RAFIK HARIRI UNIVERSITY

# DESIGN AND IMPLEMENTATION OF A SOLAR POWERED PORTABLE WATER DESALINATION PLANT


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# ABSTRACT

This research paper delves into a comprehensive study on portable water desalination plants, exploring a wide spectrum of aspects ranging from destination plants and techniques to history, design, prototyping, and implementation. In an era plagued by water scarcity, our research focuses on the development of innovative solutions. We meticulously examine existing destination plants and desalination techniques, assessing their efficacy and limitations. Drawing from historical perspectives, we trace the evolution of desalination technology, highlighting key milestones and breakthroughs. The core of our study revolves around the design phase, where we delve deep into the intricacies of creating a portable water desalination plant. Through rigorous prototyping and testing, we refine the design to ensure optimal performance and efficiency. Finally, our research culminates in the successful implementation of a solar-powered portable desalination plant, showcasing a sustainable and mobile solution to address freshwater shortages. This paper not only presents a holistic overview of desalination methods but also provides practical insights into the process of designing, prototyping, and deploying a portable water desalination plant, making a significant contribution to the field of sustainable water technology.

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# LIST OF ABBREVIATIONS

RO: Reverse Osmosis

SW: Salinized Water

TDS: Total Dissolved Solids

PH: potential of hydrogen

PP: Polypropylene Filter

GAC Filter (Granular Activated Carbon Filter)

75GPD RO Filter (Reverse Osmosis Filter)

SWRO: Sea water Reverse Osmosis

BWRO: Brine water Reverse Osmosis

ED: Electrodialysis

# TIME PLAN

## Gant Chart:

| ID | Name | ID | Name |
|---|---|---|---|
| 1 | Discussing BE ideas | 11 | Designing and Ordering Chassis |
| 2 | Going through portable water desalination | 12 | Coding sensors and OLED screen |
| 3 | SLP Approval by Advisor | 13 | Mounting Electric and Mechanical Systems on... |
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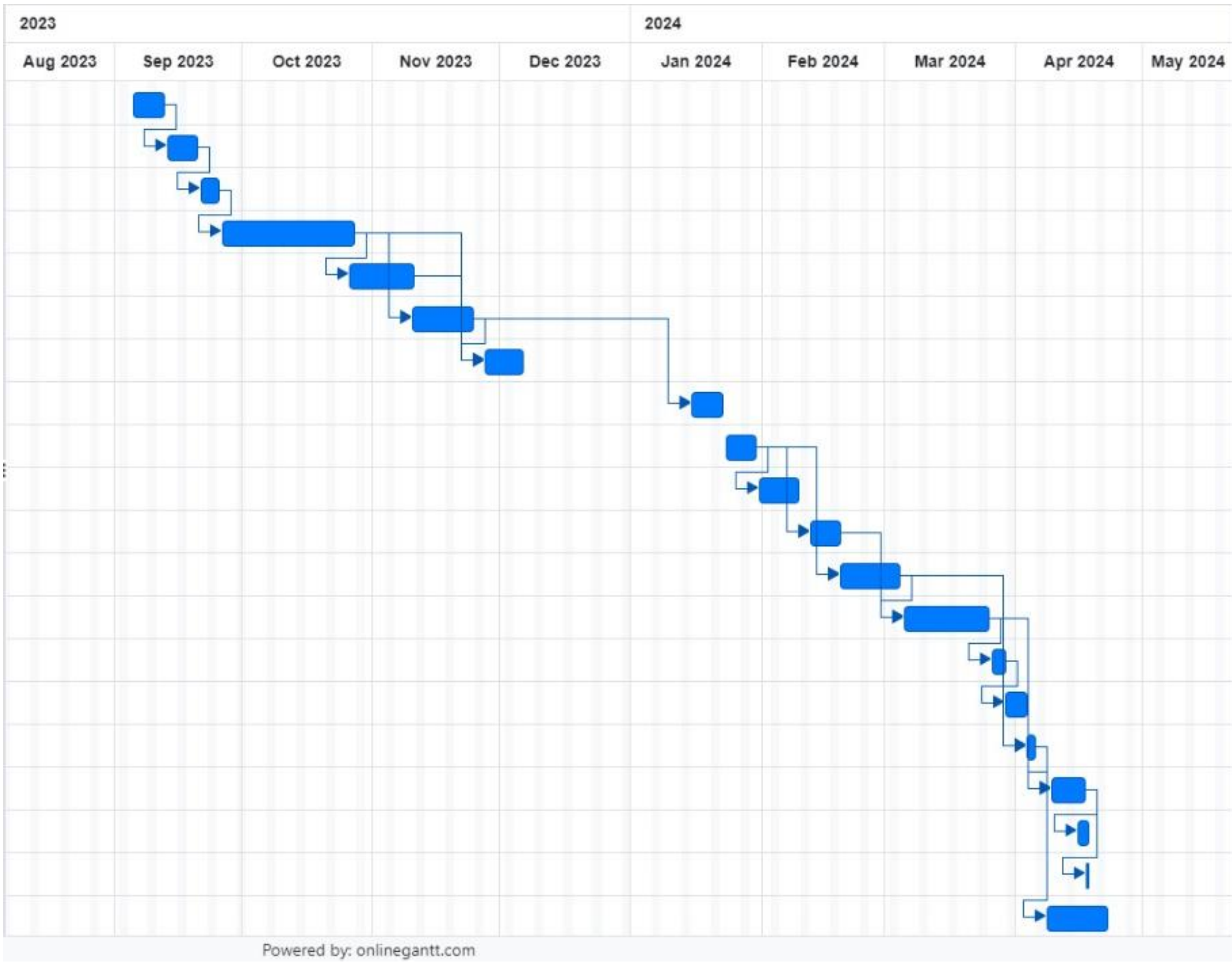
| 7 | Writing and Submitting BE1 Report | 17 | Testing and Tuning |
| 8 | Bill of Materials | 18 | Testing Water Samples |
| 9 | Construction Planning | 19 | Presenting the Project |
| 10 | Ordering RO and other components | 20 | Writing the Final Report |



