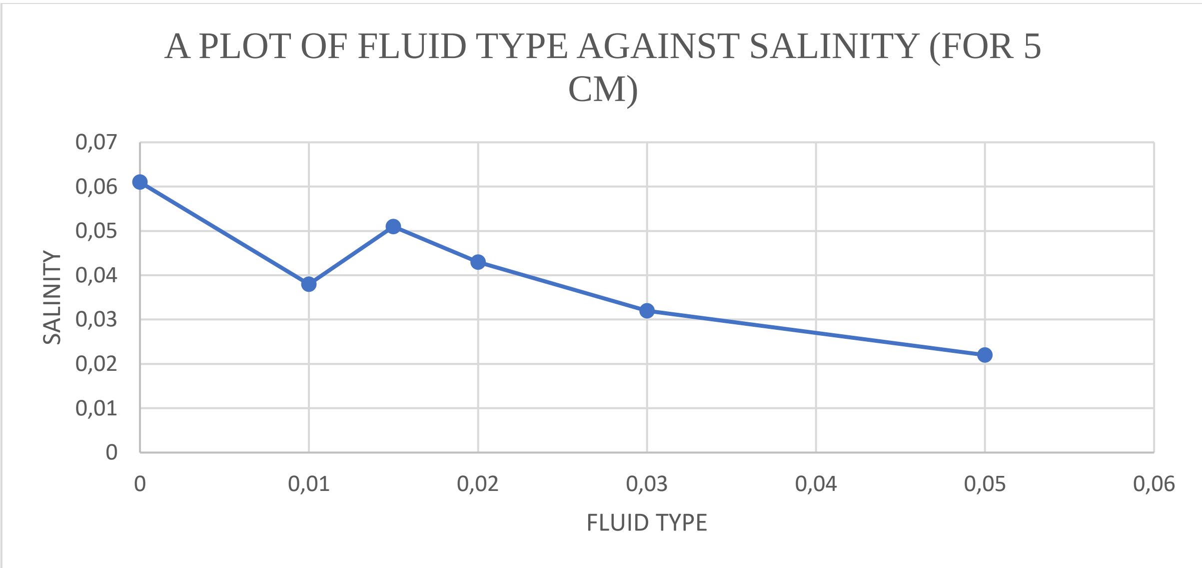

Fig 4.7 Salinity of fluids after being placed 5 cm away from heat source to check if light affects desalination.

The observation made is, the salt concentration for each fluid decreased after the experiments. However, they were greater than the previous experiments conducted for the conventional 2 cm distance. At 4 cm away from the heat or light source, the salinity keeps decreasing as concentration increases. The concentration of seawater is 0.05 ppt after desalination which is greater than the average 0.029 ppt for the 2 cm experiments. This is also the same for the nanofluids. The same trend can be noted in the experiment for the 5 cm distance where the average salinity after desalination is greater than that of the 2cm experiments. This also means that when the distance from the light source varies the salinity results will vary. For this research, the optimal distance for desalination based on the results obtained is 2cm since it has yielded lower salinity results after the entire desalination process.

4.6 Extinction coefficients of fluids

Light absorption by fluids will depend on the optical properties these fluids possess. The concentration of fluids can affect light absorption. The Beer Lambert law was used for this experiment to obtain results and analyse. The extinction coefficient (*K*) is measured and used for analysis. Three different fluids were used for the experiments in this section and the results are examined. The three fluids used in this section are.

- Distilled water
- Desalinated 0.03% Nanofluid
- Distilled water + Salt + Nanoparticles

Fluid Type	**I_0 (W/m^2)**	**I_1 (W/m^2)**	**z/cm**	***K* (m^{-1})**
Distilled Water	10744	1285	4.4	48.26
Desalinated 0.03% nanofluid	10744	264	4.4	84.23
Distilled Water + Salt+ CB nanoparticles	10744	77.1	4.4	112.2

Table 4.4 The results for extinction coefficient of different fluids

The extinction coefficient has a vital influence on the thermal absorption of these working fluids (Nguyen, 2022). Finding out the particles present in these working fluids after desalination was essential. As previous studied by Kosinska et al, the use of this approach was vital in determining if there were particles present in these working fluids. This also introduced the need for the comparative analysis of the fluids noted in Table 4.4.

