MARMARA UNIVERSITY

FACULTY OF ENGINEERING

DESIGN AND MANUFACTURİNG OF WASTE OR SEAWATER TREATMENT SYSTEM USING SOLAR ENERGY

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By

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ABSTRACT

Design and Manufacturing of Water or Seawater Treatment System Using Solar Energy

The increasing global demand for potable water, coupled with the escalating concerns over energy consumption and environmental sustainability, has spurred the development of innovative solutions in the field of water treatment. This study focuses on the design and manufacturing of a novel water treatment system incorporating evacuated solar collectors, aiming to harness solar energy for the efficient purification of water resources.

The proposed system integrates evacuated solar collectors to exploit solar radiation effectively, providing an eco-friendly and cost-efficient energy source for the water treatment process. The evacuated solar collectors enhance thermal efficiency by minimizing heat losses, allowing the system to operate optimally even in diverse environmental conditions.

The design phase involves the careful consideration of key parameters such as collector configuration, absorber material selection, and system integration to achieve an optimal balance between energy efficiency and manufacturing feasibility. In the manufacturing phase, emphasis is placed on utilizing sustainable materials and streamlined fabrication processes to ensure the system's environmental impact is minimized.

This research not only contributes to the development of an eco-friendly water treatment solution but also addresses the imperative need for sustainable energy sources in water purification processes. The synergistic integration of evacuated solar collectors with water treatment technologies underscores the potential for scalable, environmentally conscious solutions that can significantly impact water accessibility and quality on a global scale.

SYMBOLS

Q	: Heat
m	: Mass
c_p	: Specific Heat
ΔT	: Temperature Difference
m_w	: Mass of Water
d_w	: Density of Water
V_w	: Volume of Water
T_1	: First Temperature
T_2	: Second Temperature
π	: pi
r	: Radius
L	: Length
I	: Solar Irradiation
A_{abs}	: Area
η	: Efficiency
Q_{max}	: Max Heat
Q_{act}	: Actual Heat

Table of Contents

Table of Figures

I. Introduction

Two-thirds of the Earth's surface is composed of water. Approximately 97% of this water, an immense quantity, exists in the form of saline in the seas and oceans. Due to the elevated salt concentration and other constituents present in oceanic and marine waters, they are unsuitable for human consumption. Nevertheless, these waters find application in industrial processes, particularly in the cooling systems of factories and energy facilities. Clean water sources such as lakes and underground reservoirs are progressively diminishing. The principal factors contributing to this decline are anthropogenic, encompassing pollution, unregulated resource utilization, and environmental degradation.

In tandem with the rapidly expanding global population, currently estimated at 8 billion 10 million, projections indicate a continued rise. According to reports from the United Nations, the world's population is anticipated to reach 8.5 billion by 2030, 9.7 billion by 2050, and 10.4 billion by 2080, maintaining this level until 2100.

Clean water accessibility faces significant challenges, particularly in African nations. The compounding effects of a swiftly growing population and depleting resources suggest an increasingly arduous path to obtaining clean water. While extensive water treatment facilities strive to meet this demand, achieving a requisite treatment volume appears to be a protracted challenge. The substantial energy demand in water treatment plants also translates to elevated costs.

Fundamentally, there are two distinct treatment methodologies: thermal distillation and reverse osmosis. Thermal distillation relies on the application of heat to vaporize water, followed by the condensation of the vapor back into a liquid state. This method is strategically located near energy facilities due to its substantial energy requirement (approximately 10 kW/m3). Conversely, reverse osmosis employs a semi-permeable membrane with pores suitable only for the passage of water molecules, allowing for the transit of fresh water. This method necessitates high pressure, with an associated energy requirement of (approximately 3 kW/m3).

Energy needs can be met through the utilization of both fossil and renewable resources. Fossil resources are confronted with environmental pollution and depletion issues. On the other hand, environmentally friendly and cost-effective renewable resources are increasingly advancing and being favored today. Renewable energy sources include Wind, Solar, Hydropower, Hydrogen, Geothermal, Biomass, and Wave energy. Solar energy technologies harness sunlight to generate heat or electricity. Solar energy is evaluated in terms of light, heat, and electricity. Technologies for obtaining heat from solar energy are progressively evolving worldwide. Even in a country with minimal sunlight, such as Sweden, outdoor temperatures at minus four degrees Celsius can yield water at 70 degrees Celsius through devices that store solar energy.

In this project, the objective is to address the freshwater demand with renewable energy and design a more portable system. The method is based on thermal distillation, and solar energy is chosen as the energy source. Due to the inefficiency of photovoltaic panels in meeting the electricity demand, panels utilizing radiation and heat conduction were selected. Evolving technology has led to the development of panels in a circular form, consisting of nested vacuum-insulated dual tubes. These panels have low maintenance and operating costs. The cycle is completed by the density resulting from the temperature difference, ensuring the heating of the water in the insulated storage tank. As known, water evaporates at any temperature. Based on this principle, the system, capable of reaching temperatures of 70-80 degrees Celsius on a sunny and clear day, aims to distill water with the addition of steam outlets. This setup also provides students with the opportunity to conduct experiments and work with solar energy, a renewable energy system.

II. Theory

II.I. Water

Water, a molecule composed of two hydrogen atoms and one oxygen atom (H_2O), stands as a quintessential substance in the realm of molecular biology and environmental science. Water's unique physical properties arise from its polar covalent bond and hydrogen bonding. The polar nature of the molecule gives rise to cohesion, adhesion, and surface tension. Additionally, the ability of water to exist in three states—solid, liquid, and gas—under common terrestrial conditions is attributed to its exceptional heat capacity and high latent heat of fusion and vaporization. In the biological realm, water plays a pivotal role as a solvent, facilitating biochemical reactions essential for life. Its solvent properties extend to a wide range of organic and inorganic compounds, making it a universal medium for metabolic processes within living organisms. Moreover, water's high specific heat and thermal conductivity contribute to the temperature regulation of organisms and ecosystems. The environmental significance of water is vast and complex. Aquatic ecosystems, ranging from freshwater habitats to marine environments, harbor diverse biota and are integral to global biogeochemical cycles. The vulnerability of these ecosystems to pollution, climate change, and anthropogenic activities necessitates a scientific approach to environmental stewardship, encompassing monitoring, modeling, and mitigation strategies. While rooted in scientific principles, water transcends its molecular nature to hold cultural and symbolic importance. Cultural practices and beliefs surrounding water, such as purification rituals, underscore its symbolic significance in various societies. Understanding the intersection of scientific understanding and cultural perceptions provides a holistic view of water's role in human societies. Scientifically assessing the challenges associated with water resources reveals issues of water scarcity, pollution, and unsustainable consumption patterns. The application of scientific methodologies, including remote sensing, hydrological modeling, and water quality assessments, becomes imperative for effective conservation strategies. Technological innovations, such as advanced water treatment technologies and sustainable water management practices, are essential components of a scientifically informed approach to addressing these challenges. Water, as a scientifically intricate molecule, pervades various disciplines, from molecular biology to environmental science. Recognizing its molecular properties, biological significance, environmental role, and the challenges it faces allows us to approach water-related issues with a scientific lens. As we navigate the complexities of water conservation, a multidisciplinary and scientifically informed approach is crucial to ensuring the sustainable management of this indispensable resource for the benefit of current and future generations.

II.I.I. What is Sea water

Seawater, comprising the vast expanses of Earth's oceans, is a complex and dynamic substance that plays a crucial role in the planet's ecosystems. Seawater is primarily composed of water molecules but contains a diverse array of dissolved salts, minerals, gases, and organic matter. The salinity of seawater, the concentration of dissolved salts, averages around 3.5%, contributing to its distinct taste and buoyancy. Its physical properties, such as density, viscosity, and refractive index, differ from freshwater, influencing the behavior of marine organisms and the oceanic environment. The chemical composition of seawater is a complex interplay of ions, including sodium, chloride, magnesium, and sulfate. These ions contribute to the overall salinity and create a chemically diverse environment. Seawater's chemical balance is delicately maintained through processes such as precipitation, evaporation, and the continuous cycling of elements, showcasing the dynamic nature of oceanic chemistry. Seawater is the cradle of life on Earth, supporting an astonishing diversity of marine organisms.

Phytoplankton, microscopic algae, harness the sun's energy through photosynthesis, forming the foundation of the marine food web. The intricate balance of predator-prey relationships, symbiotic interactions, and nutrient cycling within seawater sustains ecosystems that are vital for global biodiversity and climate regulation. Despite its resilience, seawater faces significant challenges in the modern era. Human activities, such as pollution, overfishing, and climate change, pose threats to the delicate balance of marine ecosystems. Rising sea temperatures, ocean acidification, and plastic pollution are among the pressing issues that require urgent attention to safeguard the health of our oceans and the life they support. Efforts in the conservation and sustainable management of seawater resources are paramount. Implementing marine protected areas, regulating fishing practices, and reducing plastic waste are crucial steps towards preserving the integrity of marine ecosystems. International collaboration and awareness campaigns play a vital role in fostering a global commitment to the responsible stewardship of our oceans. Seawater, with its rich composition and diverse properties, is a captivating subject of study. Its ecological significance, supporting life on Earth, underscores the importance of responsible environmental stewardship. As we navigate the challenges posed by human activities and climate change, a collective commitment to the conservation and sustainable management of seawater is essential for the well-being of our planet and the myriad life forms that call the oceans home.

II.I.II. What is inside Sea Water

Seawater is a complex solution that primarily consists of water and various dissolved substances. The composition of seawater is not uniform and can vary slightly depending on factors such as location, depth, and proximity to coastlines. However, the major components found in seawater include:

- Water (H_2O): The primary component of seawater is, of course, water molecules. They make up about 96.5% of the total volume of seawater.
- Seawater contains a variety of salts, with sodium chloride (table salt) being the most abundant. Other salts include magnesium chloride, calcium chloride, and potassium chloride. The average salinity of seawater is about 3.5%, meaning that about 35 grams of salt are dissolved in every 1,000 grams (1 liter) of seawater.
- Trace Elements: Seawater contains a range of trace elements in smaller concentrations, including elements like bromine, iodine, sulfur, strontium, and fluorine.
- Gases: Dissolved gases in seawater include oxygen, nitrogen, and carbon dioxide. The concentration of these gases can vary with depth and location.
- Organic Matter: Seawater contains dissolved organic matter, such as decaying plant and animal material, as well as substances released by marine organisms.
- Dissolved Nutrients: Seawater is rich in nutrients essential for marine life, including nitrate, phosphate, and silicate. These nutrients play a crucial role in supporting the growth of phytoplankton and other marine organisms.
- Microorganisms: Seawater is teeming with microscopic organisms, including bacteria, viruses, and various planktonic organisms.
- Suspended Particles: Seawater can also contain suspended particles, such as silt, clay, and organic particles, which contribute to the turbidity of the water.

It's important to note that the composition of seawater is not constant and can be influenced by factors like ocean currents, temperature, and human activities. Oceanographers use instruments to measure the specific composition of seawater in different locations and depths to understand its variability and the dynamics of marine ecosystems.

*Table 1 Principal Constituents of Seawater**

Ionic Constituent	g/kg of Seawater	moles/kg**	Relative concentration
Chloride	19.162	0.5405	1.0000
Sodium	10.679	0.4645	0.8593
Magnessium	1.278	0.0526	0.0974
Sulfate	2.680	0.0279	0.0517
Calcium	0.4096	0.01022	0.0189
Potassium	0.3953	0.01011	0.0187
Carbon (Inorganic)	0.0276	0.0023	0.0043
Bromide	0.0663	0.00083	0.00154
Boron	0.0044	0.00041	0.00075
Strontium	0.0079	0.00009	0.000165
Fluoride	0.0013	0.00007	0.000125

*Concentrations at salinity equal to 34.7

**Ionic concentrations are conventionally expressed in molecular units. One mole per kilogram is equivalent to 6.023{1023} ions or molecules per kilogram of seawater. The relative concentrations in column 4 provide the number of ions of each constituent in one kilogram of seawater as compared to the number of chloride ions in one kilogram of seawater.

II.I.III. Salinity and Salinity Distribution

Salinity is a crucial parameter used by oceanographers to characterize the total salt content of seawater. Practical salinity (symbol S) is a dimensionless quantity that provides a measure of the concentration of dissolved salts in seawater. Here are some key points related to practical salinity and its determination:

- Measurement Method:
    - Practical salinity is determined through measurements of the electrical conductivity and temperature of seawater.
    - These measurements are interpreted using an algorithm developed by the United Nations Educational Scientific and Cultural Organization (UNESCO).

- Density Calculation:
  - Practical salinity, along with temperature, is used to calculate the density of seawater samples accurately.
  - The density of seawater is a critical parameter in understanding oceanographic processes and the behavior of water masses.
- Major Ions Concentration:
  - Due to the constant relative proportions of the principal constituents in seawater, salinity can be used to directly calculate the concentrations of major ions, such as sodium, chloride, and others.
  - This information is valuable for studying the chemical composition of seawater.
- Original Purpose:
  - The measure of practical salinity was originally developed to provide an approximate measure of the total mass of salt in one kilogram of seawater.
  - It offers a standardized way to express and compare salt concentrations in different seawater samples.
- Representation:
  - Salinity is typically expressed in parts per thousand (ppt) or practical salinity units (psu). Seawater with a practical salinity equal to 35 contains approximately 35 grams of salt and 965 grams of water in one kilogram, which can also be written as 35 ppt (or 35 psu).

II.I.IV. Salinity Distribition

The discussion of salinity, the salt content of the oceans, involves two fundamental concepts that shape the understanding of oceanic salt distribution:

- Steady State of Oceans:
  - The present-day oceans are considered to be in a steady state, receiving as much salt as they lose over time.
  - This equilibrium is crucial for maintaining a relatively constant salinity level in the oceans.
- Uniformity of Sea Salt Composition:
  - The oceans have been mixed over an extensive time period, resulting in sea salt having a uniform composition everywhere in the open ocean.

    - This uniformity ensures that the salinity of oceans varies little over space or time.

Factors Influencing Salinity Variation:

- Range of Salinity: The observed range of salinity in the open ocean is generally from 33 to 37 grams of salt per kilogram of seawater, or practical salinity units (psu).
- Departure from Mean Value: Deviations from the mean value of approximately 35 psu are often caused by surface processes that locally add or remove freshwater.
- Influence of Evaporation and Precipitation:
    - Regions with high evaporation experience elevated surface salinities.
    - Areas of high precipitation, conversely, have depressed surface salinities.
    - Nearshore regions close to large freshwater sources may have lowered salinity due to dilution.

Examples of Salinity Variation:

- Baltic Sea: Salinity values in areas of the Baltic Sea can be depressed to 10 psu or less.
- Red Sea: The Red Sea experiences increased salinity (up to 41 psu) due to evaporation, accentuated by water isolation.
- Coastal Lagoons: Salinities in coastal lagoons with high evaporation can be much higher.

Complexities in Salinity at Different Depths:

- Sea Ice Formation: In high latitudes where sea ice forms seasonally, melting ice reduces seawater salinity, while ice formation elevates it.
- Deep Ocean Processes: At depth, seawater percolating into fissures associated with deep-ocean ridges and crustal rifts may alter salinity. Superheated water returning to the ocean carries dissolved salts from magmatic material.

Extreme Salinity Cases:

- Red Sea Brine Pools: Pools of brine in depressions at the bottom of the Red Sea can have salt concentrations as high as 256 psu, with a composition different from open ocean sea salt.

Uniformity in Open Ocean Salinity:

- Average Depths: Salinities at greater depths in the open oceans are quite uniform, with average values of 34.5 to 35 psu.
- Surface Processes Impact: These salinities are determined by surface processes, such as evaporation and precipitation, when the water was last in contact with the surface.

Latitudinal Influences:

- Intertropical Convergence: High precipitation near the equator (5° N) results in a latitudinal depression of surface salinity.
- Subtropical Zones: Around 30°–35° N and 30°–35° S, subtropical zones experience high evaporation, leading to increased surface salinity.
- Mid-Latitudes: At 50°–60° N and 50°–60° S, precipitation increases again, impacting surface salinity.

Understanding the factors influencing salinity is essential for comprehending oceanic dynamics, climate patterns, and the interconnectedness of Earth's systems.

II.I.V. Thermal Properties of Sea Water

Water and its unique properties, including specific heat capacity, specific heat, latent heat of fusion, and latent heat of vaporization, play an important role in controlling Earth's climate, weather patterns, and energy transfer processes. . Adding salt to water can affect these properties, so it is important to understand water and its properties under different conditions. The presence of salt slightly reduces the heat capacity of water. Salt water at 35 psu has a specific heat of 0.932, pure water has a specific heat of 1.000. Pure water freezes at 0 °C and boils at 100 °C (212 °F) under normal pressure conditions. Adding salt lowers the freezing point and raises the boiling point. By adding salt, the temperature of maximum density is lower than that of pure water (4 °C [39.2 °F]). Adding salt causes the temperature of maximum density to drop faster than the freezing point. At a salinity of 24.70 psu, the freezing point and temperature of maximum density are equal to −1.332 °C (29.6 °F). In open sea saline waters above 24.7 psu, the freezing point is the temperature of maximum density. When water changes shape, the hydrogen bonds between the molecules break. Energy is needed to break the hydrogen bonds, which allows water to go from solid to liquid and from liquid to air. Energy is released when hydrogen bonds form and change water from liquid to solid or from gas to liquid. The thermal energy input required to change water from a solid at 0°C to a liquid at 0°C is the latent heat of fusion and 80 calories per gram of ice. The latent heat of fusion of water is the highest of all common substances. Because of this, it releases heat during ice formation and steam during melting. This prevents the air from warming in the form of land and sea ice, which melts over time. When water changes from a liquid to a gas, a large amount of heat energy, known as the latent heat of vaporization, is required to break the hydrogen bonds. To convert 1 gram of liquid water into 1 gram of water vapor at 100°C and normal pressure requires 540 calories per gram of water. When water evaporates at a temperature below its boiling point, the sugar evaporates and turns into a gas without first melting, in a process called sublimation. Below 100°C, evaporation and sublimation require more energy per gram than 540 calories. At 20°C (68°F), it takes about 585 calories to evaporate 1 gram of water. When the water vapor returns to the liquid, the latent heat of the vapor is released.