# CHAPTER 1

# INTRODUCTION

## 1.1 Background Information

With a growing population and climate change-induced droughts, the demand for fresh water has never been higher. Desalination, the process of removing salt and other impurities from seawater, offers a promising solution, especially for coastal regions facing acute water shortages. Traditional desalination plants are often large, stationary, and energy-intensive, making them unsuitable for remote or disaster-stricken areas. However, harnessing solar power for desalination not only makes the process environmentally sustainable but also enables mobility, allowing the technology to be deployed in remote or emergency situations where access to fresh water is limited. This innovative approach integrates the principles of solar energy conversion and desalination, presenting a holistic solution to the pressing global water crisis while promoting the use of renewable energy sources for a more sustainable future. The development of a portable, solar-powered desalination plant has the potential to provide clean and safe drinking water to communities worldwide, transforming lives and contributing significantly to the achievement of the United Nations Sustainable Development Goal of ensuring clean water and sanitation for all.

## 1.2 Literature Review

### *1.2.1 History of Water Desalination*

Bronze Age (ca. 3200–1100 BC):

1. The Minoan civilization, starting in prehistoric times, was known for treating potable water, including seawater, using appropriate devices. They used clay-made oblong filters like Defner and Minoan ceramic filters like Spanakis, which operated under high-speed turbulent conditions. Minoan sailors first produced drinking water from seawater, dominating the seas with their merchant fleet

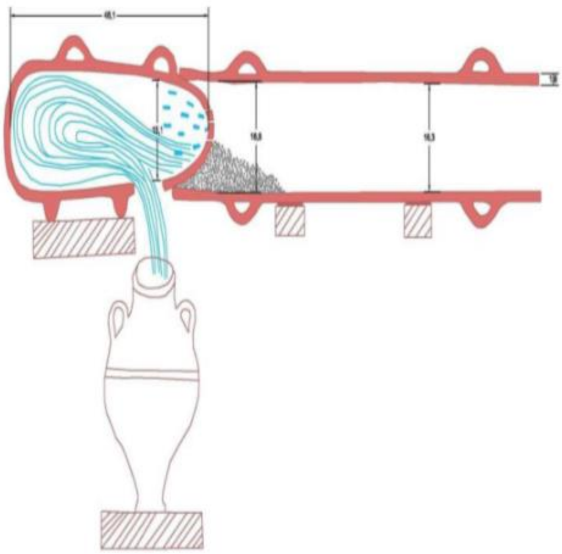


Figure 1:Water Ceramic Filter

2. Ancient India used water treatment methods in 2000 BC, including heating water and filtration, to improve drinking water taste. The principle of coagulation was discovered after 1500 BC, and desalination and water reuse technology were introduced after 500 BC to augment water supply in coastal urban regions. The Indus Valley civilization, one of the oldest and most advanced, developed agriculture, reservoirs, canals, wells, and water harvesting methods. Although aware of oceanic calamities, there is no recorded technique of desalination in Indian literature.

3. Iran Empire: The oldest water supply network, including desalination system, was found in Chogha Zanbil, an ancient Elamite complex in southwest Iran. The network was a river-reservoir system, diverting water from the Karkheh River to a large tank for storage. After desalination and treatment, the water was transferred to another reservoir with a volume of 350 m3. The ancient Pre-Persian civilization of the Elamites, who lived in Khuzestan, was able to manage water resources effectively due to their water-rich environment.

Historical Times (ca. 1000 BC–330 AD):

Classical and Hellenistic Periods:

4. Desalination has been practiced for millennia, with Greek seamen boiling seawater to separate freshwater from salt. Ionian philosophers, including Aristotle, identified water recycling as a result of meteorological phenomena. Aristotle's concepts were influenced by

Ionic philosophers, and desalination has numerous applications, particularly in arid and semi-arid areas. Seamen boil seawater, collect evaporated water, and drink it from squeezing to address freshwater scarcity.

Romain Period:

5. Romans used clay filters to trap salt, and water could be purified through heating, sand and gravel filtration, and straining. Desalination has a long history, with a reference in the Bible (Exodus 15:22–26) for its use. When Jews visited Marah, they couldn't use potable water due to its bitterness. God showed them a log, which mixed with the water, and the drinkable water became sweet. This miracle should be considered a miracle rather than scientific evidence.

Chinese Dynasties:

6. Desalination technology, dating back over 2000 years, has been studied by the National Oceanic Bureau since 1958. Bamboo mats used for steaming rice formed a thin outer layer, allowing salt to be adsorbent. In the Southern Song Dynasty, seaweed was cooked using bamboo mats and steamers. Seawater desalination has been successful in China, with farmers using sea ice to maintain soil moisture.