Distilled water had the lowest corresponding extinction coefficient (K_{dw}= 48.26m^{-1}), followed by the desalinated sample of which a concentration of 0.03%. To achieve these results, the light intensities of these fluids had to be measured. For analysis and examination purposes, the same volume of fluid was used for each experiment as well. The same transparent beaker was used as well for each experiment to ensure the distance (z) was easy to measure. These parameters aided in calculating the extinction coefficient.

When the extinction coefficients in Table 4.4 were compared, it was noted that the desalinated fluid contains some particles because the (K) value is higher than that of the distilled water.

4.7 Summary

The different fluids used for this research showed different results. The theoretical salinity of sea water used was reduced after the entire desalination process had taken place. The experiments revealed that heating and boiling play an important role in reducing salinity of fluids and this helped to achieve results. The different type of fluids used helped to understand how boiling affects different fluids. Convection played an important role in each experiment setup and helped in heat transfer. The different distances D, used for different analysis also help in determining the best position of a beaker away from a heat source for effective desalination. This distance was a guess distance, but after several experiments 2cm was found to be the most desirable. The distance was important as it was also a factor in determining how quick a fluid will start boiling. Radiation played an important role in these experiments as there was no contact with between the beaker containing the fluid and the heat source.

Consequently, this same distance affected the desalination results. The distance D was altered from the conventional 2cm to (4cm and 5cm) to check if light affected desalination in any way. It was worth noting that the salinity of the fluids decreased but was much greater compared to the initial 2cm experiments. Table 4.2 and 4.3 provide the average salinity of seawater after desalination after using both setups. The set including pump yielded a more efficient result compared to the to the one without. Thus, in Table 4.3 the average salinity is seen to be 0.019 ppt which is lesser than the 0.029ppt noted in Table 4.2. This value further increases as the distance is increased to 4cm and 5cm (see Fig 4.6 and Fig 4.7).

The salinity of the other fluids which are coffee and nanofluids also decreased after experiments were conducted. A noticeable thing was the ability of these fluids to dissolve salt completely although they contained other particles. Nanofluids show rather interesting results which led to the decision to prepare nanofluids without SDS and use for experiments. Although both had different results, one thing was very noticeable and trendy. As the concentration of the nanofluids increased, the salinity after salinity also kept decreasing (see Fig. 4.3 and Fig 4.4).

Coffee showed an opposing trend to that of nanofluids. As the concentration of coffee increased, the salinity of the fluid after desalination kept increasing (Fig. 4.5). All fluids gave results that showed that indeed the set did help reduce salt concentration.

4.9 Uncertainty Analysis

The laboratory devices and equipment used in all the experiments consist of some form of uncertainties. These uncertainties are worth noting to ensure accuracy of the results and to help eradicate any present errors. Also, the environmental factors of the laboratory did affect results in several ways and introduce different form of uncertainties.

Measurements done which were with respect to nanofluid preparations, a weighing scale manufactured by Sartorius was used. The nanofluids were prepared using tap water or distilled water, SDS, nanoparticles and salt when needed. The sweater water was also formed using common salt and tap water. The coffee was also prepared using coffee and tap water. All the particles and substance were weighed with the scale. The resulted in a concentration uncertainty of ±2.0%, when calculated.

The ambient environmental factors did affect temperature measurements as the experiments were conducted at different seasons of the year. The experiments were conducted in the laboratory having initial temperatures which corresponded to the ambient temperature inside the room. This means the starting temperature for each experiment varied and possibly caused erratic initial temperatures that could have prolonged the heating or boiling time. Although temperature measurements were not mainly of essence in this research work, it was worth noting as it affected the time needed to complete experiments.

Time measurements for initial experiments may have experienced some delays because of certain interferences and paramount actions. The time taken to check the volume and possibly note the time probably introduced some uncertainties. This occurred in almost all experiments where time had to be noted.

For the conductivity meter, the residue from nanofluids and the constant used of water and alcohol for cleaning could have affected results as experiments were done repeatedly. The conductivity also operated based on ambient temperature conditions which introduces uncertainties. Table 4.5 show the noted uncertainties which for respective instruments which are listed.