II.II. Sun

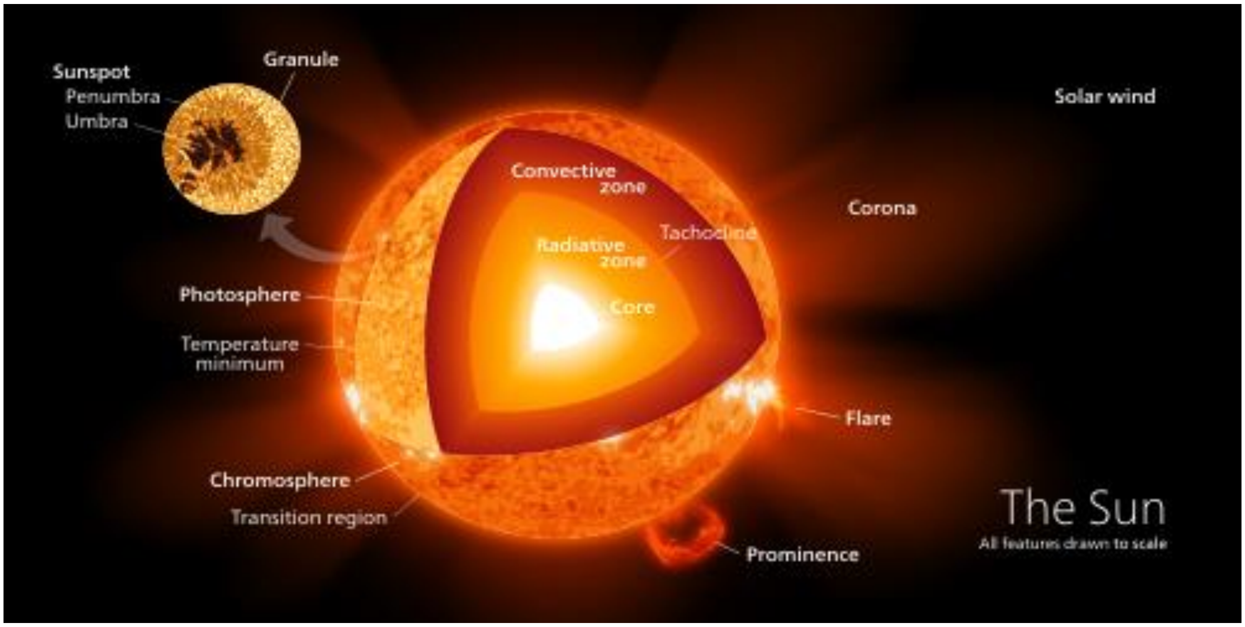

Figure 1 Sun

The Sun, a G-type main-sequence star at the center of our solar system, stands as a cosmic beacon radiating light, heat, and life-giving energy.

The Sun, with its radiant luminosity, is a fundamental celestial entity that governs the dynamics of our solar system. Understanding its composition and the processes occurring within its core provides crucial insights into the broader mechanisms driving stellar evolution.

Primarily composed of hydrogen (about 74%) and helium (about 24%), the Sun is a massive, nearly spherical ball of hot plasma. Beneath its visible surface lies the core, where temperatures and pressures are so extreme that nuclear fusion reactions occur, converting hydrogen into helium and releasing a tremendous amount of energy.

The Sun's energy is primarily generated through a series of nuclear fusion reactions occurring in its core. The most notable process is the proton-proton chain reaction, where hydrogen nuclei fuse to form helium, liberating energy in the form of photons. This energy production, sustained by the delicate balance between gravitational forces and internal pressure, has persisted for billions of years.

The Sun exhibits various dynamic phenomena collectively known as solar activity. Solar flares, sunspots, and coronal mass ejections are manifestations of the Sun's magnetic activity. Understanding these phenomena is crucial for predicting space weather and its potential impacts on communication systems and satellite operations.

The Sun's energy is the driving force behind Earth's climate, weather patterns, and the sustenance of life through photosynthesis. Solar radiation interacts with Earth's atmosphere, influencing temperature distributions, wind patterns, and ocean currents.

Advancements in space exploration have allowed scientists to study the Sun more closely. Solar observatories, such as the Solar and Heliospheric Observatory (SOHO) and the Solar Dynamics Observatory (SDO), provide invaluable data about solar processes, aiding in the comprehension of solar dynamics.

Continues to captivate scientists and astronomers alike. Its profound influence on the solar system and its role in sustaining life on Earth underscore the importance of ongoing research to deepen our understanding of this remarkable cosmic entity.

II.II.I. Physical Properties

Our Sun, a celestial luminary of moderate dimensions, boasts a radius extending approximately 435,000 miles (700,000 kilometers). While numerous stars dwarf its size, the Sun's mass eclipses our terrestrial abode by a staggering measure—requiring more than 330,000 Earths to match its gravitational heft. To fill the voluminous expanse occupied by the Sun, a prodigious 1.3 million Earths would be necessary.

In the vast cosmic theater, the Sun is a close celestial neighbor, stationed at a distance of about 93 million miles (150 million kilometers) from Earth. Yet, in the cosmic ballet, it’s nearest stellar companions belong to the Alpha Centauri triple star system. Proxima Centauri, a red dwarf, stands 4.24 light-years distant, while the sunlike pair, Alpha Centauri A and B, engage in a gravitational dance 4.37 light-years away. A light-year, measuring the vast expanse light traverses in one Earthly orbit, translates to an astronomical distance of about 6 trillion miles (9.5 trillion kilometers).

The Sun, a colossal sphere predominantly composed of hydrogen and helium, is a cosmic marvel held in a delicate cosmic dance by the force of its own gravity. Structured in layers, the Sun's interior harbors the core, the radiative zone, and the convection zone. Progressing outward, we encounter the visible surface, or photosphere, succeeded by the chromosphere, the transition zone, and finally, the corona—a vast outer expanse enveloping the Sun. As solar material accelerates away from the corona, forming the solar wind, it establishes an expansive magnetic "bubble" known as the heliosphere, extending far beyond the orbit of our planetary companions. Earth, nestled within the heliosphere, resides within the extended reaches of the Sun's atmosphere, while the realm beyond the heliosphere unveils interstellar space. At the core, where temperatures soar to an astonishing 27 million °F (15 million °C) within an 86,000-mile (138,000 kilometers) thickness, nuclear fusion processes convert hydrogen into helium, fueling the Sun's radiant heat and light. The core's density, a remarkable 150 grams per cubic centimeter (g/cm^3), surpasses that of gold (19.3 g/cm^3) by 8 times or lead (11.3 g/cm^3) by 13 times. Radiant energy from the core embarks on a journey through the radiative zone, a meandering path taking approximately 170,000 years to traverse from the core to the summit of the convection zone. Transitioning outward, the convection zone witnesses a drop in temperature to below 3.5 million °F (2 million °C). In this dynamic region, buoyant bubbles of hot plasma, a medley of ionized atoms, ascend towards the photosphere, the layer we perceive as the Sun's surface.

II.II.II. Solar Lights and Energy

The Sun, a perpetual celestial furnace, radiates an abundance of energy, a beacon in the sky that has captivated human imagination for millennia. Understanding the mechanisms by which we can tap into this cosmic powerhouse provides a pivotal gateway to a more sustainable energy paradigm. Nuclear fusion reactions within the Sun's core produce an immense amount of energy in the form of light and heat. This radiant energy, in the form of photons, embarks on a journey across the vastness of space, reaching Earth and offering a potent source of power waiting to be harnessed.

Photovoltaic (PV) cells, colloquially known as solar cells, represent a revolutionary technology that directly converts sunlight into electricity. These cells, typically composed of semiconductor materials, enable the capture and utilization of solar photons, providing a clean and renewable energy source for various applications. Beyond electricity generation, solar thermal systems leverage the Sun's heat to produce steam, driving turbines that generate power. This technology is adaptable for diverse uses, from heating water for residential purposes to large-scale solar power plants capable of supplying energy to entire communities. One challenge of solar energy lies in its intermittency due to day-night cycles and varying weather conditions. Advances in energy storage technologies, such as batteries and innovative thermal storage systems, offer solutions to store excess solar energy for use during periods of low sunlight.

Solar energy stands out as a sustainable and environmentally friendly alternative to traditional fossil fuels. Its adoption contributes to reduced greenhouse gas emissions, mitigates climate change, and diminishes reliance on finite resources, aligning with global efforts toward a greener and cleaner energy future. The solar energy industry presents economic opportunities and job creation while fostering energy independence. As technology advances and costs decrease, solar power becomes increasingly accessible, leading to widespread adoption on a global scale. While the potential of solar energy is immense, challenges such as storage efficiency, material sustainability, and initial infrastructure costs persist. Ongoing research and technological advancements promise to address these challenges, paving the way for an era where solar energy plays a central role in our energy portfolio.

Solar energy represents a sustainable, clean, and abundant energy future. It is possible to move towards an era where humanity progresses by harnessing the power of the sun and resolving the complexities of converting it into various forms of energy.

II.II.III. Thermal Solar Energy

In the pursuit of sustainable and eco-friendly energy sources, thermal solar energy emerges as a pivotal frontier within the realm of renewable energy. At the heart of thermal solar energy lies the art of capturing the radiant heat emitted by the sun, offering a versatile and sustainable solution to our escalating energy demands. This scientific inquiry aims to uncover the underlying principles and intricate technologies that drive the conversion of solar heat into usable energy. Central to the concept is the art of capturing solar heat and transforming it into practical energy. Solar collectors, be they flat-plate or concentrating collectors, play a pivotal role in absorbing and concentrating solar radiation. Understanding the thermodynamic nuances governing heat transfer and conversion becomes imperative for optimizing energy outputs. Diverse in their design, flat-plate collectors, consisting of dark absorbers and transparent covers, absorb sunlight and convert it into heat, transferring it to a fluid medium. Meanwhile, concentrating collectors leverage mirrors or lenses to focus sunlight onto a smaller area, intensifying the heat for elevated energy yields. Ongoing advancements within collector technologies aim to enhance efficiency and broaden their spectrum of applications. A persistent challenge in solar energy utilization is its intermittent nature due to varying sunlight availability. Enter thermal energy storage systems, employing high heat capacity materials to act as reservoirs, storing excess energy during peak sunlight hours. This ensures a consistent energy supply even during periods of reduced sunlight. In the realm of power generation, thermal solar energy finds expression through various systems, notably in solar-thermal power plants. Concentrated Solar Power (CSP) systems utilize mirrors or lenses to focus sunlight onto a small area, generating high-temperature heat that propels turbines for electricity production. Beyond the realm of electricity generation, thermal solar energy permeates various sectors, influencing industrial processes, water heating, and space heating in both residential and commercial domains. Integrated systems strive to offer sustainable solutions, catering to diverse energy demands in developed and emerging economies alike. A hallmark of thermal solar energy lies in its capacity to significantly reduce greenhouse gas emissions and environmental impact when contrasted with conventional fossil fuel-based sources. Its inherent sustainability aligns seamlessly with global initiatives aimed at climate change mitigation and transitioning towards a cleaner, more sustainable energy future. While the promise of thermal solar energy is immense, challenges persist in areas such as cost-effectiveness, technological advancements, and widespread adoption. Ongoing research endeavors focus on addressing these challenges, with potential breakthroughs in materials, design, and integration poised to enhance efficiency and accessibility.

II.III. Renewable Energy

Renewable Energy is the energy derived from ongoing natural processes. Currently, 80% of global energy is obtained from fossil fuels. Renewable energy sources play a crucial role in reducing dependency on fossil fuels such as coal, oil, and natural gas. Renewable energy sources include Solar, Wind, Biomass, Geothermal, Hydropower, Hydrogen, and Ocean Energy (Wave and Tidal). Simply put, renewable energy sources are those used in the production of other forms of energy, such as solar, water, wind, and wave, without being depleted. Renewable energy sources are derived from natural sources and are energies that can be sustained. Renewable energy sources do not deplete over time, unlike fossil energy sources. Coal, oil, and natural gas are examples of non-renewable energies.

II.III.I. Solar

The Sun serves as an energy source for all planets in the solar system, making it an indispensable resource, particularly for all living organisms on Earth. Solar panels, especially during the summer months, have become one of the most important renewable energy sources, offering convenience and significant reductions in electricity bills. Commonly found on the roofs of homes in both urban and rural areas, solar panels can be used to heat water, fulfill the household's hot water needs, or contribute to the heating system by supplying hot water to the heating installation. Solar energy technologies harness sunlight to generate heat or electricity. Solar energy can be utilized in the forms of light, heat, and electricity. Solar energy systems directly convert the collected energy into electricity, and they can be installed on building rooftops, devices, or even vehicles. Concentrated solar power plants operate based on reflecting sunlight onto a relatively small area using mirror and lens arrangements, producing electricity or heat.

II.III.II. Wind

Wind energy's source is, in fact, solar energy. The pressure difference created by the uneven heating of land and seas by solar energy generates wind. Wind turbines, installed in regions where the impact of the wind is prominent, convert the existing kinetic energy of the wind first into mechanical energy and then into electrical energy. The energy obtained from the wind depends on the current speed and duration of the wind. As of today, wind energy meets about 2% of the world's electricity needs. Compared to other electricity generation techniques, wind turbine technologies have minimal harmful effects on the environment.

II.III.III. Biomass

Biomass is an infinite source of energy that can be obtained everywhere, and it is considered a suitable and significant energy source, particularly for rural areas, due to its potential to contribute to socio-economic development. Specifically cultivated crops such as corn and wheat, grasses, algae, marine algae, animal waste, manure, industrial waste, and all organic waste from households (fruit and vegetable scraps) serve as sources for biomass. As fossil fuels (such as coal, etc.) deplete and contribute to environmental pollution, the use of biomass is gaining increasing importance as a solution to energy problems.

II.III.IV. Geothermal

"Geothermal" means "earth heat." Waters formed as a result of natural events and particularly precipitation reach the magma layer through cracks in the Earth's crust. The heated waters in this magma layer reach the Earth's surface as hot water and steam. This water and steam reaching the Earth's surface can be converted into various forms of energy through turbines. Generally speaking, the stored thermal energy in the Earth's crust constitutes geothermal energy. The extracted energy is converted into electrical energy in geothermal power plants. Additionally, it can be used in central heating and cooling systems in homes and workplaces, in many physiotherapy centers preferred by patients, and in tourist centers.

II.III.V. Hydropower

Hydropower energy is based on harnessing the energy of flowing water and converting this energy into electrical power. Hydropower plants are renewable and serve as a clean energy source for nature. They are particularly effective in areas with significant elevation, where the flow rate of water is higher. Because the energy of flowing water is the primary focus in hydropower plants, they are used extensively for improving fisheries, facilitating transportation, irrigation, and most importantly, energy production.

II.III.VI. Hydrogen

Due to the current technology and production challenges, the use of hydrogen energy is not yet widespread. However, with the advancement of technology, hydrogen energy is becoming one of the most important candidates to meet the world's energy needs as a clean energy source. In the future, it is anticipated that hydrogen energy will be used in the production of electricity, heat, and fuel cells.

II.III.VII. Ocean

In fact, oceans can be considered as two separate energy sources. The first is thermal energy dependent on solar heat, and the second is mechanical energy derived from waves and tides. Covering approximately 70% of the Earth's surface, oceans also constitute the world's largest solar collectors. The temperature difference between the warm surface waters and the cool waters in the depths, heated by excess solar radiation on the ocean's surface, creates a natural thermal energy. If harnessed sufficiently, even a small portion of this energy would be adequate to meet the energy needs of the entire world.

II.IV. Water Desalination Methods

Water desalination is the process of removing salt and other impurities from seawater or brackish water to make it suitable for human consumption, agriculture, or industrial use. There are several methods of water desalination, each with its own advantages and disadvantages. Here are some common water desalination methods:

1. Distillation
    - Multi-Stage Flash Distillation (MSF): In this method, seawater is evaporated in multiple stages at different temperatures, and the vapor is condensed to produce fresh water.
    - Multi-Effect Distillation (MED): Similar to MSF, MED involves multiple stages of evaporation, but it uses the heat from the condensation of the steam in one stage to drive the evaporation in the next stage.
2. Reverse Osmosis (RO)

    This is the most widely used desalination method. It involves pushing seawater through a semi-permeable membrane to separate salts and impurities, leaving fresh water on one side and concentrated brine on the other.
3. Electrodialysis (ED)

    ED uses an electric field to drive ions through ion-selective membranes, separating salts from water. It is less common than reverse osmosis but is employed in certain desalination applications.
4. Ion Exchange

    In this method, ions in the water are exchanged with ions on a resin or other exchange medium. This is not as common for large-scale desalination but may be used for specific water treatment applications.
5. Freezing

    In the freezing method, seawater is frozen, and the ice is separated from the concentrated brine. The ice is then melted to obtain fresh water. This method is less common and typically used in smaller-scale applications.

6. Solar Desalination

   This method utilizes solar energy to heat seawater, causing it to evaporate. The vapor is then condensed to produce fresh water. Solar desalination can be achieved through various techniques, such as solar stills and solar-assisted multi-effect distillation.

Each desalination method has its own energy requirements, environmental considerations, and economic feasibility. The choice of method depends on factors such as the quality of the source water, energy availability, cost constraints, and environmental impact. Reverse osmosis and multi-stage flash distillation are among the most widely used methods for large-scale desalination plants.

II.IV.I. Distillation

Multi Stage Flash Distillation (MSF)

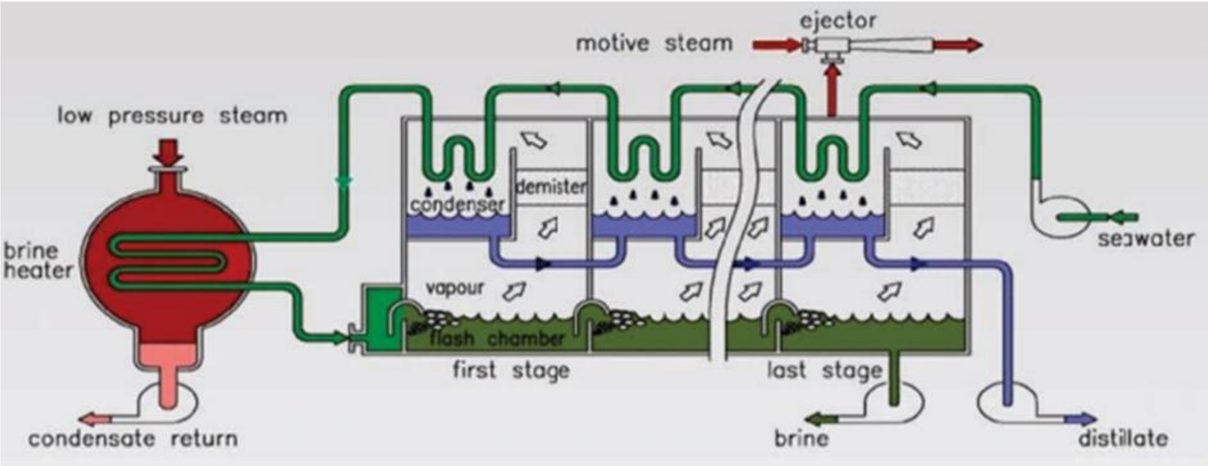

Figure 2 Multi Stage Flash Distillation method

MSF is a thermal desalination technology based on the flashing process, where seawater is evaporated in multiple stages to produce distillate quality water directly from seawater. The process involves pre-heating seawater and then heating it to a top brine temperature of about 90-120 degrees Celsius in a brine heater using low-pressure steam. The pre-heated seawater is flashed in successive stages maintained at decreasing levels of pressure. Each stage is a chamber where the flashing process occurs. The vapor produced in each stage is condensed on the outside surface of a preheating condenser, which helps preheat the incoming feed seawater. The condensed vapor is recovered as pure water, resulting in the separation of fresh water from the concentrated brine.