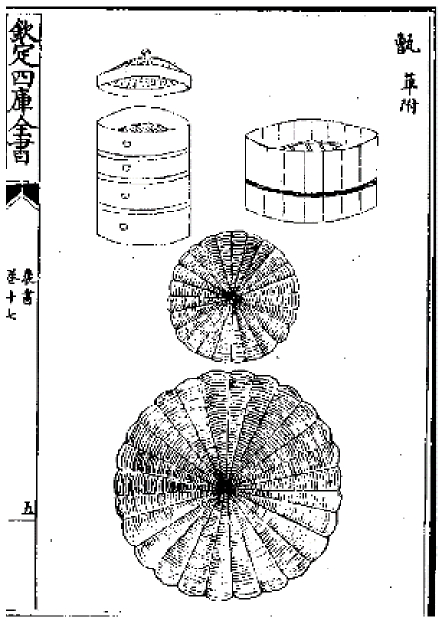


Figure 2: Desalination Tool in China

Medieval Times (ca. 330–1400 AD):

7. After the Roman Empire's fall, desalination and water treatment faced uncertainty due to enemy destruction. Early desalination experiments were limited, but Jabir Ibn Hayyan published an article on distillation in the 7th century AD. Scholars like Abu Mansour Al-Harawi and Leonardo da Vinci discovered low-cost, large-quantity distilled water. The first desalination plant was installed in Tunisia in 1560.

Desalination in Early and Mid-Modern Times (ca. 1400–1850 AD):

8. Desalination was a common practice on ocean-bound ships before the Industrial Revolution. Thomas Jefferson and Sir Richard Hawkins introduced heat-based methods in the 15th century, but scale-up difficulties hindered their implementation. Steam engines and European Colonial expansion improved water desalination technology.

Desalination in Contemporary Times (1850 AD–Present):

9. India: The Central Salt and Marine Chemical Research Institute (CSMCRI) in India began investigating desalination in 1960, developing technology for salt and marine chemical production from seawater. The technology and electrodialysis and RO technology, and participated in desalination work using nuclear power plants. Private companies implemented RO technology to enhance demineralization and produce quality water. The United Nations declared 1981-1990 as the "International Decade for Water Supply and Sanitation.

10. China: China has been researching desalination since 1958, with various departments studying electrodialysis, pressure distillation, waste heat flash desalination, and RO technology. In 1977, standpipe multi-effect distillation equipment was invented, and in 1997, the first seawater RO desalination site was developed.

11. Other Countries: Water desalination technologies improved around 1850 with steam engines, leading to the establishment of new plants in Saudi Arabia, Kuwait, Bahrain, and Qatar in the 1950s. Multiple-effect evaporators and the Office of Saline Water were established in 1955, and research improved after World War II. Today, over 20,000

desalination plants operate worldwide, providing water to over 330 million people with underwater scarcity.

### *1.2.2 Water Desalination Methods:*

Like many Processes there are many ways to desalinate water, some of the best methods are:

1. Reverse Osmosis:

   Osmosis is a natural phenomenon that has long been understood by humans. Simply put, osmosis is the spontaneous movement of water molecules over a semipermeable membrane from a solution with low solute concentration (low osmotic pressure) to one with high solute concentration (high osmotic pressure) (Fig. 3a). Because the membrane is semipermeable, only water molecules are allowed to flow through while the solutes are rejected. When the chemical potentials across the membrane are equal, the osmosis process is said to be at an equilibrium condition (Fig. 3b). Applying external pressure to the solution with a greater concentration (feed solution) can stop or reverse the flow of water molecules. In case the applied pressure difference is greater in magnitude than the osmotic pressure difference across the membrane, water molecules are forced to flow in a direction opposite to that of the natural osmosis phenomenon [1]. In such a case, the process occurring is known as RO and is depicted in Fig 3.

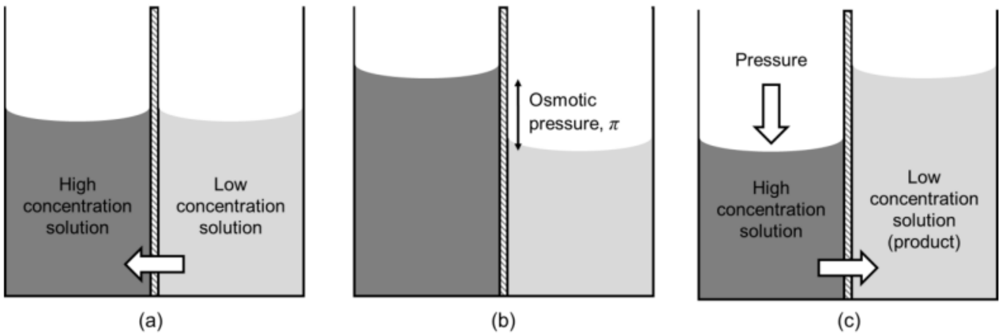



Figure 3: Reverse Osmosis

2. Multi-Stage Flash Desalination [2]: The MSF system is schematically depicted in Figure 4. The system comprises six primary streams: heating steam, distillate product, rejected brine, recycling brine, rejected cooling seawater, and intake seawater [2]. A brine heater, pumping units, venting system, cooling water control loop, and flashing stages are all part of the system. Heat recovery and heat rejection are the two categories into which the flashing stages are split. In the heat rejection segment, there