Instrument	Parameter	Uncertainty	Unit	Manufacturer
Tape Measure	Length	± 0.05	cm	(-)
Thermocouple	Temperature	± 0.3	°C	Omega Engineering
Conductivity Meter	Conductivity	± 2	mS/cm	Traceable
Weighing scale	Mass	± 0.0001	g	Sartorius
Stopwatch	Time	± 1	mins	Apple

Table 4.5 Uncertainties of laboratory instruments

CHAPTER FIVE
CONCLUSION

This thesis focused on three main fluids for desalination. These fluids are seawater, nanofluids and coffee. The experimental investigations help to gain insight into world desalination solutions and how to use alternative methods to obtain pure water from seawater. This research focused on using evaporation and boiling to perform effective desalination. The reduction of the 35ppt of the salt concentration to a lesser concentration was a major focus in this thesis. The main objective was to produce water or a fluid which has a salinity measure less than the initial fluid being used for any experiment.

The use of carbon black nanofluids played a significant role in desalination in this research. The use of the carbon black nanofluids helped to reduce salinity of fluids after desalination. This research work contributed to the use of simplified system to improve desalination of seawater. The use of a heat source placed close at a 2cm to the fluid whose salinity had to be reduced helped to reduce salt content. As stated earlier, the right amount of carbon black Nanofluids mixed with seawater helped to reduce salt content significantly. The simple set ups which worked based on boiling and evaporation helped to efficiently obtain good results from each experiment. Although all results obtained were not the same as values noted from scientific literature, salinity of fluids measured after every experiment was reduced significantly.

Various fluids were used for the different experiments, but the main aim was to reduce salinity after each experiment. In contrast to the use of common use of reverse osmosis for desalination, this research did not employ that method but achieved the aim of reducing salinity. The average seawater salinity reduced from 35ppt to an average of 0.029ppt. The other fluids prepared to act like sea water also showed gave similar results. For coffee although no pure water was obtained after each experiment, the salinity reduced to an average of 0.033ppt. Nanofluids formed with SDS which had a concentration higher than 0.05% proved to have decrease salinity although they also provided no clean or pure water. The average salinity after these concentrations was of nano fluids was 0.017ppt. For nanofluids with concentrations less than 0.05%, clear water was produced after desalination, and each had a different salinity. This category also proved that without SDS used in preparing nanofluids, the salinity of fluids decreases after desalination. This research also contributed to knowing that, light and heat intensity affects desalination. When different distances were used for this parameter, the result showed that different salinity for each concentration as distance was being increased.

Despite the results obtained from this research and conclusion drawn further investigation can be done to improve desalination. More in-depth analysis and observations can be made for much bigger breakthrough. The use of a different tube orientations can be used for the transport of fluids. It will also be very beneficial to study temperature conditions necessary for each concentration to achieve more effective results.

CHAPTER SIX

FUTURE WORKS

1. Create a set up that has a filter to help achieve an improved an effective desalination result.

2. The irradiation source should be adjustable so that different temperature ranges can be used to find a suitable temperature for desalination.

3. Improve the set up with more features so that different parameters such as osmotic pressure and capillary measured for more accurate results.

4. Different distances can be used for the same set up to check if there will be any new changes or observations made.

5. How to properly dispose waste carbon black nanofluids and the environmental impact can be worked on.

6. Further investigation into different concentration of carbon black nanofluids that can be used for desalination.

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APPENDICES

Appendix A

Fluid flow duration

Experimentally obtained results for time taken to transport 10ml of working fluids.

Table A.1 Average time taken to transport 10ml of water.

Fluid Type	D	T	t
Tap Water	2	>100	21
Tap Water	2	>100	23
Tap Water	2	>100	18
Tap Water	2	>100	21
Tap Water	2	>100	19
Average			20,4

Fluid Type	D	T	t
Coffee	2	>100	15
Coffee	2	>100	16
Coffee	2	>100	17
Coffee	2	>100	16
Coffee	2	>100	17
Average			16,2

Fluid Type	D	T	t
Nanofluid (0.010%)	2	>100	21
Nanofluid (0.010%)	2	>100	19
Nanofluid (0.010%)	2	>100	18
Nanofluid (0.010%)	2	>100	17

Nanofluid (0.010%)	2	>100	20
Average			19

Fluid Type	**D**	**T**	**t**
Nanofluid (0.015%)	2	>100	19
Nanofluid (0.015%)	2	>100	15
Nanofluid (0.015%)	2	>100	16
Nanofluid (0.015%)	2	>100	20
Nanofluid (0.015%)	2	>100	18
Average			17,6