MSF is capable of accepting higher contaminant loading in feed seawater, including suspended solids, heavy metals, oil, grease, chemical oxygen demand (COD), biochemical oxygen demand (BOD), and other impurities. It is suitable for producing distillate quality product water required for applications such as power plants, process industries, and other applications where higher purity water is needed.

MSF is commonly employed in situations where the production of high-purity water is essential, such as in power plants and various industrial processes. The process relies on the input of low-pressure steam to heat the seawater and drive the flashing process in each stage.

MSF is one of the established and effective technologies for large-scale desalination, particularly when high-purity water is required for specific industrial applications.

Multi Effect Distillation (MED)

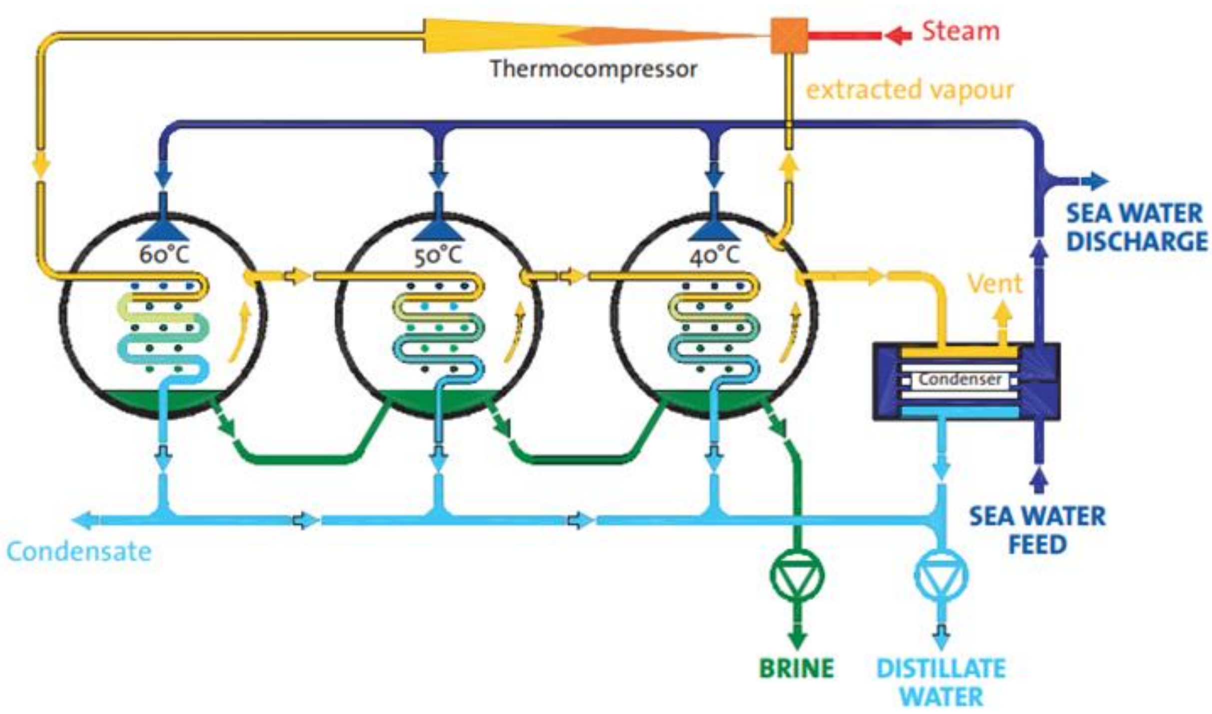

Figure 3 Multi Effect Distillation method

Multiple Effect Distillation (MED) is a desalination method that utilizes a sequence of evaporators known as "effects" to distill fresh water from seawater. The basic principle involves lowering the ambient pressure to allow seawater to boil at lower temperatures. The MED process is considered thermodynamically efficient.

- The process starts with seawater being preheated in tubes. The preheated seawater then enters the first effect, where it is elevated to its boiling point.

Seawater is sprayed onto the surface of evaporator tubes to encourage quick evaporation. External steam, usually supplied by a dual-purpose power plant, heats the tubes. The steam produced in the first effect condenses on the opposite side of the tubes. The condensed steam, now in the form of freshwater, is recycled as boiler feedwater in the power plant. Only a portion of the seawater in the first effect evaporates, and the remaining feedwater is directed to the second effect.

- The process of evaporation and condensation is repeated in subsequent effects, each at decreasing pressures and temperatures. The seawater feed goes through multiple effects, with each effect contributing to the overall desalination process. The number of effects in a plant can range from 4 to 21, depending on factors such as temperature limits and performance requirements.

- The overall performance of the MED plant is closely related to the number of effects. The power consumption of a MED plant is typically lower than that of a Multi Stage Flash (MSF) plant. MED is considered more thermodynamically efficient than MSF in terms of heat transport.

- Some plants may operate with a top brine temperature (TBT) of around 70°C in the first phase to reduce the risk of seawater scaling. The top brine temperature is limited to prevent scaling on the external surface of tubes.

- Horizontal MED plants have been successfully employed for several decades. While MED plants are currently in the minority compared to MSF plants, their numbers have been growing, especially in regions like the Middle East.

Multiple Effect Distillation is a desalination method that maximizes the use of energy by employing a sequence of evaporators, allowing seawater to boil at decreasing pressures and temperatures in multiple stages, thus enhancing overall efficiency.

II.IV.II. Reserve Osmosis (RO)

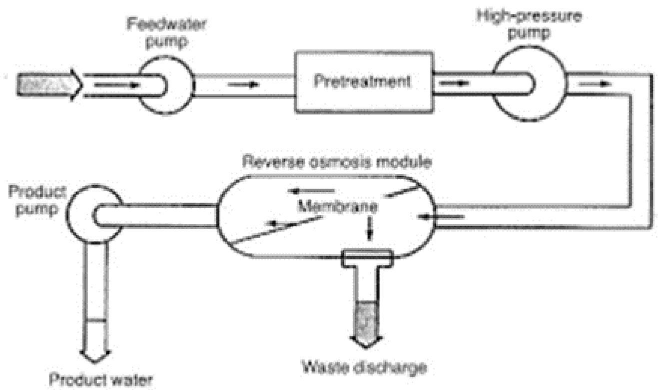

Figure 4 Reverse Osmosis Process I

Reverse osmosis (RO) is a water treatment process that functions as a cellular membrane used to remove ions, unwanted molecules, and larger particles from drinking water.

In reverse osmosis, pressure is applied to overcome the osmotic pressure through the chemical potential differences of the solvent, which is a thermodynamic parameter. Reverse osmosis removes many dissolved and suspended chemical species and biological entities (primarily bacteria) from water, making it applicable in both industrial processes and drinking water production. The result is that the solute is held on the pressurized side of the membrane, allowing the pure solvent to pass through to the other side. For it to be "selective," the membrane must not allow large molecules or ions through its pores (holes) but must permit smaller components of the solution, such as water (H2O), to pass freely.

In the normal osmosis process, the solvent naturally moves from a region of low solute concentration (high water potential) through the membrane to a region of high solute concentration (low water potential). The driving force for the movement of the solvent is the decrease in Gibbs free energy of the system as the difference in solvent concentration on both sides of the membrane decreases, creating osmotic pressure due to the solvent moving to a more concentrated solution. Therefore, applying external pressure to reverse the natural flow of pure solvent is called reverse osmosis. The process is similar to other membrane technology applications.

Reverse osmosis differs from filtration because of the liquid flow mechanism across a membrane. In membrane filtration, the dominant separation mechanism is sieving where filtration occurs where the pores are 0.01 micrometers or larger, theoretically achieving perfect efficiency independent of parameters like solution pressure and concentration. In contrast, reverse osmosis involves solvent diffusion through a membrane that is either nonporous or has pores of 0.001 micrometers using nanofiltration. The dominant separation mechanism arises from differences in solubility or diffusion, and the process depends on pressure, solute concentration, and other conditions.

Reverse osmosis is most commonly known for its use in purifying drinking water from seawater, removing salt and other waste materials from water molecules.

The basic process of water purification with reverse osmosis consists of two stages: In the first stage, the water to be treated is passed through various filters to remove sediment, particles, lime, and microorganisms. This helps reduce the pollution load on the main equipment, the membranes. In the second stage, the water is pumped to high pressures and conveyed to semi-permeable membranes. Thanks to the crossflow principle in the membranes, impurities such as salt, heavy metals, bacteria, sediment, and dissolved ions in the water are purified at a rate of 95-99.8%.

The terms "purification" and "cleaning" are used in different contexts. Purified waters are produced for different purposes such as drinking water or industrial use, each having different characteristics. For example, reverse osmosis machines designed to produce drinking water produce water with an approximate microsiemens/cm conductivity, while industrial-grade osmosis machines can produce below this value (1μ). Reverse osmosis enables the production of water of suitable quality for various uses, including drinking, industrial, agricultural water, and municipal water.

Membranes, the main maintenance element in the system, wear out over time and need to be replaced or cleaned. Advances in technology have significantly reduced membrane maintenance and operating costs. The average replacement intervals are almost up to three years, with a cost of approximately 0.05 USD per cubic meter of production.

Polymer Membrane Selection

In conventional water treatment processes, spiral-wound reverse osmosis membrane elements are the usual choice. However, the designer has the option to choose from other polymers. The classic polymer selection is usually made with cellulose-based membranes (cellulose acetate (CA) or cellulose triacetate CTA). The most significant advantage of these polymers is their resistance to

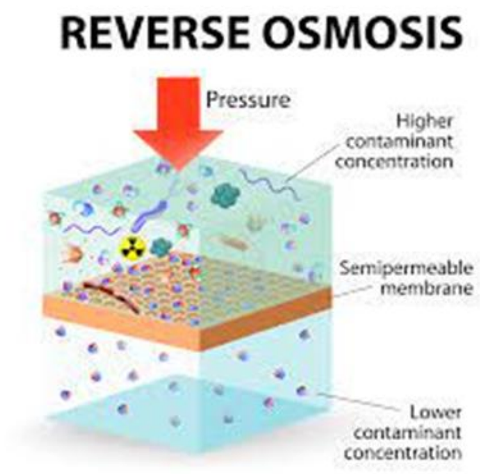

Figure 5Reverse Osmosis Process II

chlorinated waters. However, they are negatively affected by alcoholic liquids and certain bacteria. Thin Film Composite (TFC) membranes are relatively new-generation polymers. As explained earlier, they are composed of a very thin (2500 A) film polymer overlaid on a polysulfone sub-coating.

Generally, TFC membranes have a high level of mineral separation and water purification capacity compared to cellulose membranes. They cater to a wide range of purification pH, are resistant to bacterial effects, but are susceptible to chlorine in the input water. When these membranes are used, the chlorine in the input water needs to be removed.

Currently manufactured spiral-wound, chlorine-resistant CTA membranes can be used for disinfection purposes with chlorine concentrations up to 100 ppm. However, their mineral separation capacities are lower compared to TFC membranes, and high hardness can also affect their performance.

System Recovery

This term defines the percentage of treated water in relation to the input water, mathematically expressed as follows:

$$\text{Recovey} = \frac{\text{Product Water Flow Rate x 100}}{\text{Feed Water Flow Rate}}$$

Recovery is adjusted by throttling the concentrate (brine) flow using a valve or orifice or by pumping. As recovery increases, the salt concentration on the membrane surface increases, leading to the possibility of scaling. Additionally, the quality of the treated water decreases. However, reducing the concentrate disposed of on the other side leads to economic benefits in the system.

In general, when high flow treated water is desired, recovery needs to be increased, and in water treatment facilities, it can be raised up to 85%.

Applied Pressure

The treated water flow rate increases proportionally with the pump pressure. The actual pressure faced by the membrane is expressed as follows:

$$P_d = \text{Pump Pressure-Osmotic Pressure-Back Pressure}$$

Considering the desalination of input waters with high TDS, such as the removal of salt from seawater, pump pressures should be between 55-70 bars.

Typically, pump pressures are around 10-15 bars for TFC membranes in well waters and around 25 bars for cellulose membranes.

Membrane Separation Capacity

This is the membrane's ability to separate minerals and salts in water, expressed as a percentage:

$$\%Seperation = \frac{Feed\ Water\ TDS - Product\ Water\ TDS}{Feed\ Water\ TDS}\ x\ 100$$

TDS that the membrane cannot separate and passes to the treated water side is expressed as:

$$\%Passage = 100 - \%Separation$$

II.IV.III. Electrodialysis Desalination (ED)

Electrodialysis (ED) is a water desalination process that utilizes an electric field to separate ions from water. The primary objective of electrodialysis is to remove salts and other ionized substances from water, making it suitable for various applications, including drinking water, industrial processes, and agricultural use. Electrodialysis is particularly effective for desalination purposes.

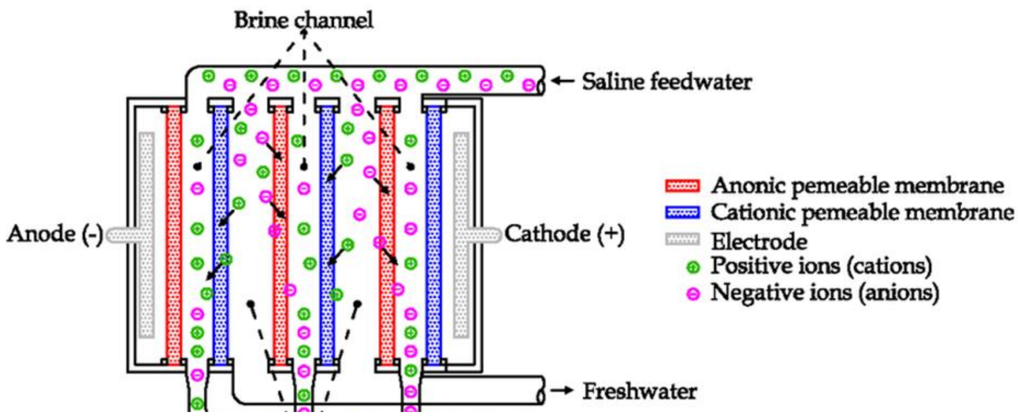

Figure 6 Electrıdialysis Desalination (ED) Process

- Basic Principle

Electrodialysis typically involves the use of an electrodialysis stack, which consists of alternating anion-selective and cation-selective ion exchange membranes. The stack is placed between two electrodes, one at each end.

- Ion Exchange Membranes

Anion-selective membranes allow only negatively charged ions (anions) to pass through. Cation-selective membranes allow only positively charged ions (cations) to pass through. These membranes create compartments between them.

- Electric Field Application

When an electric potential is applied across the stack by the electrodes, it creates an electric field. Ions in the water are attracted or repelled based on their charge.

- Ion Migration

Negatively charged ions (anions) migrate toward the positively charged electrode (anode) through the anion-selective membranes. Positively charged ions (cations) migrate toward the negatively charged electrode (cathode) through the cation-selective membranes.

- Salt Separation

As a result of this migration, ions are selectively removed from the water. Salts are effectively separated, and desalinated water is collected in the compartments between the membranes.

- Collection of Desalinated Water

Desalinated water is collected from the compartments between the membranes, and the concentrated brine (reject stream) is removed separately.

- Continuous Process

Electrodialysis is a continuous process, and it can be operated to achieve varying degrees of desalination based on the specific needs.

- Advantages of Electrodialysis

Electrodialysis is energy-efficient compared to some other desalination methods. It can selectively remove ions, providing control over the desalination process. It has applications in both brackish water and seawater desalination.

- Challenges

Fouling of membranes over time. Initial capital costs can be relatively high. Overall, electrodialysis is a promising technology for water desalination, and ongoing research aims to improve its efficiency and reduce costs for broader implementation.

II.IV.IV. Ion Exchange

Ion exchange is a reversible process that involves the interchange of ions present in an insoluble solid with ions of similar charge present in a solution surrounding the solid. This process is widely used for various applications, including water softening, demineralization, purification of chemicals, and separation of substances.

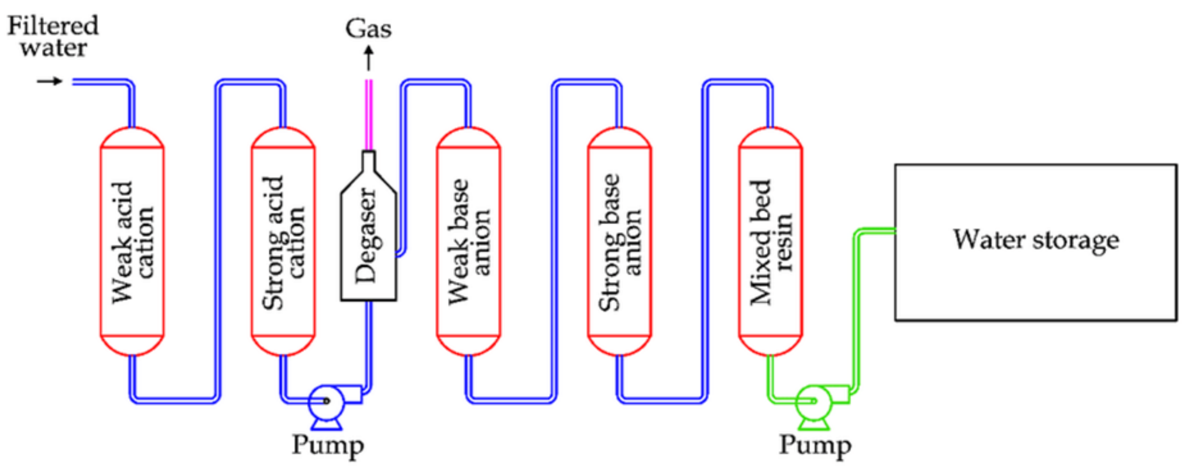

Figure 7 Ion Exchange Process

- Basic Principles

Ion exchange typically involves the use of solid polymeric ion-exchange resins, though it can include other materials like zeolites, montmorillonite, clay, and soil humus. Ion exchangers can be cation exchangers (exchange positively charged ions or cations) or anion exchangers (exchange negatively charged ions or anions). The ion exchange process is reversible, and the ion exchanger can be regenerated or loaded with desirable ions by washing with an excess of these ions.