are usually simply three flashing steps. In contrast, there are anywhere from 21 to 40 flashing stages in the heat recovery section. The heat rejection section's last flashing stage's preheater/condenser tubes are filled with the input saltwater. Similar to this, the heat recovery section's final flashing stage's preheater/condenser tubes are filled with the brine recycle stream. From the first to the last flashing step, the flashing brine flows in opposition to the brine recycle. The flashing process is propelled by saturated heated steam that has a temperature range of 97–1178C [2]. The brine stream flows inside the tubes, while the heating steam circulates on the outside of the brine heater tubes. The temperature of the brine stream rises to the ideal top brine temperature when the heating steam condenses and releases its latent heat. Similar to this, the heat recovery section's final flashing stage's preheater/condenser tubes are filled with the brine recycle stream. From the first to the last flashing step, the flashing brine flows in opposition to the brine recycle. The flashing process is propelled by saturated heated steam that has a temperature range of 97–1178C. The brine stream flows inside the tubes, while the heating steam circulates on the outside of the brine heater tubes. The temperature of the brine stream rises to the ideal top brine temperature when the heating steam condenses and releases its latent heat. Afterwards, the vapor condenses on the preheater/condenser tubes outside surface. Over the course of the flashing stages, the condensed vapor gathers over the distillate trays to create the final product water, which is then removed from the last flashing stage. The brine recycling stream in the heat recovery portion is preheated using the vapor latent heat released during the condensation process. In the heat rejection portion, the same procedure occurs in the preheater/condenser tubes. This causes the seawater temperature in the heat rejection section's final stage to rise to a higher value that is equivalent to the flashing brine's temperature. The heat rejection segment is where the input seawater stream exits, splitting into two streams. The two streams are the feed seawater stream, which is mixed in the brine pool during the last flashing stage of the heat rejection section, and the cooling seawater stream, which is rejected back to the sea. The rejected brine stream is taken out of the brine pool before the feed seawater stream is mixed there. Conversely, brine recycling is removed from a site subsequent to the mixing point. The brine recycling is added to the final stage of the heat recovery section, while the brine blowdown is rejected into the sea.

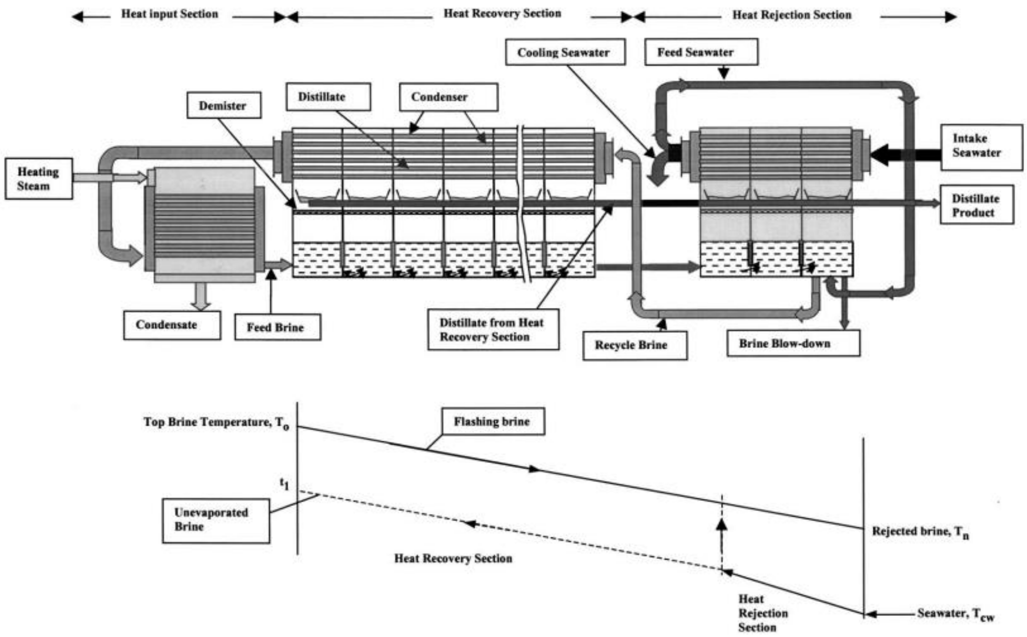



Figure 4: Multi-stage flash desalination process and temperature profiles.

3. Multi-Effect Desalination: Like MSF, MED also includes many steps of condensation and evaporation of saltwater. Energy-wise, it is more efficient than MSF. This section of the research introduces the various MED setups and provides a brief description of how the MED desalination technology works. The MED plant is made up of several feed water preheaters and flashing chambers, as well as a main condenser connected in series with several single evaporators (effects). MED systems are often employed in three different configurations: Forward Feed (FF), Backward Feed (BF), and Parallel Cross Feed (PCF). Co-current arrangement is another name for an FF layout where feed and vapor enter the effects and flow in the same direction. Feed and vapors enter the effects of BF (counter-current cascade) at opposite flow directions [3].