Fluid Type	**D**	**T**	**t**
Nanofluid (0.020%)	2	>100	18
Nanofluid (0.020%)	2	>100	10
Nanofluid (0.020%)	2	>100	13
Nanofluid (0.020%)	2	>100	12
Nanofluid (0.020%)	2	>100	12
Average			13

Fluid Type	**D**	**T**	**t**
Nanofluid (0.030%)	2	>100	17
Nanofluid (0.030%)	2	>100	16
Nanofluid (0.030%)	2	>100	16
Nanofluid (0.030%)	2	>100	19
Nanofluid (0.030%)	2	>100	17
Average			17

Fluid Type	**D**	**T**	**t**
Nanofluid(0.040%)	2	>100	15
Nanofluid(0.040%)	2	>100	13
Nanofluid(0.040%)	2	>100	15
Nanofluid(0.040%)	2	>100	16
Nanofluid(0.040%)	2	>100	15
Average			14,8

Fluid Type	**D**	**T**	**t**
Nanofluid (0.050)%	2	>100	17
Nanofluid (0.050%)	2	>100	18
Nanofluid (0.050%)	2	>100	14
Nanofluid (0.050%)	2	>100	15
Nanofluid (0.050%)	2	>100	14
Average			15,6

APPENDIX B

SALINITY DATA FROM EXPERIMENTS

The methods used in section 3.4, which aided in analyzing results provide data from the experiments conducted. The salinity after the desalination process for the working fluids are noted and compared to the initial 35ppt.

B.1 Seawater

D	**t (mins)**	**Salinity (**µS)
2cm	30	0.029
2cm	29	0.031
2cm	30	0.026
2cm	32	0.029
2cm	28	0.032
Average Salinity		0.029

Table B.1 Average salinity of seawater after desalination using the set up without a pump.

D	**t (mins)**	**Salinity (**µS)
2cm	82	0.019
2cm	76	0.018
2cm	78	0.019
2cm	80	0.018
2cm	77	0.019
Average Salinity		0.019

Table B.2 Average Salinity of seawater after desalination using the set up with a pump.

B.2 COFFEE

Concentration(g/L)	**Salinity ppt**
0,05	0,014

0,06	0,029
0,07	0,035
0,08	0,035
0,1	0,034

B.3 NANOFLUIDS

Nanofluid Type (Wt %)	Salinity (ppt)
0,01	0,018
0,015	0,028
0,02	0,019
0,03	0,021
0,04	0,029
0,05	0,03
0,06	0,016
0,07	0,016
0,08	0,018
0,1	0,018

B.4 NANOFLUIDS FORMED WITHOUT SDS

NANOFLUID TYPE (%)	TIME TAKEN (mins)	SALINITY (ppt)
0,01	20	0,07
0,015	24	0,045
0,02	19	0,036
0,03	20	0,036
0,04	15	0,027
0,05	17	0,026