- Types of Exchange

Cation Exchange: Involves exchanging positively charged ions. Examples: CM (Carboxymethyl group, weak cation exchange), SP (sulphopropyl group, strong cation exchange).

Anion Exchange: Involves exchanging negatively charged ions. Examples: DEAE-Sepharose, QFF.

- Applications

Ion exchange is widely used in various industries such as food and beverage, hydrometallurgy, metals finishing, chemical, petrochemical, pharmaceutical technology, sugar and sweetener production, water treatment, and more. It is used for water softening, water purification, water decontamination, and the preparation of high-purity water for power engineering, electronic, and nuclear industries. Ion exchange is employed in household filters to produce soft water for laundry detergents, soaps, and water heaters. In industrial and analytical ion-exchange chromatography, it is used for chemical analysis and separation of ions, including biochemistry applications. Ion-exchange processes are used in the extraction and purification of biologically produced substances such as proteins and DNA/RNA. It plays a crucial role in the separation and purification of metals, including the separation of uranium from plutonium and lanthanides from each other.

- Desalination Using Ion Exchange

Ion exchange can be used for desalination, and liquid-phase ion-exchange desalination has been demonstrated. In this technique, anions and cations in saltwater are exchanged for carbonate anions and calcium cations, respectively, using electrophoresis. Calcium and carbonate ions react to form calcium carbonate, which precipitates, leaving behind fresh water. This desalination method occurs at ambient temperature and pressure, requiring no membranes or solid ion exchangers.

Overall, ion exchange is a versatile and widely used method for various separation and purification processes, with applications ranging from water treatment to the nuclear industry.

II.IV.V. Freezing Desalination

The freezing desalination method, also known as freeze desalination or freeze-thaw desalination, harnesses the physical properties of water to separate freshwater from saline solutions.

The process involves inducing controlled freezing of saline water, exploiting the fact that pure water freezes at a higher temperature than saltwater. By lowering the temperature of the saline solution below its freezing point, ice crystals form, capturing the salts and impurities while leaving behind a concentrated brine. Subsequent separation of ice from brine results in the extraction of freshwater.

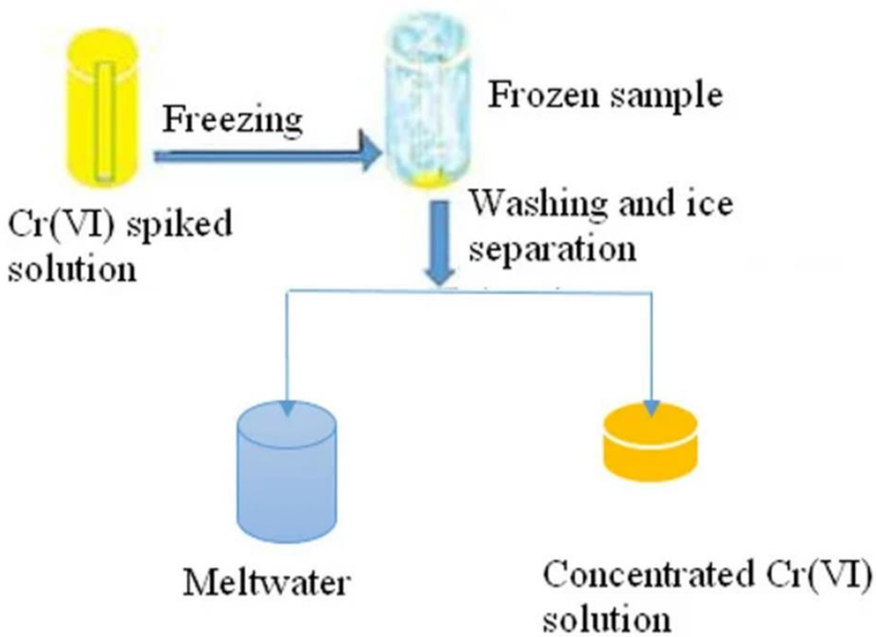

Figure 8 Freezing Desalination method

The freezing point depression of seawater is approximately -1.9°C due to the dissolved salts. This means that to initiate freezing, the temperature of the saline solution must be lowered beyond this point. Efficient separation of ice crystals from the concentrated brine is crucial. Various methods, including centrifugation and filtration, are employed, each with its associated energy requirements.

The overall energy consumption of the freezing desalination process is a critical parameter. It includes energy for cooling the saline solution, inducing freezing, and separating ice from brine. Advancements in refrigeration technologies and heat exchange systems can significantly impact the efficiency of the process. While freezing desalination shows promise, challenges such as energy consumption, equipment durability, and environmental impact must be addressed. Ongoing research aims to optimize the process, exploring advanced materials for heat exchange, innovative separation techniques, and renewable energy sources to enhance sustainability.

Freezing desalination stands as a scientifically intriguing and potentially viable method for freshwater production. By leveraging the principles of thermodynamics and phase change, this approach offers a unique solution to the global water crisis. Continued research and technological advancements will play a pivotal role in unlocking the full potential of freezing desalination as a sustainable and efficient method for meeting the world's growing demand for freshwater.

II.IV.VI. Solar Desalination

Solar energy collected as electricity or heat can be used to distill water. Solar thermal systems such as flat solar collectors, evacuated tubes, solar troughs, and solar ponds absorb solar energy and convert it into thermal energy that drives thermal desalination processes. The use of solar thermal energy for desalination can be classified as direct, where solar thermal energy is collected directly into brackish water, such as in solar boilers and solar ponds, or indirect, where solar thermal energy is absorbed in a solar collector and then transferred. to brackish water, such as in solar desalination (HDH) and diffusion-controlled desalination. Technical simplicity, low maintenance requirements and ease of use are very important for the successful implementation of distributed solar desalination systems.

Solar Still

The solar still is one of the oldest and simplest methods of water desalination. A solar still consists of a structural element called a basin covered with a transparent material to allow the incident solar radiation to pass through to the basin's saline water for thermal absorption and evaporation. Solar energy absorption, saline water evaporation, and freshwater condensation occur within a single enclosure for a solar still. Solar stills inherently operate as direct collection systems. The use of solar distillation with solar stills is considered a well-established technology. Due to its low maintenance requirement, it is employed globally for freshwater production. Typically, the basin is colored dark or black to enhance solar flux absorption. The water is heated by the solar rays absorbed by the basin, increasing the water vapor pressure until some portion of the saline water evaporates, as shown in Figure 9. The water vapor moves upward and typically condenses on the cool glass cover, then runs down through a guiding channel to the collection reservoir.

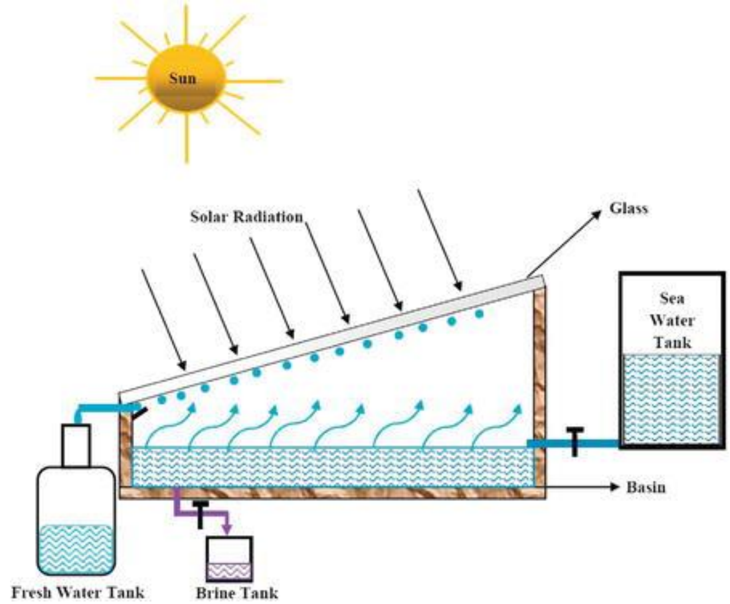

Figure 9 Solar Still Process

The gap distance between the solar still basin and the transparent cover surface significantly impacts its performance, with performance improving as the gap distance decreases. Consequently, various design enhancements have been explored as seen on Figure 10. The basin is typically constructed from a metallic corrugated sheet, such as flat, black-coated aluminum.

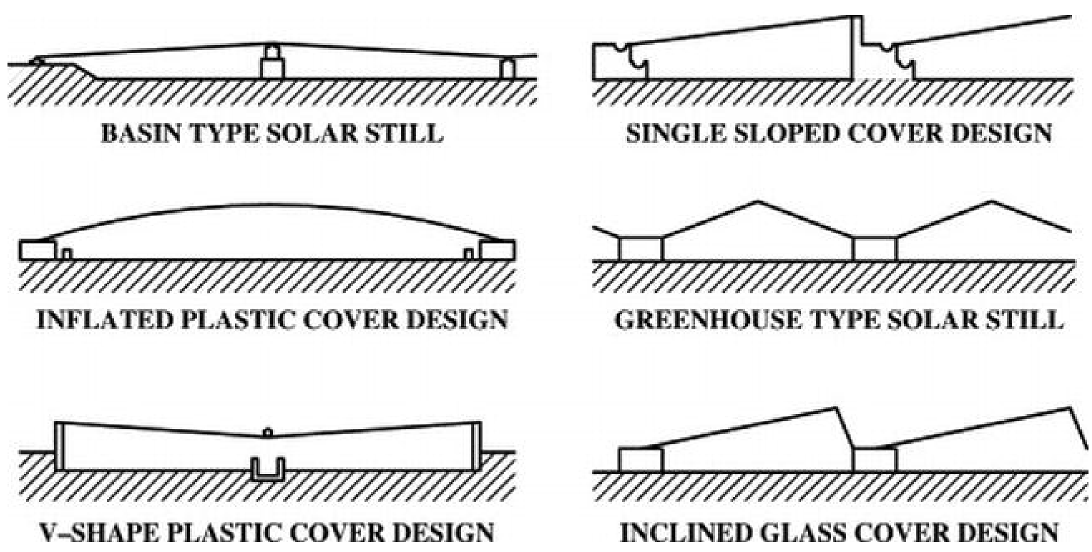

Figure 10 Different types of Solar Still

In this project, solar stills will be primarily obtained. Vacuum solar tubes will be used for the heating system, and water will be distilled. Due to its simplicity, low cost, and sustainability, the solar still is considered highly suitable for the project. Some modifications are required for the existing vacuum tube system, and the necessary requirements for manufacturing should be addressed.

II.V. Evacuated Tube Collectors

Solar Evacuated tube Collectors for Hot Water

The evacuated tube collector (ETC) consists of several sealed glass tubes which have a thermally conductive copper rod or pipe inside allowing for much high thermal efficiency and working temperature compared to the flat plate solar collectors even during a freezing cold day.

Pipes called riser, soldered to the absorber plate carry liquid that is heated by the sun and in a direct heating system, water is heated as it circulates through the panels to the storage tank. In indirect systems, the sun’s energy heats a glycol/water mixture that cannot freeze and which, in turn, heats the water in the tank.

While this type of solar hot water systems is cheap and easy to install, the problem with flat plate collectors is that they are “flat”. This produces one limitation to their efficiency as they can only operate at maximum efficiency when the sun is directly overhead at midday. At other times, the sun’s rays are striking the collector at varying angles bouncing off the glazing material thereby reducing their efficiency.

Solar hot water systems that use Evacuated Tube Collectors as their heat source overcome this problem because the solar collector uses individual rounded tubes which are always perpendicular to the sun’s rays for most of the day. This allows a solar hot water system using an evacuated tube collector to operate at a much high efficiency and temperature for a much longer period than a conventional single flat plate collector installed system.

Also, another advantage of solar evacuated tube technology is that the weight and roof structural problems caused by standard flat plate systems are eliminated as the solar tubes are not filled with large amounts of heavy water.

The Evacuated tube collector consists of several rows of parallel transparent glass tubes connected to a header pipe and which are used in place of the blackened heat absorbing plate we saw in the previous flat plate collector.

These glass tubes are cylindrical in shape. Therefore, the angle of the sunlight is always perpendicular to the heat absorbing tubes which enables these collectors to perform well even when sunlight is low such as when it is early in the morning or late in the afternoon, or when shaded by clouds. Evacuated tube collectors are particularly useful in areas with cold, cloudy wintry weathers.

So how do solar evacuated tube collectors work? Evacuated tube collectors are made up of a single or multiple rows of parallel, transparent glass tubes supported on a frame. Each individual tube varies in diameter from between 1" (25mm) to 3" (75mm) and between 5′ (1500mm) to 8′ (2400mm) in length depending upon the manufacturer.

Each tube consists of a thick glass outer tube and a thinner glass inner tube, (called a “twin-glass tube”) or a “thermos-flask tube” which is covered with a special coating that absorbs solar energy but inhibits heat loss. The tubes are made of borosilicate or soda lime glass, which is strong, resistant to high temperatures and has a high transmittance for solar irradiation.

Unlike flat panel collectors, evacuated tube collectors do not heat the water directly within the tubes. Instead, air is removed or evacuated from the space between the two tubes, forming a vacuum (hence the name evacuated tubes).

This vacuum acts as an insulator reducing any heat loss significantly to the surrounding atmosphere either through convection or radiation making the collector much more efficient than the internal insulating that flat plate collectors have to offer. With the assistance of this vacuum, evacuated tube collectors generally produce higher fluid temperatures than they’re flat plate counterparts so may become very hot in summer.

Figure 11 Evacuated Tubes

Figure 12 Evacuated Tube Collector System for Hot Water

Model		JVN	JVT
Structure		All-glass double-layer coaxial	
Tube material		High quality borosilicate glass 3.3	
Outer tube diameter and thickness		Φ=47 & =1.6mm, Φ=58 & =1.6mm / 2.0mm / 2.2mm	
Inner tube diameter and thickness		Φ=37 & =1.6mm, Φ=47 & =1.6mm	
Tube length		1500mm / 1800mm	
Absorptive coating	Structure	AL/N/AL	ALN/AIN-SS/Cu
	Sediment method	Magnetron sputtering plating	
	Absorptance	a=0.88-0.92(AM1.5)	a=0.93-0.96(AM1.5)
	Emittance ratio	Σ=0.04-0.08(80°C±5°C)	Σ=0.04-0.06(80°C±5°C)
Vacuum quality		$p \le 5.0 \times 10^{-2}$ Pa	$p \le 5.0 \times 10^{-2}$ Pa
Stagnation parameter		Y=250-260m^2. °C/kw	Y=270-300m^2. °C/kw
Solar irradiation under stagnation		H=4.7MJ/m^2	H=3.7-4.2MJ/m^2
Average heat loss coefficient		U_{LT}=0.4-0.6W(m^2.°C)	U_{LT}=0.4-0.6W(m^2.°C)
Hail resistance		Φ25mm / Φ40mm	

Figure 13 Evacuated Tubes Specifications

Evacuated Tube Collector

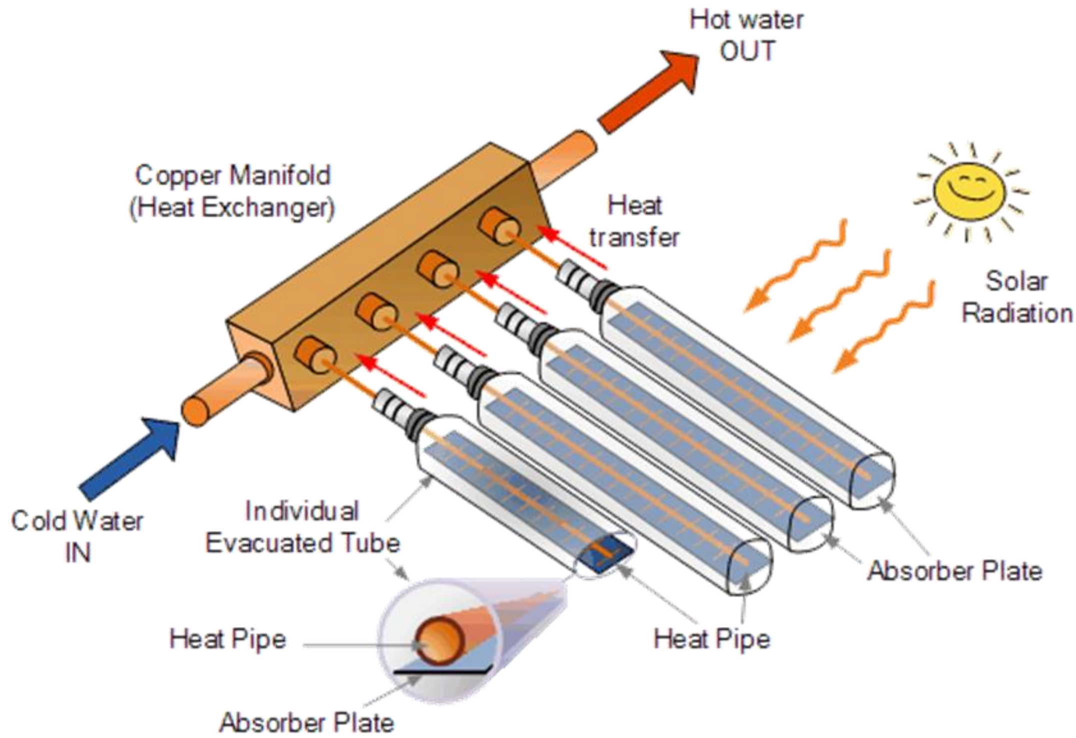

Figure 14 Evacuated Tube Collector Section

Inside each glass tube, a flat or curved aluminum or copper fin is attached to a metal heat pipe running through the inner tube. The fin is covered with a selective coating that transfers heat to the fluid that is circulating through the pipe. This sealed copper heat pipe transfers the solar heat via convection of its internal heat transfer fluid to a “hot bulb” that indirectly heats a copper manifold within the header tank.