4. Electrodialysis: An ED system often consisted of an electrodialysis stack, spacers, electrodes, gasket seal, power supply, and IEMs. Two end plates that are squeezed by bolts and nuts seal the ED stack. Several IEMs, electrodes, feed and concentration compartments, spacers, and gasket gel are located inside the ED stack. Additionally, it has two electronic compartments that transform the current flowing via ions into an electron current that travels through solutions, IEMs, and an external electrical circuit. Few cell pairs constitute an ED in a laboratory setting, while hundreds of cell pairs can exist in an industrial setting (e.g., 500 cell pairs). Figure 5 [4] depicts the ED system's structure, which consists of chambers for concentration and dilution.

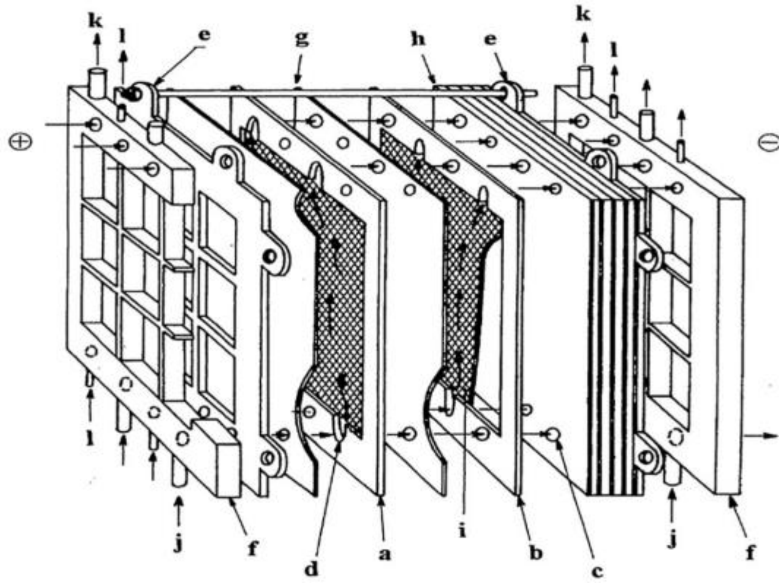



Figure 5: Structure of electro dialysis bench system (adapted from ref. [38]). (a) Desalting cell; (b) concentrating cell; (c) duct; (d) slot; (e) fastening frame; (f) feeding frame; (g) cation exchange membrane; (h) anion exchange membrane; (i) spacer; (j) feed

5. Solar Desalination: The method of using sun energy to extract salt from saline water (also known as brine or brackish water) is called solar desalination. The process of evaporation and condensation is followed in sun desalination, much like in natural rain. During this process, solar radiation strikes the cover plate's upper surface, transmitting the maximum amount of flux through it and into the basin area that holds the water. Along with radiative heat transfer, convective heat transfer is important in this process. The water's surrounding basin area's darkened surface aids in absorbing as much incident

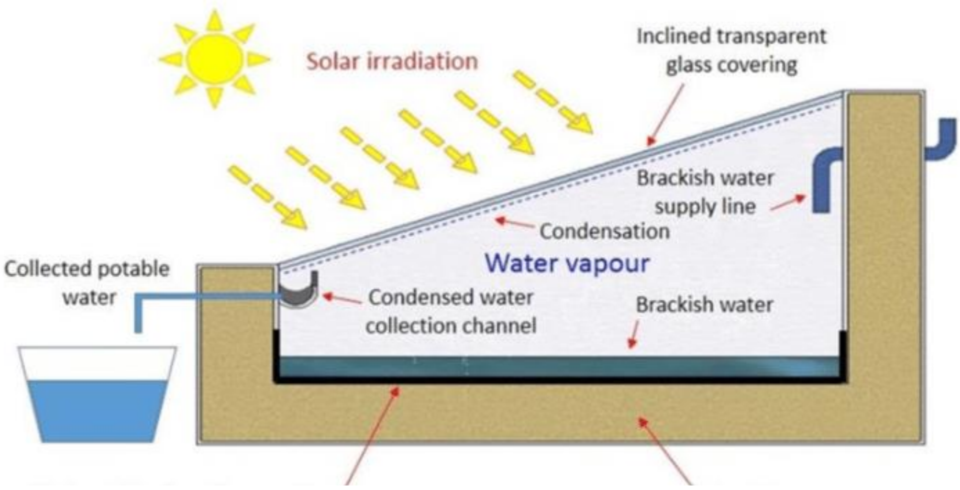



Figure 7 : Solar Still

radiation as possible rather than reflecting it back into the surrounding environment. The evaporation takes place at all temperature from the water surface, and it gets accelerated by heating thus, the rate of heat transfer gets increases that enhance the evaporation [5]. This evaporated water vapor gets condensed on the inside surface of the cover plate which is relatively a cooler surface where it liberates its latent heat of condensation and turns into a saturated liquid, then it glides down toward the trough channels and from there it gets collected into the bottle [5].