APPENDIX C

RESULTS FROM EXPERIMENTS

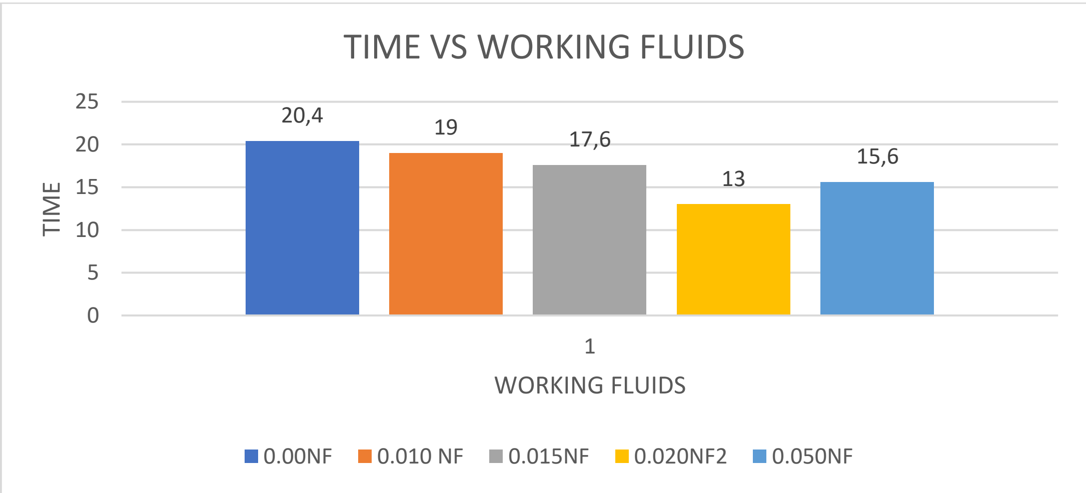

Figure C.1 The time taken for a fluid to be transported from the beaker close to the heat to volumetric flask and fill up to 10ml.

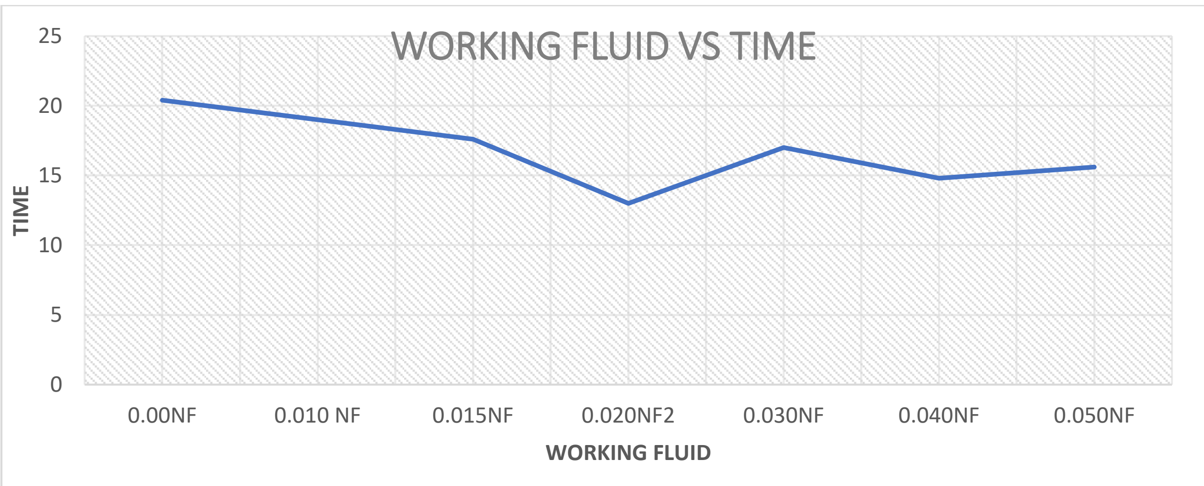

Figure C.2 The time taken for a fluid to be transported from the beaker close to the heat to volumetric flask and fill up to 10ml.