These copper pipes are all connected to a common manifold which is then connected to a storage tank, thus heating the hot water during the day. The hot water can then be used at night or the next day due to the insulating properties of the tank.

The insulation properties of the vacuum are so good that while the inner tube may be as high as 150o C, the outer tube is cooler to touch. This means that evacuated tube water heaters can perform well and can heat water to fairly high temperatures even in cold weather when flat plate collectors perform poorly due to heat loss.

However, the downside of using evacuated tubes is that the panel can be a lot more expensive compared to standard flat plate collectors or solar batch collectors. Evacuated tube solar collectors are well suited to commercial and industrial hot water heating applications and can be an effective alternative to flat plate collectors for domestic space heating, especially in areas where it is often cloudy.

Evacuated tube collectors are overall more modern and more efficient compared to the standard flat plate collectors as they can extract the heat out of the air on a humid, dull overcast days and do not need direct sunlight to operate. Due to the vacuum inside the glass tube, the total efficiency in all areas is higher and there is a better performance even when the sun is not at an optimum angle.

For these types of solar hot water panels, the configuration of the vacuum tube is what's important. There are a few different vacuum tube configurations, single wall tube, double wall tube, direct flow or heat pipe, and these differences can determine how the fluid is circulated around the solar hot water panel.

Heat Pipe Evacuated Tube Collectors

In heat pipe evacuated tube collectors, a sealed heat pipe, usually made of copper to increase the collector's efficiency in cold temperatures, is attached to a heat absorbing reflector plate within the vacuum sealed tube. The hollow copper heat exchanger design within the tube is evacuated of air but contains a small quantity of a low-pressure alcohol/water liquid plus some additional additives to prevent corrosion or oxidation.

This vacuum enables the liquid to vaporize at very lower temperatures than it would normally at atmospheric pressure. When sunlight in the form of solar radiation hits the surface of the absorber plate inside the tube, the liquid in the heat pipe quickly turns into a hot vapor type gas due to presence of the vacuum. As this gas vapor is now lighter, it rises to the top portion of the pipe heating it up to a very high temperature.

The top part of the heat pipe, and therefore the evacuated tube is connected to a copper heat exchanger called the "manifold". When the hot vapors still inside the sealed heat tube enters the manifold, the heat energy of the vapor is transferred to the water or glycol fluid flowing through the connecting manifold. As the hot vapor loses energy and cools, it condenses back from a gas to a liquid flowing back down the heat pipe to be reheated.

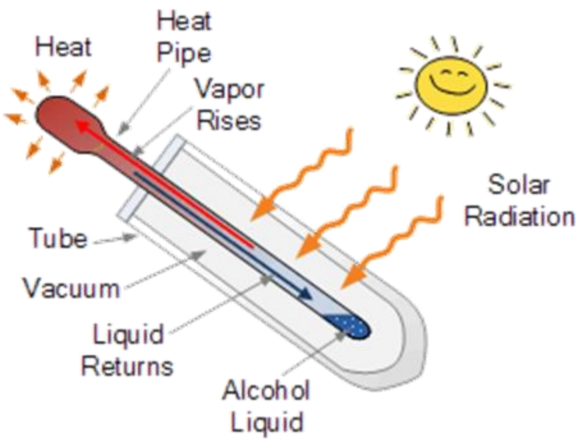

Figure 15 Heat Pipe Evacuated Tube

The heat pipe and therefore the evacuated tube collectors must be mounted in such a way as to have a minimum tilt angle (around 30^o) for the internal liquid of the heat pipe to return back down to the hot absorber plate at the bottom of the tube. This process of converting a liquid into a gas and back into a liquid again continues inside the sealed heat pipe if the sun shines.

The main advantage of Heat Pipe Evacuated Tube Collectors is that there is a "dry" connection between the absorber plate and the manifold making installation much easier than with direct flow collectors. Also, in the event an evacuated tube cracking or breaking and the vacuum becoming lost the individual tube can be exchanged without emptying or dismantling the entire system. This flexibility makes heat pipe evacuated tube solar hot water collectors ideal for closed loop solar designs as the modular assembly allows for easy installation and ability to easily expand by adding as many tubes as you want.

Direct Flow Evacuated Tube Collector

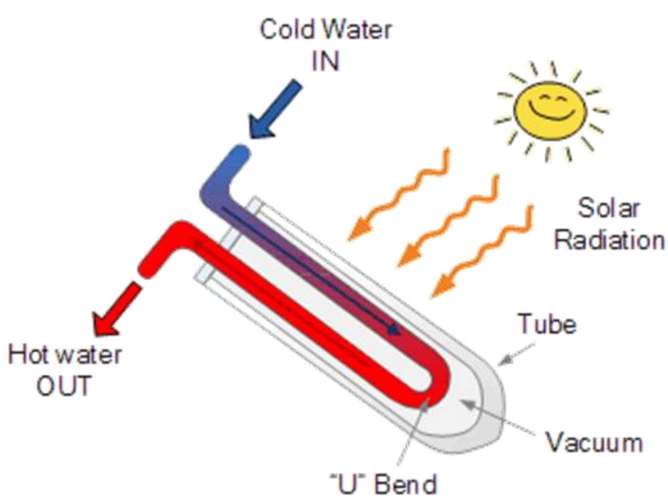

Figure 16 Direct Flow Evacuated Tube

Direct flow evacuated tube collectors also known as "U" pipe collectors, are different from the previous ones in that they have two heat pipes running through the center of the tube. One pipe acts as the flow pipe while the other acts as the return pipe. Both pipes are connected at the bottom of the tube with a "U-bend", hence the name.

The heat absorbing reflective plate acts like a dividing strip which separates the flow and the return pipes through the solar collector tubes. The absorber plate and the heat transfer tube are also vacuum sealed inside a glass tube providing exceptional insulation properties.

The hollow heat pipes and the flat or curved reflector plate are made from copper with a selective coating to increase the collector's overall efficiency. This evacuated tube configuration is similar in operation to the flat plate collectors, apart from the vacuum provided by the outer tube.

Since the heat transfer fluid flows into and out of each tube, direct flow evacuated tube collectors are not as flexible as the heat pipe types. If a tube cracks or breaks it cannot be easily replaced. The system will require draining as there is a "wet" connection between the tube and manifold.

Other Considerations when using Evacuated Tube Collectors

Due to the sealed vacuum within their design, evacuated tube collectors can get very hot, exceeding the boiling point of water during the hot summer months. These high temperatures can cause significant issues in an existing domestic solar hot water system such as overheating and cracking of the evacuated glass tubes.

To help prevent this from happening in hot summer climates, bypass valves and large heat exchangers are used to "dump" the excess heat as well as mixer valves which mix regular (cool) water with the hot water, to ensure the temperature and pressure levels never exceed a preset limit.

Also, heat pipe collectors should never be exposed to direct sunlight without a heat transfer fluid flowing through the heat exchanger. Doing so will cause the empty heat exchanger to become extremely hot and which may crack due to the sudden shock once cold water begins to flow through it.

Even though evacuated tube collectors are capable of heating water to +50 degrees Celsius in the winter, the outer glass tube of an evacuated tube does not heat up like a normal flat plate solar collectors when in use. This is due to the inherent insulation properties of the vacuum inside the tube which prevents the outer heat tube from being cooled by the outside ambient temperature which can be well below freezing.

Thus, in the colder winter months, these types of collectors cannot melt away the large quantity of snow that falls on them at any one time which means clearing the snow and ice from the glass tubes daily can be a problem without breaking them.

Even if it is very snowy or very cold, enough sunlight will get through to keep the tubes well above freezing and still be able to preheat the water which can then be heated further by a standard electrical immersion heater or gas burner reducing the costs of heating the water in winter.

Evacuated Tube Collectors are a very efficient way of heating much of your hot water use just using the power of the sun. They can achieve high very temperatures but are more fragile than other types of solar collectors and are much more expensive to install. They can be used in either an active open-loop (without heat exchanger) or an active closed-loop (with heat exchanger) solar hot water system, but a pump is required to circulate the heat transfer fluid from collector to storage to stop it from overheating.

In our next tutorial about Solar Heating, we will look at another way of heating water using a type of batch collector known commonly as an Integral Collector Storage system or ICS and see how they can be used to both generate and store the solar hot water.

III. Manufacturing

Ready-made solar systems are available. However, these systems are too large and cumbersome for experimentation. In this project, we aimed to create a more minimal system. Since solar energy systems are not available in Istanbul, we had to travel to Erzincan to procure the necessary components. After contacting the factory, the storage was manufactured and reached us approximately a month later. Following this process, with the help of our instructor, tubes and gaskets were obtained from Gebze. The final component we needed, the supporting scaffold, was fabricated by an ironworker in Hasanpaşa. 3D and 2D technical drawings of each element were created using the SolidWorks program. The ready-made tubes, gaskets, and tank were modeled. The supporting scaffold was designed to fit the appropriate dimensions and sent for manufacturing. To facilitate transportation, wheels and detachable parts were used.

To collect steam, we decided to utilize the discharge pipe located on top of the storage. We obtained a hose suitable for the diameter of this pipe. With the help of a collection container attached to the storage, our goal was to condense the incoming steam and accumulate the water.

At the end of this process, assembly was carried out at the school. After assembly, it was necessary to perform a leak test. For this purpose, we filled the storage with a certain amount of water. After waiting for a while, we determined that the gaskets performed their function, and the assembly was successful. Now, our system is ready for experimentation on a sunny day.

In the upcoming pages, we will see the design and manufacturing stages step by step.

III.I. Modelling

III.I.I. Tank

We took measurements and created a solid model for the tank since it adheres to standard dimensions. During measurements, we utilized tools such as a tape measure and calipers. The tank consists of a double wall, and there is insulation material between the two walls to provide thermal insulation.