6. Freeze-Thaw Desalination: The freezer is some sort of vessel where the crystals of ice are created. This, the principal component of the procedure, specifies the kind of freezing that is done. The brine and ice slurry are delivered to an ice separation machine after the formation of the ice crystals. In this place, the ice crystals and brine are divided. Usually, this device takes the shape of a press, filter, centrifuge, wash column, or gravity drainage system. This unit frequently doubles as a wash unit as well, where entrained brine is removed from the ice crystals by washing them with clean water. The melting unit, where the ice crystals are subsequently melted and the finished product water is obtained, is the last unit. Energy recovery is an important part of the process, and the melting unit is one of the major places where energy can be recovered [6].

| Technology | Avg. Capacity ($10^3$ $m^3$ /day) | Input | Recovery ratio | Water Quality (ppm) | Energy Consumption | | Cost |
|---|---|---|---|---|---|---|---|
| | | | | | Electrical [kWh/ $m^3$ ] | Thermal [kJ/kg] | [$/$m^3$] |
| SWRO | 1-320 | SW | 0.42 | 400-500 | 3-6 | no | 0.45-1.72 |
| BWRO | Up to 98 | BW | 0.65 | 200-500 | 1.5-2.5 | no | 0.26-1.33 |
| MSF | 50-70 | SW | 0.22 | 10 | 4-6 | 190-390 | 0.56-1.75 |
| MED | 0.6-30 | SW | 0.25 | 10 | 1.5-2.5 | 230-390 | 0.52-1.5 |
| ED | Up to 145 | BW | 0.9 | 150-500 | 2.64-5.5 | no | 0.6-1.05 |

Table 1: The state of the art of commercial desalination technologies. Note: SW is the abbreviation of Seawater; BW brackish water.

### *1.2.3 Scalability of Water Treatment Plants:*

Water desalination is conducted at various scales, ranging from small, decentralized systems to large, centralized facilities. The scale of water desalination depends on several factors, including the specific location, population needs, available resources, and funding.

The scale at which desalination is conducted depends on the specific water needs of the population, the availability of water resources, the level of investment, technological advancements, and environmental considerations. It's important to select an appropriate scale based on factors like cost-effectiveness, energy efficiency, and sustainability to ensure the optimal use of desalinated water resources.

Here are the main scales at which water desalination is typically conducted:

- **Small-Scale Desalination:** Small-scale desalination systems are designed to meet the water needs of individual households, small communities, or industrial facilities. These systems are often portable and can be installed in remote or off-grid areas where access to freshwater is limited.
- **Municipal-Scale Desalination:** Municipal-scale desalination plants are designed to meet the water demands of entire towns or cities. They have a significantly higher capacity than community-scale plants and can produce millions of gallons of freshwater per day.
- **Industrial-Scale Desalination:** Industrial-scale desalination plants cater to the water needs of industries, such as power plants, refineries, chemical plants, and manufacturing facilities. These plants often have very high capacity to supply the substantial water requirements of industrial processes.

Water Desalination scaling can be done of various aspects; however, this report will scale the water desalination as large, medium, or small depending on quantity of water produced from each plant in a unit of $m^3$ /day. Furthermore, industrial plants that produce less than 10,000 $m^3$ /day are considered as small-scale water desalination plants, plants that produce from 10,000 $m^3$ /day to 100,000 $m^3$ /day are considered as medium scale industrial plants, and all plants that produce more than 100,000 $m^3$ /day are considered as large-scale water desalination plants.

| Water Desalination Plants (Scales) | Water production ($m^3$ /day) | Example |
| --- | --- | --- |
| Small | 10,000 $m^3$ /day > | Solar still |
| Medium | 10,000 $m^3$/day- 100,000 $m^3$/day | Cyprus Desalination Plant (Cyprus) |
| Large | 100,000 $m^3$/day< | Victoria Desalination Plant (Australia) |

Table 2: Water Desalination Plants Scaling

- **<u>Solar Still:</u>** a very simple device for evaporating and condensing water, using only the power of the sun. Clearly it will work best in areas blessed with lots of good sunshine, but the device can operate effectively in most parts of the world. It can be constructed out of inexpensive and readily available materials, and has no moving parts, so that life expectancy is very good. One of the most significant aspects, however, is that the source water can be of any quality, including badly polluted, highly saline, or even pure sea water, and yet the resulting product is still of the highest quality. Thus, finding the source of water is seldom going to present any problem. Even kitchen wastewater can be used.

  A bath with standard dimensions of 87×193 cm will on average produce 3 gallons of water per day. With 10 hours of hot sunshine per day, this can increase to 5 gallons (1320 $m^3$/day). Two or three such units should provide all the water which a family will require for all their drinking, cooking, and washing requirements, particularly if recycled water is used for flushing toilets and garden irrigation.

- **<u>Larnaca Desalination Plant (Cyprus):</u>** Larnaca desalination plant is currently within the 10 largest SWRO plants in Europe. It has an installed capacity of 54,000 $m^3$/d with product water conforming to WHO and EU drinking standards with innovative features such as 8 elements per pressure vessel and fully automated plant operation control. The plant is now in its 6th year of successful operation meeting all its contractual requirements on energy consumption, water quality and water quantity. The plant operation strategy was to initially make the plant efficient, thus improving the plant processes to reach optimum operational conditions, and subsequently operate the plant effectively i.e., sustain a stable and efficient plant operation, achieving continuously the targeted plant performance.

- **<u>Victoria Desalination Plant (Australia):</u>** The Victorian Desalination Plant, based near Wonthaggi, Australia, can provide a source of drinking water independent of rainfall for Melbourne and some regional communities. It can supply up to 450,000 m3 of drinking water per day. The AquaSure consortium, which brings together leaders in the field of infrastructure, design, construction, finance, including SUEZ & Thiess, has been contracted by the Victorian Government to finance, design, build, operate and maintain the Victorian Desalination Plant for the 30-year project term. This AUD 3.5 billion Victorian Desalination Project is a Public Private Partnership (PPP) which has delivered the biggest desalination plant in Australia and one of the biggest reverse osmosis plants in the world.