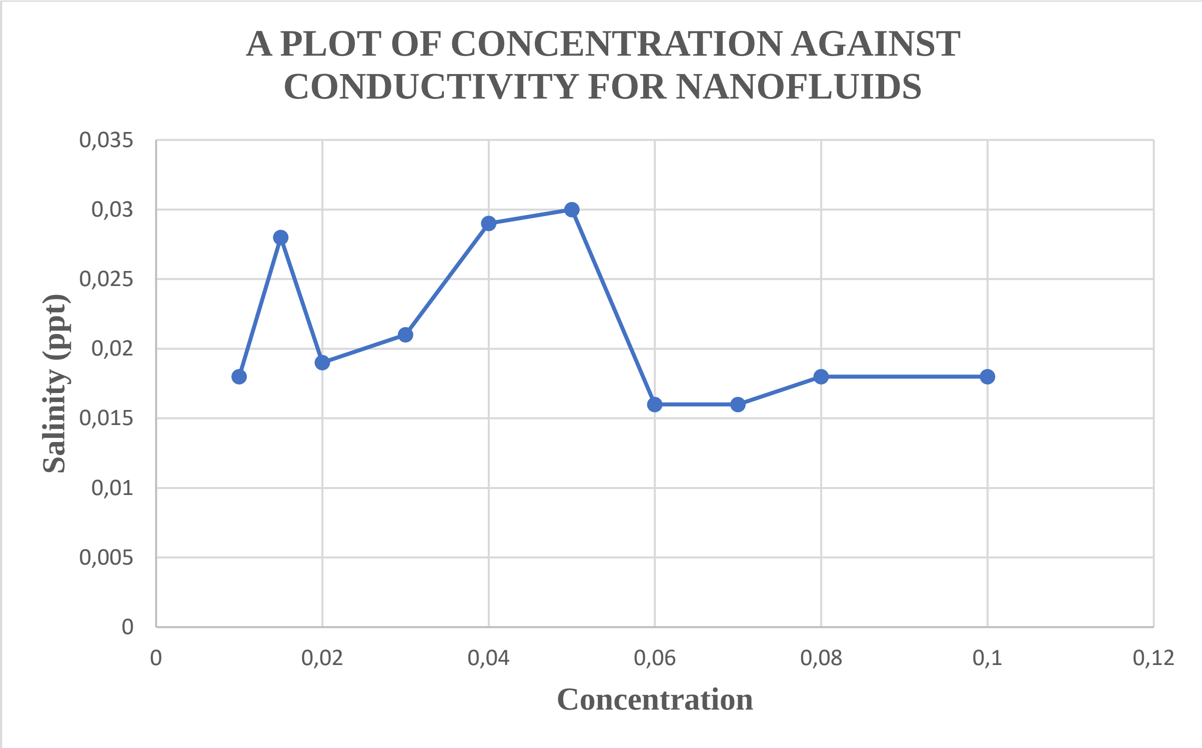

Figure C.3 Salinity of nanofluids after desalination

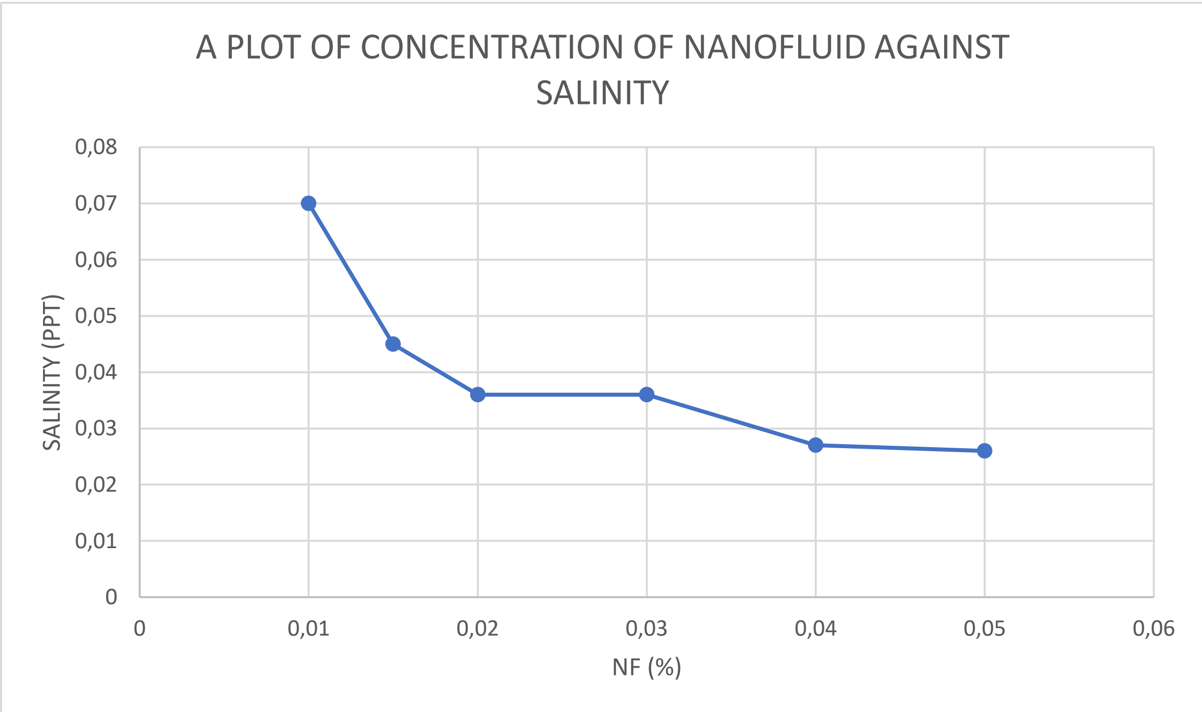

Fig. C.4 Salinity of nanofluids formed without SDS after desalination using experimental setup.