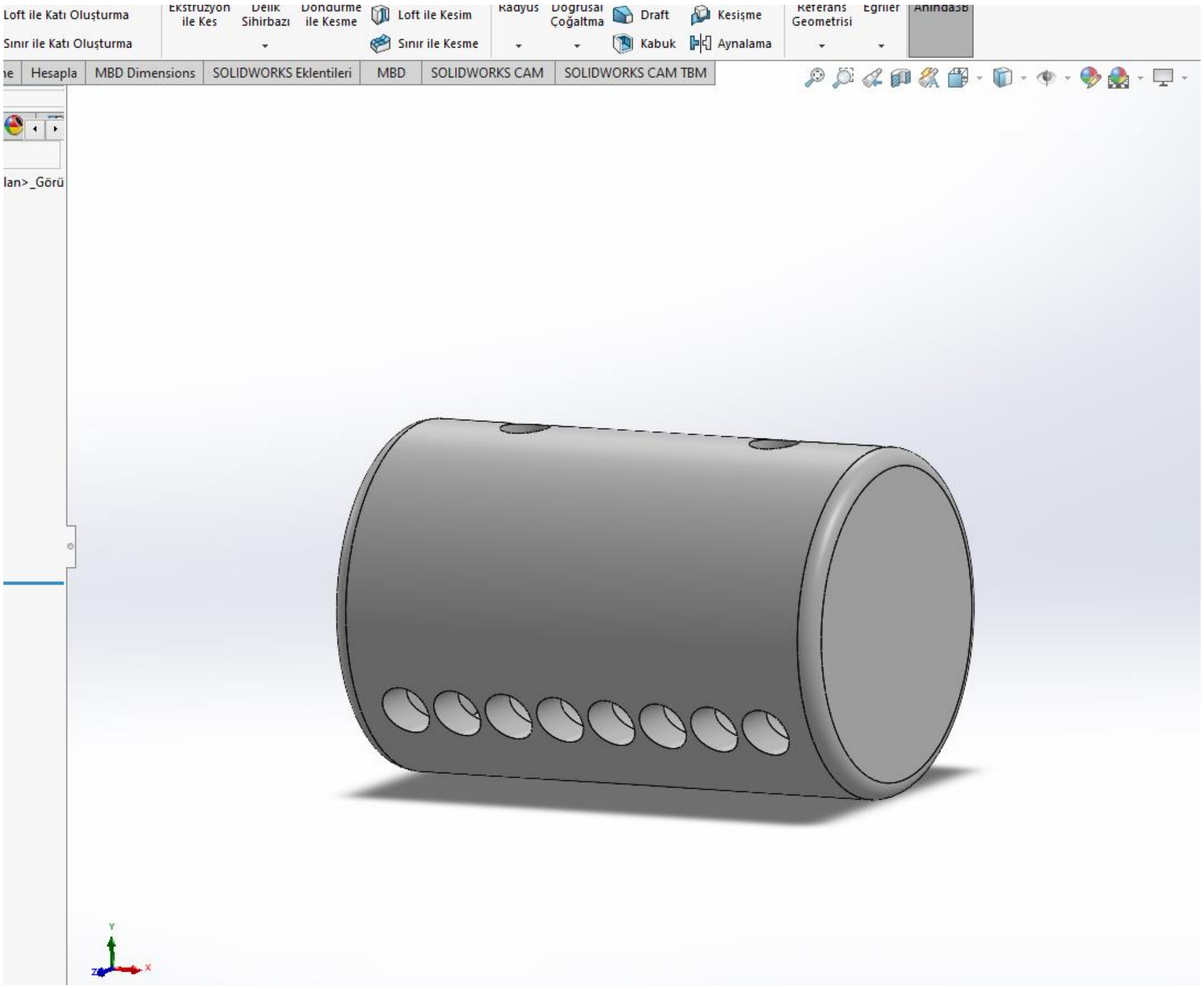

Figure 17 SolidWorks model of Tank

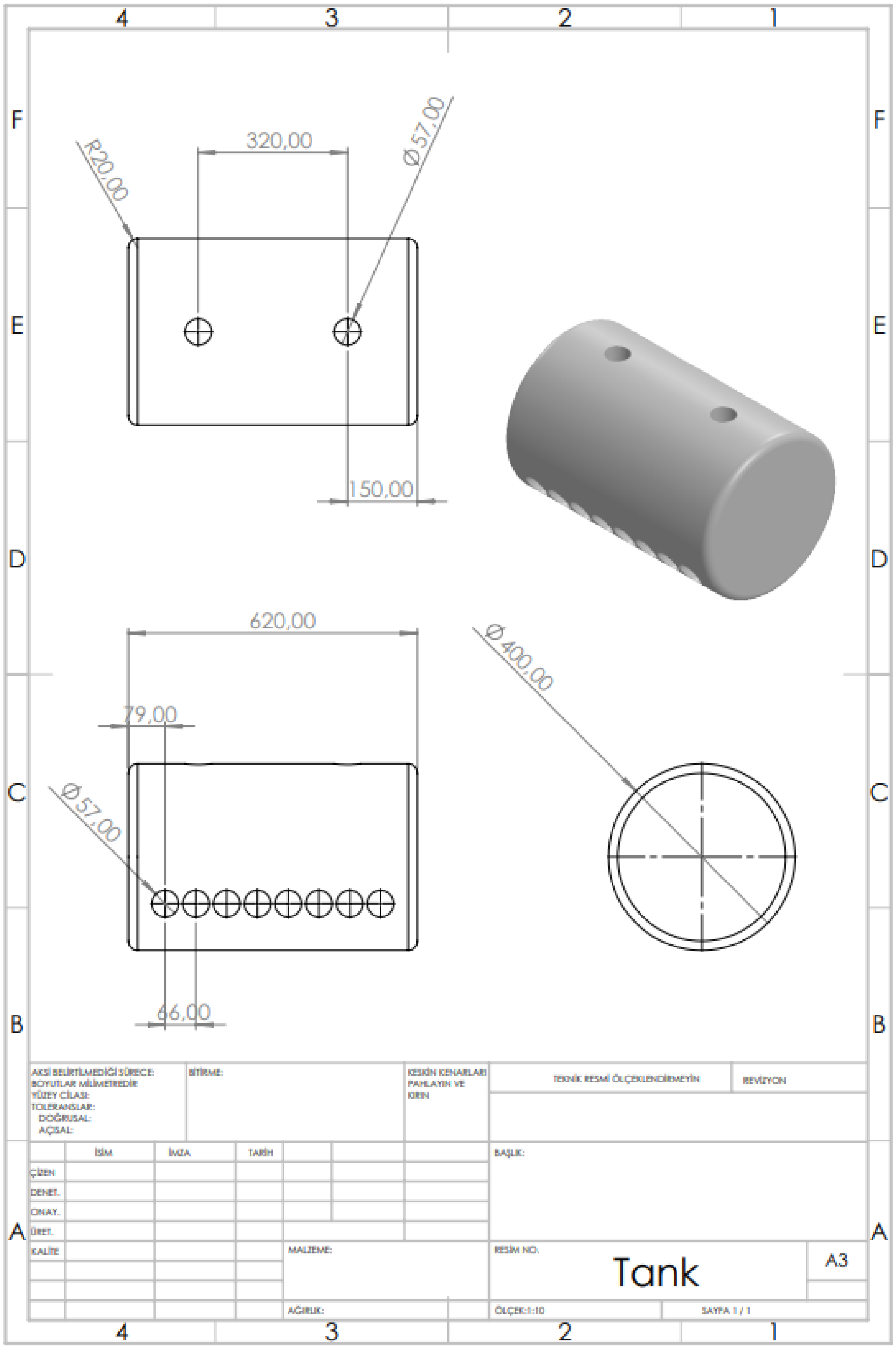

Figure 18 Technical Drawing of Tank

III.I.II. Gasket and Dust Cover

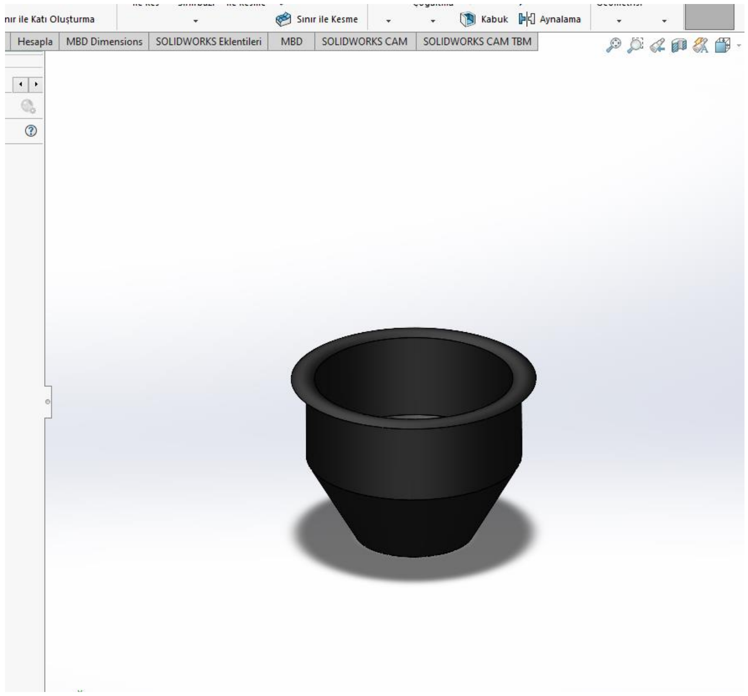

Figure 20 SolidWorks model of Gasket

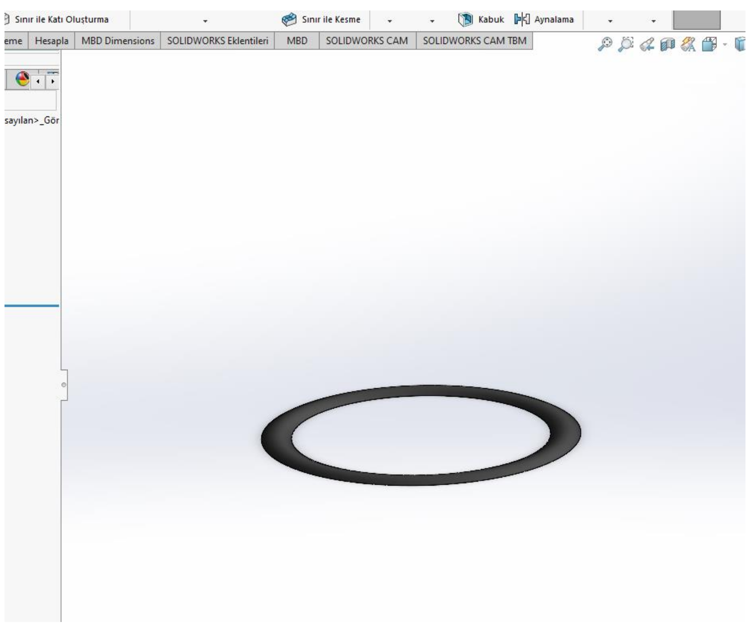

Figure 19 SolidWorks model of Dust Cover

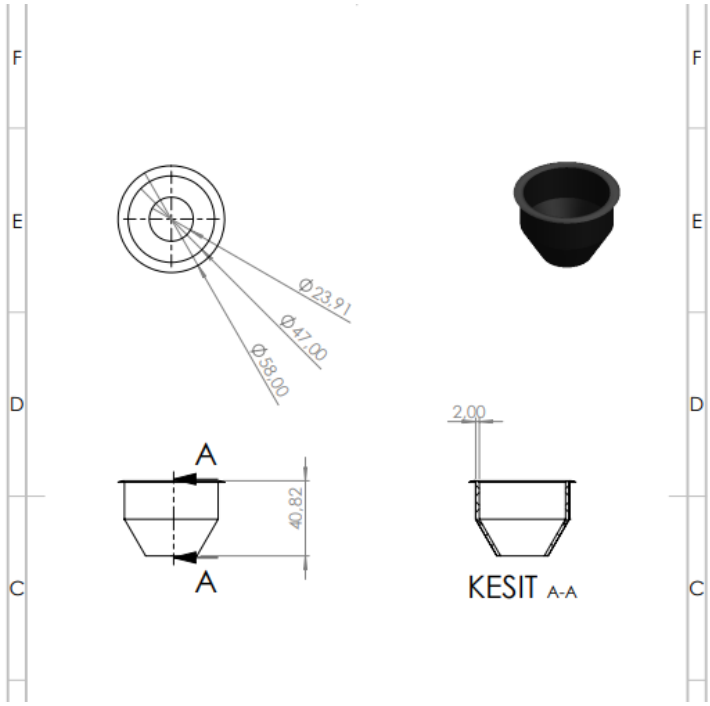

Figure 21 Technical Drawing of Gasket

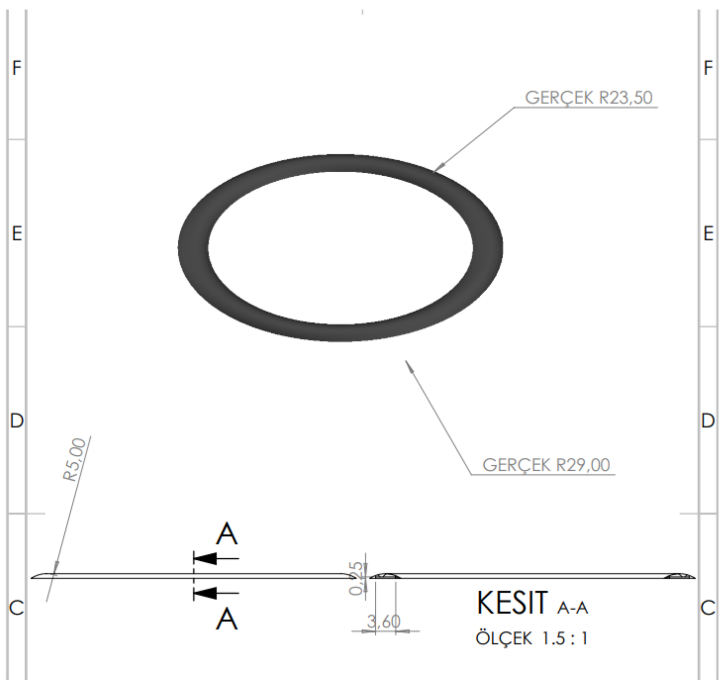

Figure 22 Technical Drawing of Dust Cover

III.I.III. Evacuated Solar Tube

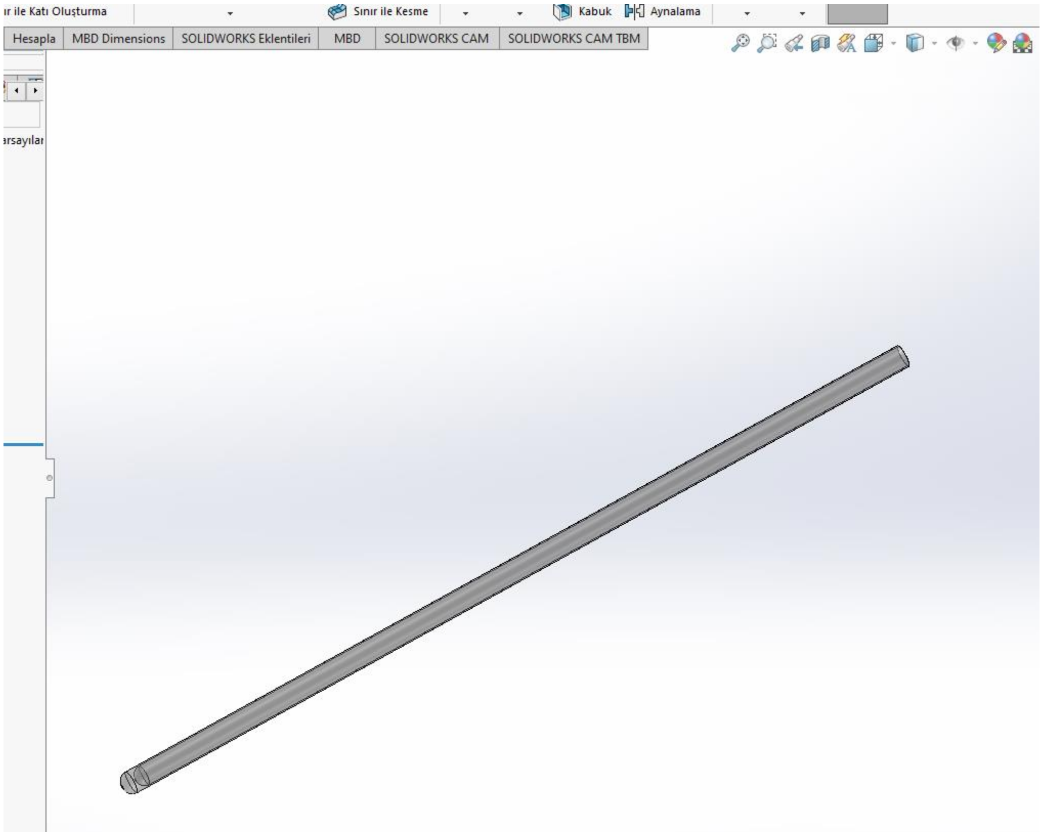

Figure 23 SolidWorks model of Evacuated Solar Tube

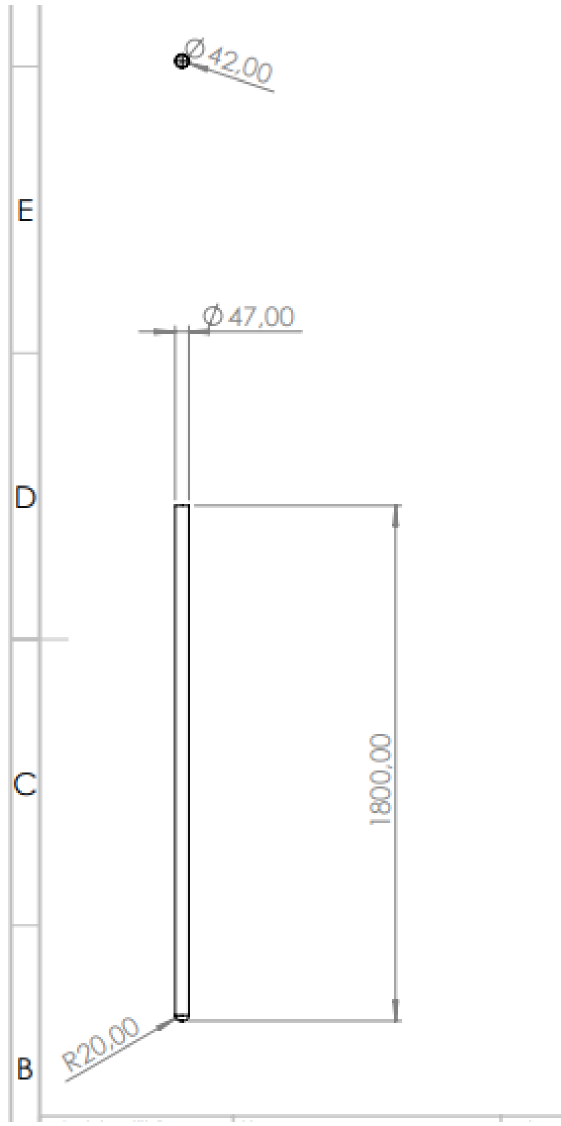

Figure 24 Technical Draving of Evacuated Solar Tube

III.I.IV. Supporting Scaffold

Other parts were purchased, but we designed and had the scaffold manufactured ourselves. In this process, we initially used a pre-existing system in Gebze as a reference. We took the measurements of that system and adapted them to our own tank. 3x3 square profile iron was used in the manufacturing. During the design phase, we specified that the scaffold angle would be 40 degrees, but due to a manufacturing error, we obtained a value between 36-37 degrees. In our literature research, we realized that for the system to function optimally, the latitude angle of the location should be considered. Since the school is located at 40°57'17.2"N 29°07'55.6"E, our goal was to achieve an angle close to 40 degrees.

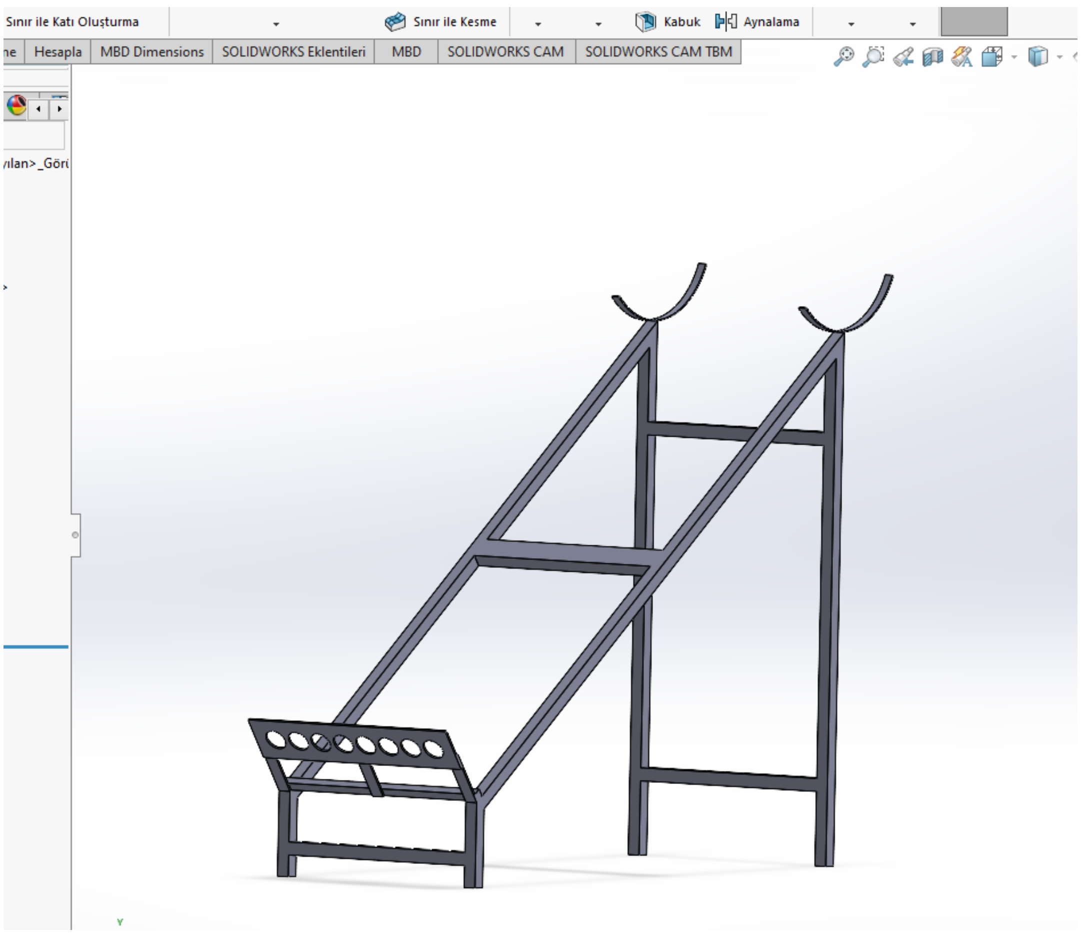

Figure 25 SolidWorks model of Supporting Scaffold

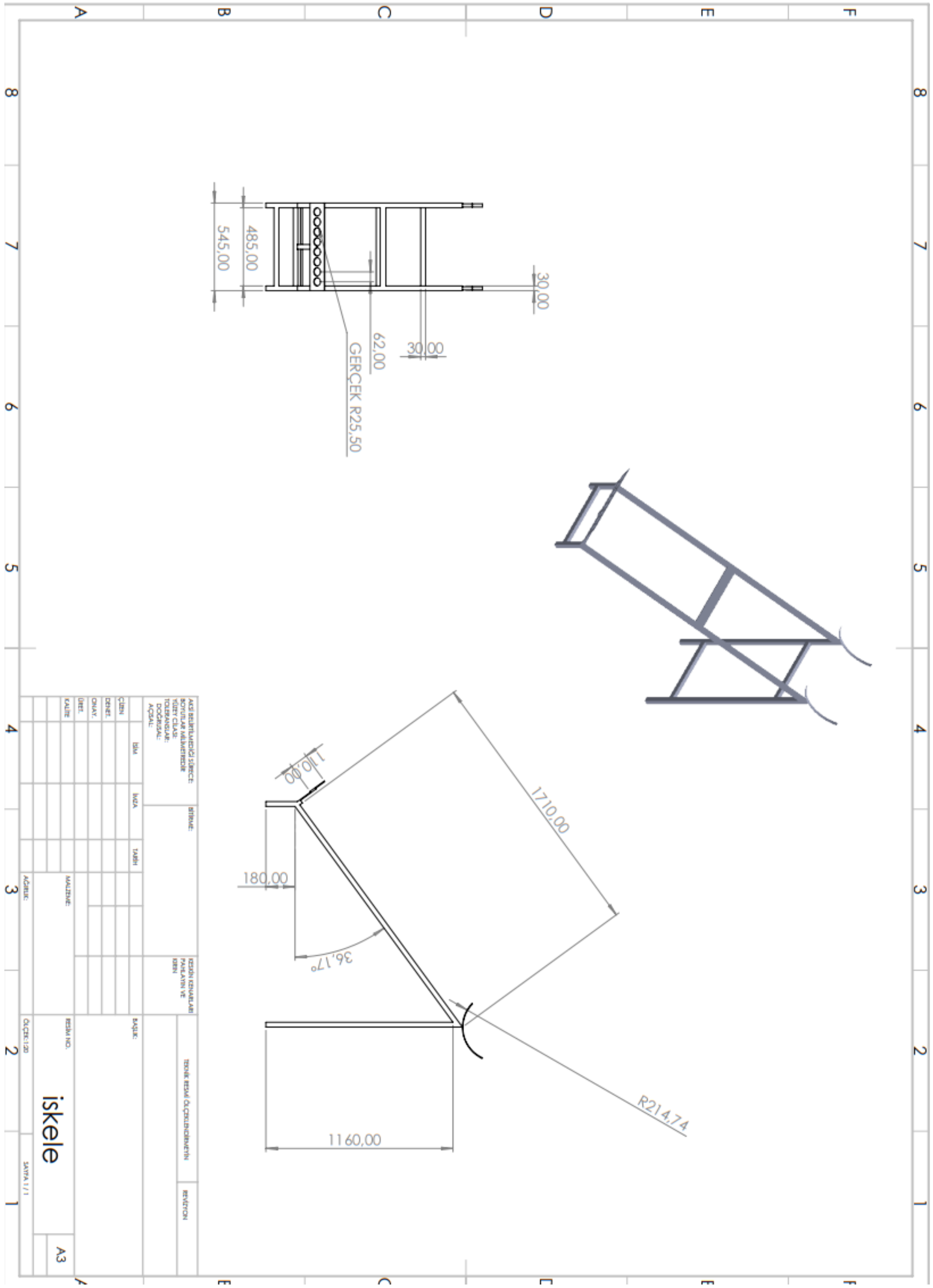

Figure 26 Technical Drawing of Supporting Scaffold

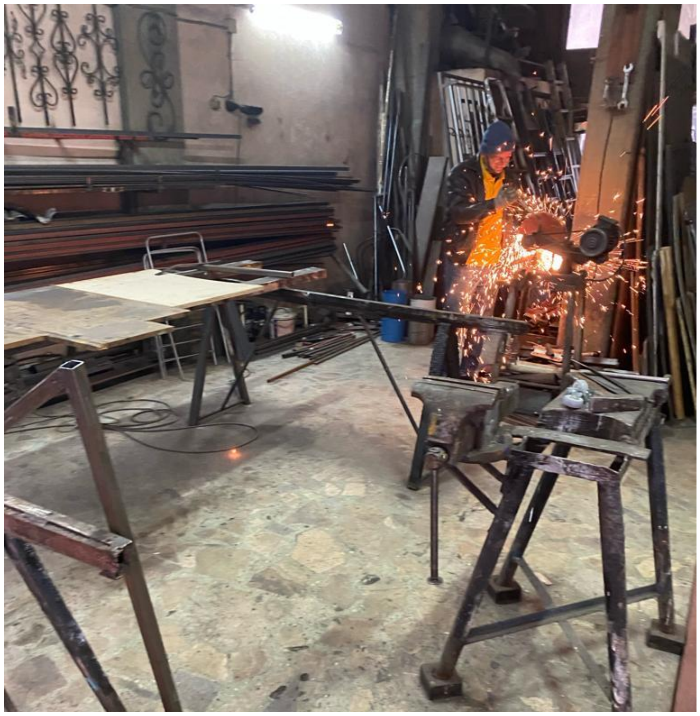

Figure 27 Cutting Process

Figure 28 Welding Process

Figure 29 Manufacturing Process

The manufacturing of the perforated metal piece that would hold the bottom parts of the tubes proved to be quite challenging for us. We wanted to use the manufacturing machines located in the Göztepe campus. However, due to technical issues in the machines, we had to outsource the manufacturing. This situation posed challenges both financially and in terms of time loss. After preparing the perforated metal, it was assembled onto the scaffold. Finally, it was painted, and wheels were attached for mobility. We transported it to the campus and proceeded to the assembly stage.