**Summary:**

| **Water Desalination Scales** | **Projects** | **Parameters** | **Technology** | **Process** | **Quantity produced** |
|---|---|---|---|---|---|
| Small | Solar-Still | 87×193 cm | Evaporation and Condensation of water | Boiling water using solar energy and passing it into multiple stages | 1320 $m^3$/d |
| Medium | Larnaca Desalination Plant | Within 10 largest SWRO plants in Europe | Reverse Osmosis | Using 6 treatment trains, 5 for seawater and one for secondary permeate treatment | 54,000 $m^3$/d |

| | | | | | |
|---|---|---|---|---|---|
| Large | Victoria Desalination Plant | 225 hectares ($225*10^4$ $m^2$) | Reverse osmosis | Multi-stage reverse osmosis | 450,000 $m^3/d$ |

Table 3: Scaling of Water Desalination Plants Summary

## 1.3 Project Motivation

The motivation for our Project stems from the pressing global challenges related to limited access to clean water, particularly in remote and disaster-stricken areas. Existing water purification systems often face limitations in terms of portability, adaptability to different environments, and energy dependency on conventional power sources. Through a comprehensive literature review, we have identified gaps in the current state of water purification technologies, emphasizing the need for a solution that is not only easily transportable but also powered by sustainable and eco-friendly means. Our project aims to address these shortcomings by developing a compact and portable RO kit tailored for diverse environmental conditions, utilizing solar energy to ensure self-sufficiency and resilience, especially in emergency situations. By incorporating solar power, we also aim to reduce operational costs and contribute to environmental sustainability, making the technology more accessible to communities with limited resources. Ultimately, our project seeks to fill the gaps identified in the literature, offering an innovative and impactful solution to the critical issue of clean water accessibility.

## 1.4 Project Objective

The objective of our project is to design, develop, and implement a novel portable reverse osmosis (RO) system powered by solar energy to address the limitations and gaps identified in existing water purification technologies. Unlike conventional RO systems, our project focuses on creating a compact and easily transportable solution optimized for various environments, with an emphasis on remote and disaster-affected areas. The key differentiators of our project lie in the integration of solar power for energy independence, the portability of the system, and its adaptability to diverse environmental conditions.

## 1.5 Design Constraints

### *1.5.1 Technical Constraints*

- Needs to be compact in size. dimensions should not exceed the size of a standard table (1 x 1 x 1 m)
- Needs to be powered by a battery and charged by either solar energy or mains voltage.

- Power consumption should be no more than 100 watts.
- Needs to be Portable (have wheels and a handle)
- Needs to be able to test for water purity (PH levels, TDS, Salinity).
- Device needs to be able to operate for 6 hours independently from any external power source.
- Must be easy to maintain and operate.

### *1.5.2 Economic Constraints:*

- **Budget:**

  Total money spend on prototype must not exceed 1000$

- **Operational Costs:**

  Energy consumption is a significant operational cost for desalination plants. Portable units may rely on different power sources, such as generators or solar panels, which can have varying costs. Energy-efficient technologies and power sources are critical for keeping operational costs in check. The system must be able to operate on multiple power sources including renewable and nonrenewable energy devices.

- **Maintenance and Repairs:**

Portable desalination units may require more frequent maintenance due to their compact design and mobile nature. Transportation and exposure to different environments can lead to wear and tear, necessitating regular inspections and repairs. For this reason, a slider door is added into the design of this machine to facilitate maintenance procedure. In addition, most components should be able to be replaced using standard materials and parts.

- **Financing and Funding:**

Securing financing for portable desalination projects can be challenging. Access to capital, government incentives, and public-private partnerships can play a crucial role in overcoming economic constraints.

# CHAPTER 2

# SYSTEM DESIGN

**2.1 Introduction:**

After listing all the key points of our findings, we aim to design a portable desalination plant. Our desalination plant is made up of a big funnel (to host water into the system), where water directly flows into a gravity filter to remove small and large particles off water. Then the water passes through a pump where pressurized water is forced into our RO system. The water passes through 5 filtration processes, where:

The 1$^{st}$ stage is a PP Filter: Removes sediment, sand, silt and rust. The 2$^{nd}$ stage is GAC filter: Removes chlorine, organic fertilizer, and agricultural chemical. The 3$^{rd}$ stage is Block Carbon: Re-filtration chlorine, and organic fertilizer. The 4$^{th}$ stage is 75GPD RO Filter: Remove Particles, heavy metal, ray and bacterial. The 5$^{th}$ stage is Post Carbon Filter: Re-filtration chlorine, and organic fertilizer. Then, water is stored in a water tank on top of the device. Once water is needed, and the tap is open, it passes through the 6$^{th}$ stage, which is a UV light filter to remove bacteria, then water can be consumed safely by the user. The system must accommodate some space for electronics, mounting of sensors in their designated location, and buffers for when needed. Figure 8 shows the flow diagram of the system.