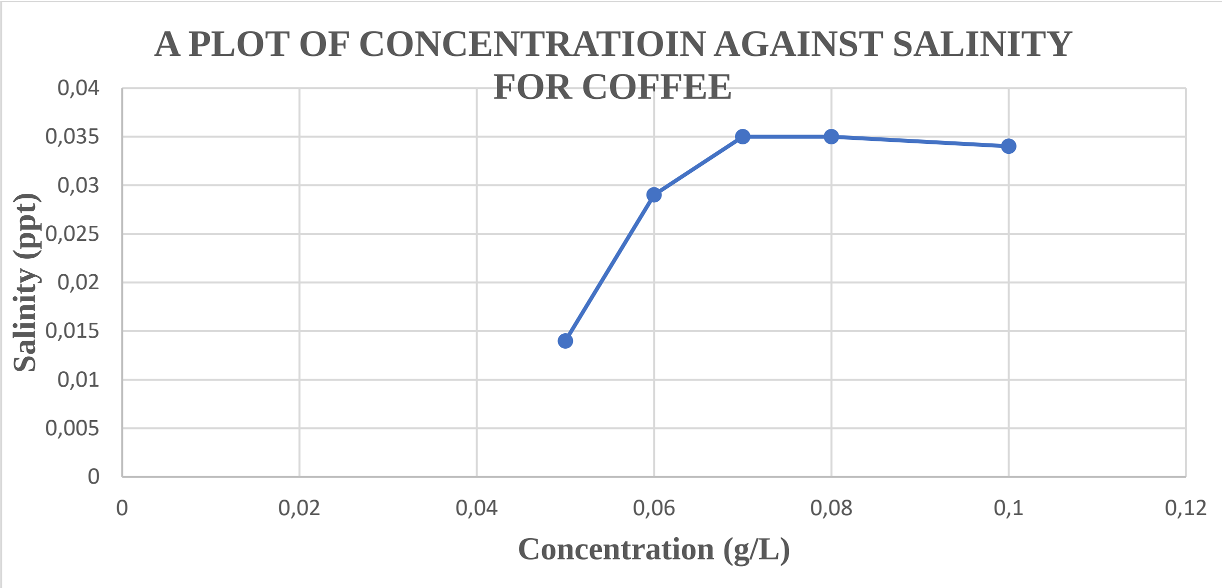

Figure C.5 Salinity of coffee after desalination

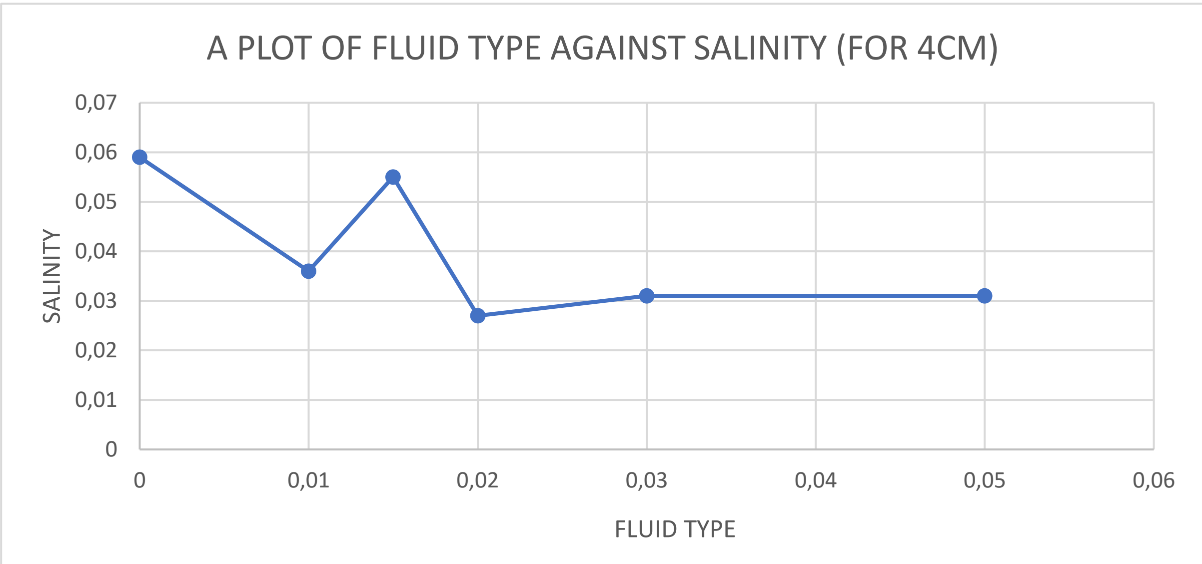

Fig C.6 Salinity of fluids after being placed 4cm away from heat source to check if light affects desalination.