III.II. Assembly

During the assembly, we paid close attention to ensuring that the glass tubes were not damaged. First, the gaskets were placed in the necessary locations. In the next step, we applied soap for lubrication to facilitate the tubes' smoother placement. The tubes were individually positioned in the tank by rotating and pushing, passing through the gasket. The crucial point here is that the tubes should extend 2-3 cm beyond the gasket inside the tank. This ensured a watertight seal. The discharge holes under the tank were closed with blind plugs. After the entire system was installed, a small amount of water was filled for the leak test. Once it was observed that there were no leaks in the system, the water was drained again.

Figure 30 Gasket Assembly

Figure 31 Assembly Process

Figure 32 Evacuated Solar Collector System

Figure 33 Evacuated Solar Collector System

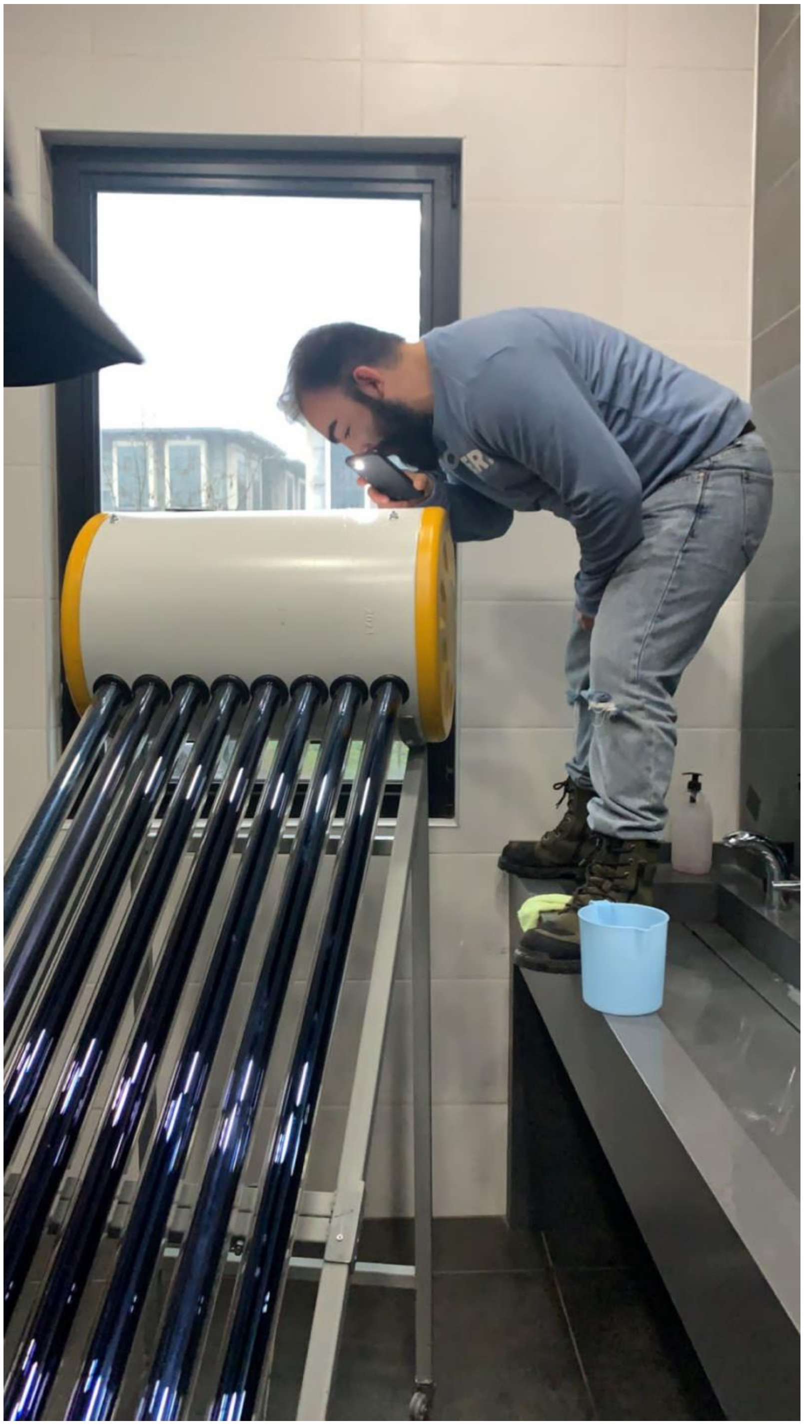

Figure 34 Leak Test

IV. Experiment

IV.I. Objective

Vacuum tube collector used in solar energy from renewable energy sources. Introduction of types, vacuum tube solar collector system examination of the equipment, parameters affecting collector efficiency and is to reveal the energy obtained with the collector.

IV.II. Introduction

There are many renewable energy sources in the world. The sun, a source of heat and light, is one of them. The increasing need for energy in the modern world has led humanity to turn to renewable energy sources. There are basically two types of energy from the sun: electricity and heat. In this experiment, the temperature increase of a certain amount of water with a known temperature will be observed using vacuum solar tubes. These tubes are known to operate at high efficiency. It can reach very high temperatures with instantaneous radiation from the sun.

IV.III. Theoretical Background

The intensity data of solar radiation is among the necessary parameters for building energy analysis and the design and performance evaluation of solar energy systems. The total solar radiation intensity can be measured with pyranometers, solarimeters, and actinographs.

Figure 35 Pyranometer

Solar energy is commonly used for hot water production. Solar water heating systems vary based on the place of water usage, the method of heating, the circulation and purpose of the water. In the system, there are collectors that gather solar energy and a tank where the water is stored. Additionally, this experimental setup aims to collect evaporated water and thus obtain fresh water.

The useful heat obtained from the collector is calculated with the formula (1) below.

$$Q = m * c_p * \Delta T \qquad (1)$$

Here, (m) represents the amount of water in the system, (c_p) denotes the specific heat of water, and (ΔT) indicates the temperature difference. The instantaneous efficiency of the collector is calculated using the following equation (2).

$$\eta = \frac{Q}{A_{abs} * I} \qquad (2)$$

In this equation, the symbol (I) represents the instantaneous solar radiation [Watt/m2], and A_{abs} denotes the absorber area of the tubes in the collector. In cases where there is a lack of pyranometers or other measurement instruments for instantaneous radiation measurement, data provided by the Ministry of Environment and Urban Planning, as available in the literature, can be utilized. In cases where optimal conditions are assumed to be provided, the manufacturer states that the efficiency ranges between 70-80 percent.

When calculating the area, it should be taken into consideration that the surface is cylindrical.

IV.IV. Experimental Procedure

- Measure and record the volumes of the water samples.
- Measure and record the solar irradiation.
- Measure and record the temperature of the water at the beginning and end of experiment.
- Measure and record the water output with steam.

IV.V. Required Calculations

- Determine the mass of the water.
- Calculate the obtained heat.
- Calculate the efficiency of the system.
- Calculate the theoretical heat gain for different times based on efficiency.

IV.VI. Required Report Format

- The report should be organized as follows: Title Page, Introduction, Experimental Setup and Procedure, Theoretical Background and Calculation Details, Results and Discussion, Conclusions, References and Appendices (if any).
- Measured and calculated quantities should be presented in tabular form.
- Show all details of your calculations.
- Discuss the possible sources of errors.
- Make recommendations for improving the experimental procedure.

V.Measurements

The experiment conditions mentioned on the previous page were considered during the calculations. Due to the absence of a measurement instrument capable of accurately measuring the solar radiation intensity during the experiment, average radiation values were used. These values were obtained from the Ministry of Environment and Urban Planning's website. On the day of the experiment (January 17th), the weather was completely clear, and the sun was bright. As it was one of the sunniest days in January, the ministry's average values of 3.6 kWh/m^2 daily radiation and 5.9 hours of average effective sunshine were used (From Figure 43). For the theoretical calculation in June, the average for that month was taken, considering the higher number of clear days and the greater solar radiation reaching the surface due to the sun's higher position in the sky. There is an almost twofold difference in radiation between the calculations for January and June.

After setting up the experimental apparatus, the scarcity of sunny days posed a challenging situation. Initially, we planned to utilize the sunlight coming through the windows; however, this method proved unsuccessful due to a coating on the school windows blocking the radiation. Nevertheless, on January 17, a sunny day, we relocated our system to the school roof to conduct the experiment. At this point, 50 liters of water were added to the system.

With the collectors positioned in the southeast direction, we initiated the experiment at 10:30. Subsequently, we decided to take measurements at one-hour intervals. However, due to deteriorating weather conditions and closure as of 12:15, we were unable to continue the experiment. Anticipating continued overcast conditions in the upcoming days, we performed theoretical calculations using the limited measurement data at hand. Due to the absence of a radiation measurement device, we had to rely on average radiation values.

During the experiment, condensation of water vapor on the covers was considered. Additionally, measurements on the spare tube revealed that the internal temperature reached up to 63 degrees. To address the formed vapor and collect it, a simple distillation setup needs to be established, followed by further measurements. However, due to limited weather conditions and time constraints, we were unable to conduct this additional experiment. Nonetheless, based on theoretical calculations, the amount of energy required to raise the water to its boiling temperature and vaporize 200 ml of water at this temperature was determined. Using June as a reference, the theoretical time required for this system to reach its boiling point and vaporize 200 ml of water was calculated.

Figure 36 The measurement taken in front of the glass indicated that the room temperature and the temperature of the water were observed to be the same.

Figure 37 Measurements were taken in the system placed on the southeast facade.

Figure 39 Temperature @11.30

Figure 38 Condensation of water droplets on the cover due to evaporation. @11.30

Figure 41 Temperature @12.15

Figure 40 Condensation of water droplets on the cover due to evaporation @12.15

Figure 42 Evacuated Solar Tube Inner Temperature.

Table 2 Measurements

Measurement	Hour	Water Temperature	Out Temperature
1	10.30	23.9	9
2	11.30	33.2	11
3	12.15	39.1	14

İSTASYON	OCK	ŞUB	MAR	NİS	MAY	HAZ	TEM	AĞU	EYL	EKİM	KAS	ARA	KWh/m²-yıl (Gözlenen)	KWh/m²-gün (Gözlenen)	KWh/m²-yıl (Model)	PV Eşdeğeri	İl alanı (km²)	Gün. süresi (saat/gün)	Gün. süresi (saat/yıl)
ADANA	62	75	113	134	167	172	181	164	130	102	68	54	1421	3.9	1525	228.8	14256	7.4	2704
ADIYAMAN	54	68	104	126	156	167	168	152	124	92	62	47	1320	3.6	1681	252.2	7572	8.1	2950
AFYON	63	82	130	153	183	199	209	192	154	107	69	53	1594	4.4	1456	218.4	14532	6.7	2461
AĞRI	58	74	115	127	161	178	183	167	136	93	58	43	1392	3.8	1383	207.4	11315	6.3	2306
AKSARAY	67	84	124	141	174	186	194	179	146	106	74	59	1534	4.2	1557	233.5	8051	7.5	2728
AMASYA	47	66	109	136	170	184	192	174	134	89	52	38	1393	3.8	1469	220.3	5731	5.6	2059
ANKARA	50	67	108	128	164	178	189	172	137	96	58	41	1389	3.8	1440	216.1	25615	6.9	2506
ANTAKYA	49	66	105	132	163	178	182	164	130	95	60	45	1369	3.8	1510	226.5	5678	7.4	2689
ANTALYA	75	91	138	160	197	208	215	196	163	123	82	66	1715	4.7	1562	234.2	20599	8.4	3054
ARDAHAN (*)	56	75	114	133	164	179	184	166	132	94	60	47	1404	3.8	1405	210.8	5495	5.9	2136
ARTVİN	50	69	114	138	168	177	169	156	126	89	55	42	1352	3.7	1310	196.5	7493	4.9	1789
AYDIN	63	76	119	145	183	197	204	187	151	110	71	57	1562	4.3	1610	241.5	7922	7.6	2768
BALIKESİR	41	53	86	113	145	162	167	152	120	80	48	34	1202	3.3	1383	207.4	14442	6.9	2528
BARTIN	42	59	93	121	158	172	182	162	121	82	49	36	1277	3.5	1200	180.0	1960	5.6	2041
BATMAN (*)	67	86	128	148	182	199	206	187	152	110	72	56	1593	4.4	1600	240.0	4671	7.5	2744
BAYBURT (*)	57	75	113	132	165	180	184	166	132	94	60	46	1404	3.8	1410	211.5	4043	6.0	2205
BİLECİK	54	67	106	129	166	180	186	169	136	91	58	45	1384	3.8	1370	205.5	4181	6.4	2318
BİNGÖL	61	83	122	144	184	210	218	196	150	99	59	47	1574	4.3	1571	235.7	8402	6.5	2360
BİTLİS	62	83	126	138	165	196	199	181	150	104	60	49	1512	4.1	1559	233.9	8413	6.4	2324
BOLU (*)	48	64	103	125	157	171	179	161	125	85	53	40	1311	3.6	1318	197.7	10716	5.4	1983
BURDUR	71	89	130	156	193	213	221	197	160	121	85	56	1691	4.6	1567	235.0	7238	7.4	2695
BURSA	48	58	90	114	146	160	166	149	119	81	52	41	1225	3.4	1418	212.8	11087	6.3	2296
ÇANAKKALE	51	67	108	141	173	186	193	174	136	95	58	45	1427	3.9	1329	199.3	9887	7.3	2649
ÇANKIRI	51	71	118	135	169	184	195	176	142	101	61	42	1445	4.0	1397	209.5	8411	6.1	2227
ÇORUM	55	75	117	137	168	183	193	177	140	96	60	44	1444	4.0	1394	209.1	12833	6.1	2230
DENİZLİ	51	65	100	124	153	171	174	154	123	87	56	44	1300	3.6	1566	234.9	11716	7.5	2722
DİYARBAKIR	63	82	126	148	193	211	216	194	156	115	72	54	1629	4.5	1620	243.1	15162	7.8	2859
DÜZCE	39	54	85	111	143	157	162	148	115	75	46	34	1169	3.2	1247	187.0	2593	5.1	1868
EDİRNE	34	47	76	103	130	139	143	131	99	66	39	29	1037	2.8	1363	204.5	6241	6.2	2248
ELAZIĞ	53	72	112	136	171	194	199	179	143	101	62	44	1467	4.0	1602	240.3	9181	7.3	2677
ERZİNCAN	58	76	114	130	158	174	182	163	131	94	60	49	1389	3.8	1463	219.4	11974	6.5	2376
ERZURUM	70	91	132	138	162	181	193	174	142	103	68	56	1511	4.1	1455	218.3	24741	6.7	2439
ESKİŞEHIR	50	66	101	121	153	166	178	160	130	89	59	39	1311	3.6	1396	209.3	13904	6.7	2439
GAZİANTEP	58	72	111	136	172	190	196	177	142	104	68	51	1478	4.0	1628	244.2	7194	7.3	2658
GİRESUN	42	55	81	96	130	146	125	109	74	70	43	32	1003	2.7	1187	178.0	7151	3.7	1351
GÜMÜŞHANE	50	88	134	149	180	198	211	192	148	101	54	39	1543	4.2	1420	213.0	6125	5.9	2144
HAKKARİ	76	95	135	147	175	191	198	181	147	110	74	67	1596	4.4	1657	248.5	7729	7.9	2877
IĞDIR	52	71	110	126	153	167	169	154	123	90	58	44	1318	3.6	1525	228.7	3584	6.3	2315
ISPARTA	59	73	107	123	149	161	168	154	126	94	64	50	1328	3.6	1535	230.3	8733	7.5	2741
İSTANBUL	41	56	95	129	166	180	184	161	127	83	50	36	1306	3.6	1303	195.5	5170	5.9	2163
İZMİR	64	79	123	151	186	203	207	186	154	111	71	55	1589	4.4	1562	234.3	11811	7.9	2893

Figure 43 Observed solar radiation intensities and sunshine duration data of the provinces (kWh/m²) (1971-2000)