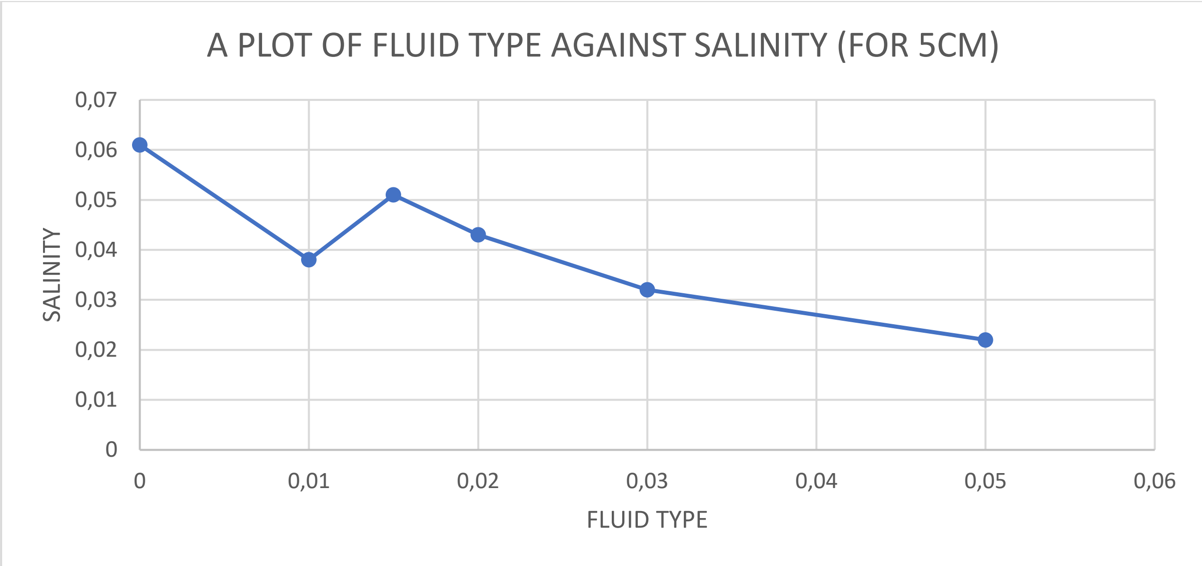

Fig C.7 Salinity of fluids after being placed 5cm away from heat source to check if light affects desalination.

Fluid Type	**I_0 (W/m^2)**	**I_1 (W/m^2)**	**z/cm**	***K* (m^{-1})**
Distilled Water	10744	1285	4.4	48.26
Desalinated 0.03% nanofluid	10744	264	4.4	84.23
Distilled Water + Salt+ CB nanoparticles	10744	77.1	4.4	112.2

Table C.1 The results for light intensity of different fluids

APPENDIX D

UNCERTAINTY IN MEASUREMENTS

The concept of uncertainty ensures measurement of a quantity of any kind is done with the proper accuracy. There are no instruments which measure the exact actual value, but the measurement uncertainty determines how accurately a measurement is performed. Measurement error is the difference between a measured quantity and its true value. There are two types of error: random error (occurring errors that are expected with any experiment) and systematic error (affecting all measurements caused by a mis calibrated instrument). The latter will produce a discrepancy with every measure, which might be constant or vary systematically with time, temperature, and other variables.

Consider a measurement represented with variable x. The measurement with its associated uncertainty can be presented as follows:

$$x_m = x_{avg} \pm \Delta x_{avg}$$

where x_m is the measured value of variable x, $\bar{x}$ is the average value and Δx_{avg} is the uncertainty in the mean. The Mean and Standard Deviation are used for quantifying the uncertainties in the experimental results.