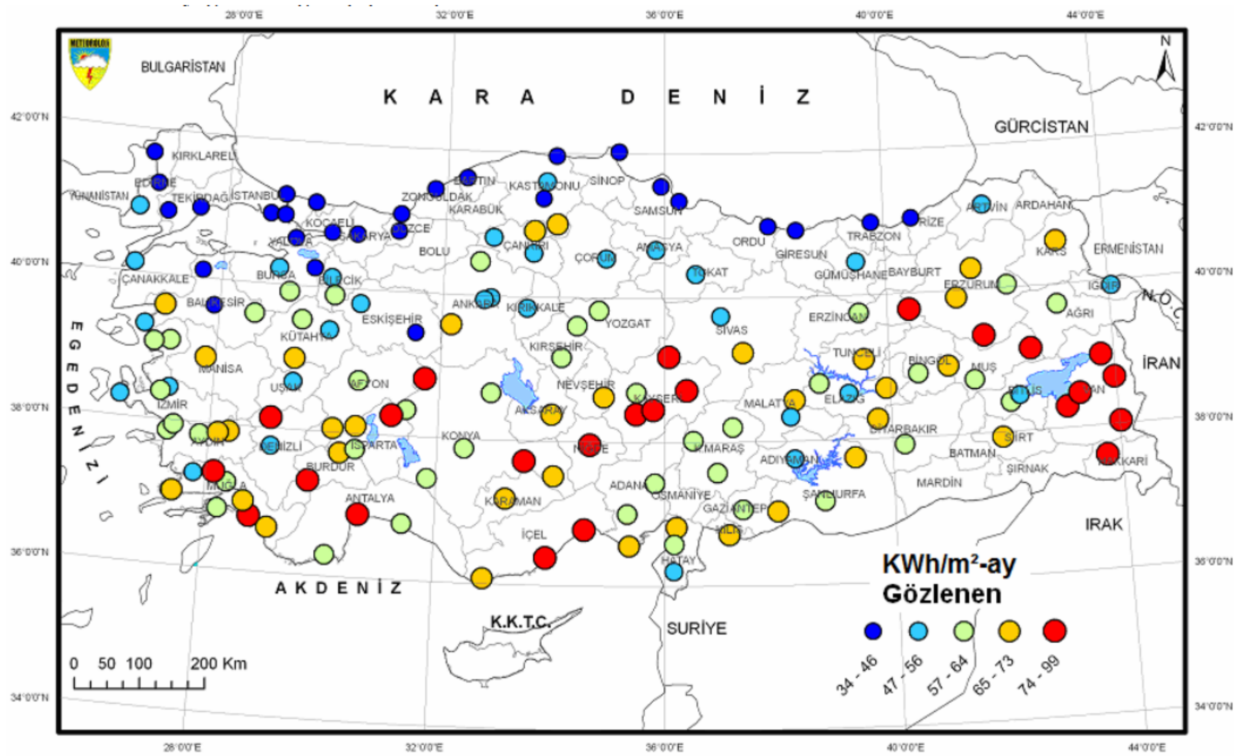

Figure 44 Average Solar Irradiation in January

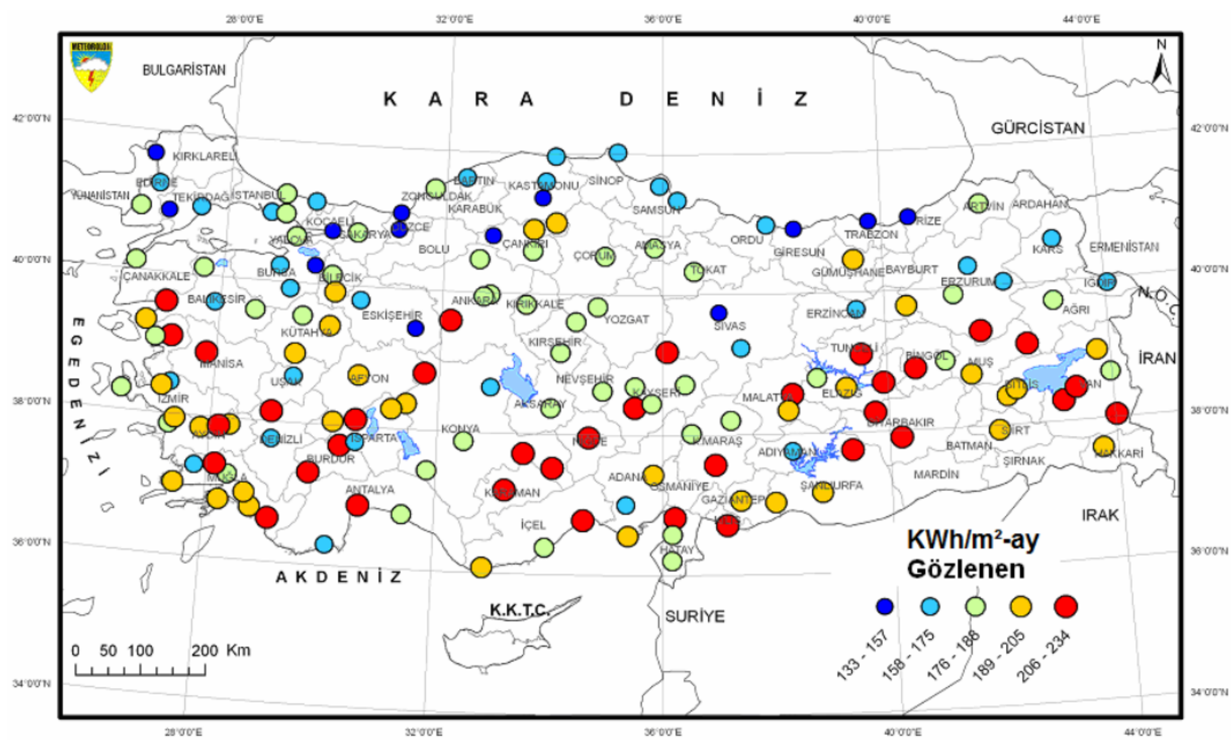

Figure 45 Average Solar Irradiation in June

VI. Calculations

First, we need to water mass.

$$m_w = d_w V_w$$

$d_w = 0.997\ {}^{g}/_{cm^3}$ @25℃

$V_w = 50\ lt = 50000\ cm^3$ so

$m_w = 49850\ g$

Now we need calculate heat.

$$Q = m * c_p * \Delta T$$

$m = m_w$

$c_p = 4.18\ {}^{J}/_{g℃}$

$\Delta T = T_2 - T_1$

$Q = 49850\ g * 4.18 J/g℃ * (39.1℃ - 23.9℃)$

$Q_{act} = 3167269\ joules$

The heat in the thermal storage tank is calculated from the temperature difference of the water in the tank.

Certainly, the calculation of the energy received during our 2-hour observation will consider the average solar radiation and sunlight hours from the study conducted by the Ministry of Environment and Forestry.

$I_{avg} = 3.6\ {}^{kWh}/_{m^2}$ @ $Istanbul$

Sunlight hour is assumed from Figure 43, 5.9 hours per day.

$I = \frac{(3.6\ kWh/m^2) * 2\ h}{5.9\ h} \quad \rightarrow \quad I = 1.22\ {}^{kWh}/_{m^2}$

Surface area of cylindrical tube

$$A = 2\pi r l$$

$r = 0.0235\ m$

$l = 1.67\ m$

$A = 0.2466\ m^2$

If we assume that the upper half of the total surface receives sunlight, and we have 8 tubes the effective area is calculated as follows:

$$A_{abs} = 8 * \frac{A}{2}$$

$A_{abs} = 0.9864\ m^2$

Total solar irradiance for a period of two hours is given by.

$$Q_{max} = I * A_{abs}$$

$Q_{max} = 1.22\ \ kWh/m^2 * 0.9864\ m^2$

$Q_{max} = 1.2034\ kWh = 4332268\ joule$

Efficiency for Evacuated Solar Tubes.

$$\eta = \frac{Q_{act}}{Q_{max}}$$

$\eta = 0.73$

The efficiency of solar tubes has been calculated as 73%, which is a quite positive result. According to information from both the manufacturer and the literature, it is anticipated that solar tubes can achieve an efficiency between 70% and 80% under favorable conditions. This suggests that the obtained 73% efficiency indicates the effective operation of the system and falls within the predicted range for solar tube efficiencies.

The calculations we have conducted so far have been based on data from the Ministry of Environment and Forestry, as well as our own measurements. Next, assuming the same efficiency and conditions, calculations will be made based on the solar radiation amount for the month of June.

$$I_{June} = 6 \; {}^{kWh}/_{m^2} \quad @June\ for\ a\ day$$

$$I_{June} = \frac{(6\ kWh/m^2) * 2\ h}{5.9\ h} \quad \rightarrow \quad I_{June} = 2.034 \; {}^{kWh}/_{m^2} \;\; @June\ for\ 2\ hour$$

$$Q_{max} = I_{June} * A_{abs}$$

$Q_{max} = 2.006\ kWh = 7222815\ joules$

$$\eta = \frac{Q_{act}}{Q_{max}}$$

$0.73 = \dfrac{Q_{act}}{7222815}$

$Q_{act} = 5272654\ joules$

$$Q_{act} = m * c_p * \Delta T$$

$$\Delta T = 25.3℃$$

$\Delta T = 25.3℃ = T_2 - T_1$

$T_2 = 49.2℃$

In the assumed scenario with the same conditions, the average solar radiation values for the month of June will be evaluated again, utilizing the daily average sunlight duration. Theoretical calculations suggest that, under the assumed conditions, the system could raise the water temperature from 23.9 degrees to 49.2 degrees within a two-hour period in the month of June.

Amount of heat needed to bring water to boiling point.

$$Q = m * c_p * \Delta T$$

$T_1 = 25℃$

$T_2 = 100℃$

Assumed.

$Q = 49850\ g * 4.18\ j/g℃ * (100℃ - 25℃)$

$Q = 15627975\ joules$

The typical heat of vaporization for water is around 2260 joules/gram. With this information, we can calculate the energy required to vaporize a specific amount of water.

Assumed one glass of water and its volume is 200 ml so that mass is 199.4 g.

$$Q = mC = m(h_2 - h_1)$$

$h_{liquid@100℃} = 419.04\ kj/kg$

$h_{gas@100℃} = 2676\ kj/kg$

$Q = 199.4\ g * (2676\, kj/kg - 419.04\, kj/kg) = 450038\ joules$

Total amount of heat is 16078012 joules.

This heat value is needed to bring water to boiling point and after that evaporate one glass of water(200ml).

In our experiment we can collect $Q_{act} = 3167269\ joules$ in 2 hours.

For January

We need $\left\{\left({}^{16078012}/_{3167269}\right) * 2\right\}$ hours and its equal to 10 hours and 9 minutes.

For June

We need $\left\{\left({}^{16078012}/_{5272654}\right) * 2\right\}$ $hours\ and\ its\ equal\ to\ 6\ hours\ and\ 6\ minutes.$

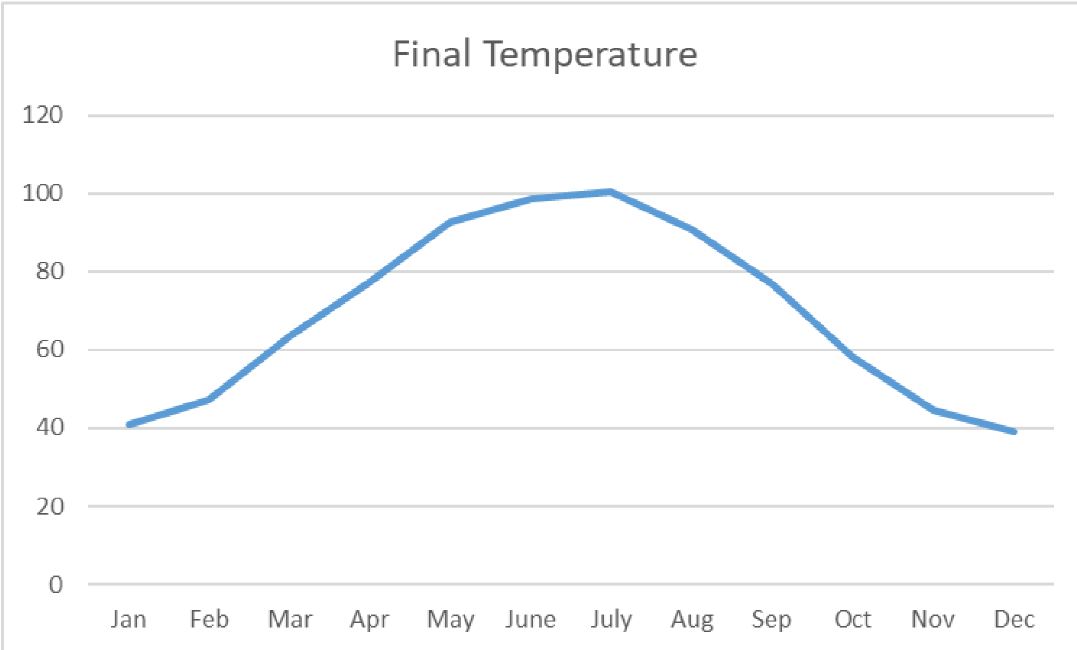

Figure 46 Average final temperatures after 6 hours for each month from Figure 43

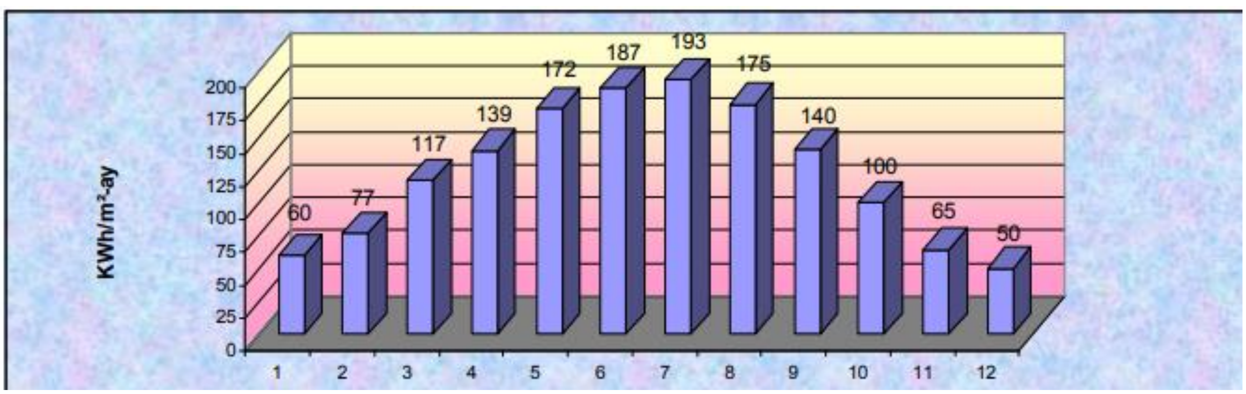

Figure 47 Average Solar Irradiation for Turkey in each month

When examining Figure 46 and Figure 47, a significant similarity between the two graphs is noticeable. The simplest conclusion to draw from this observation is that the intensity of radiation appears to be the most crucial factor influencing the final temperature obtained.

VII. Cost Analysis

Table 3 Cost Analysis ($=30Tl)

Component	Quantity	Price ($)	Total ($)	Total (TL)
Evacuated Solar Tubes	8	5	40	1200
Water Tank	1	10	10	300
Metalworking	1	50	50	1500
Gasket Set	8	2,5	20	600
Wheel	4	2	8	240
Stopper	3	5	15	450
Thermometer	1	5	5	150
Others	1	40	40	1200
		Total	188	5640

Evacuated Solar Tube solar energy systems are quite durable and environmentally friendly. These systems typically have a lifespan of around 15 years, assuming there are no malfunctions or breakages. During this period, any malfunctions that occur can generally be resolved with simple part replacements or repairs. For instance, if one of the tubes breaks, it is often sufficient to replace only the broken tube, without the need to renew the entire system.

When the system undergoes regular maintenance and especially when the entire gasket set is replaced after around the 10th year, the system can have a longer lifespan than expected. Evacuated Solar Tube systems are suitable for operation in various climates and can continue to generate energy whenever there is sunlight. Besides the initial cost, they are an economical option with almost no operating costs.

The experimental materials required for this thesis, as well as the entire system, have been provided and funded by our team. Only the shipping cost was paid for the tank, and since it was sent as a gift from the factory, its price is unknown. The cost related to the tank in Table 3 is solely the shipping cost and does not determine the material value of the tank.

Materials were assumed to be acquired at a time when the average exchange rate of the dollar was 30 Turkish Liras. The total cost is shown in Table 3 as either 188 dollars or 5640 Turkish Liras.

VIII.Conclusion

The central theme of the thesis is the purification of saline water using various methods. However, most of these methods are not environmentally friendly due to high energy costs. Additionally, facilities are often large and cumbersome, limiting access to energy sources. The aim of this thesis is to design a water purification system that is more portable and can be used in any location, powered by solar energy. In line with this objective, the first step was to target water purification using electricity generated by photovoltaic solar panels. Through research and calculations, a suitable 200 W resistor was found for the system, and a panel-battery combination supporting this resistor was provided. However, due to the low power of the found resistor, it was observed that half a liter of water reached the boiling point in almost 1 hour. Increasing the resistor power would require expensive photovoltaic panels.

Therefore, evacuated solar tube panels, which can be installed at a lower cost, were preferred. Through these panels, water is heated with solar energy, and the steam from this heated water is collected. It was determined that in this setup, a high amount of water, such as 50 liters, could reach high temperatures in a short time. This system is quite open to improvement and can be turned into an experimental and educational setup. The most significant challenge encountered during the project was adverse weather conditions. After the system became operational, there was a prolonged period without sufficient sunlight and open-air observation. On the date of the experiment, January 17, changes in weather conditions throughout the day prevented sufficient measurements. However, theoretical calculations based on available measurements demonstrated that the system is quite efficient and usable. The experiment section in the thesis content will serve as a setup that future students can use for experiments on radiation and heat transfer.

In the established system, the decrease in density due to the expansion resulting from the heating of the water in the tube leads to the movement of less dense hot water upwards into the tank. This circulation is referred to as natural circulation. Through future additions or changes to the project, it can be made more efficient. This way, more efficient results can be achieved in a shorter time. Conducting the experiment during the summer months and on sunny days, along with obtaining and using the necessary measurement tools, will contribute to obtaining healthier results.

IX. References

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