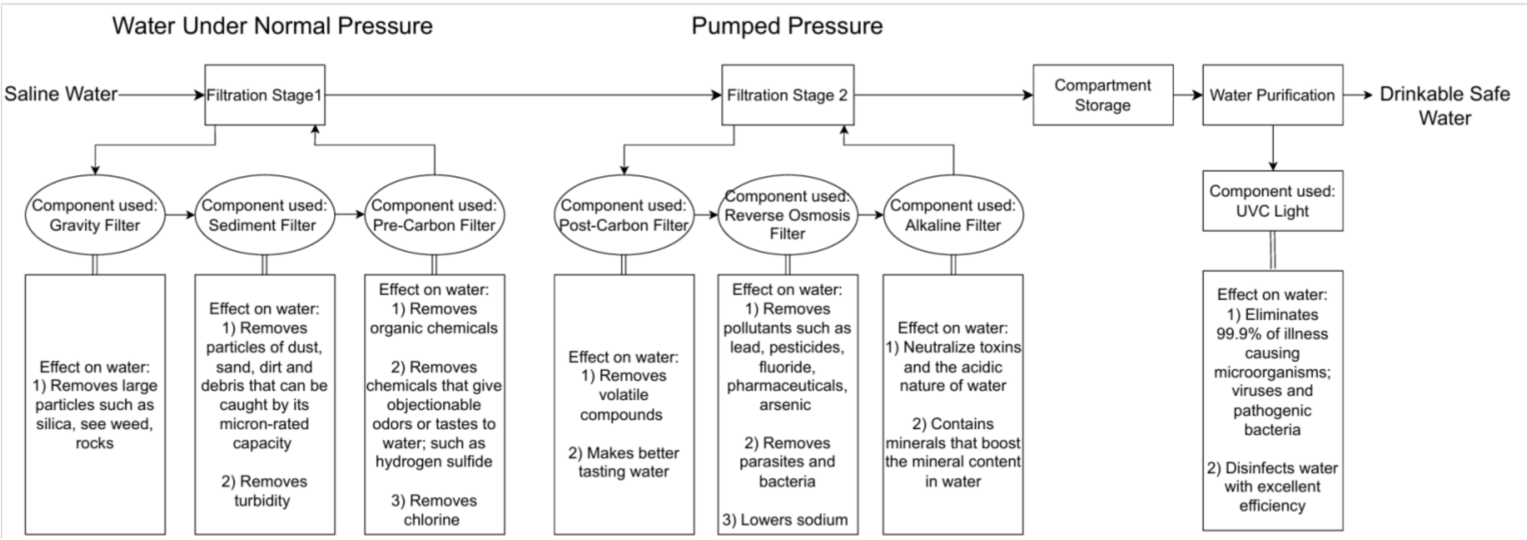



Figure 8: Flowchart Mechanism

## 2.1 Structural Design Iterations

In this section, the iterations of the chassis or body of the system will be discussed. The body went through several iterations and modifications. Each iteration improves on the previous while modifying some features for aesthetic, structural, and functional purposes. The final design is shown in the figures below.

### *2.1.1 Iteration 1- Sketches*

The initial design of the body was done using sketching software. The design will be shown in figure 9:

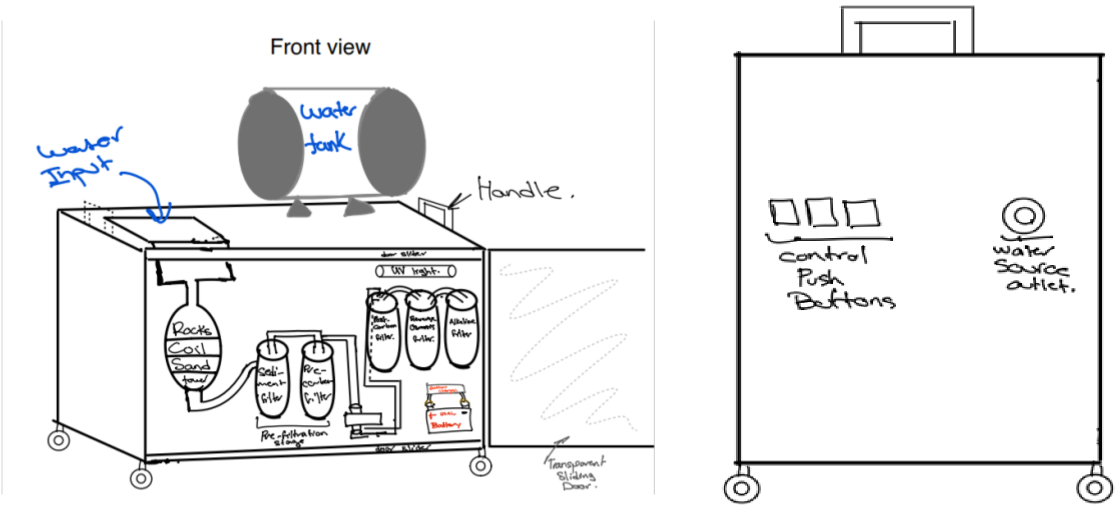



Figure 9: Front and Side View of sketch Iteration.

### *2.1.2 Iteration 2- CAD Design*

After the first design iteration and with the help of our advisor, we were able to develop a CAD drawing of the prototype that was built using SolidWorks and is presented in figures 10 and 11. Through SolidWorks, stress analysis was done to present the possible fatigue and deformation of the chassis at different positions and loads for different chassis material. This simulation gave us a general view of the best materials to be used and placement of hinges that is required to push the machine. Table 4 shows the components' names listed in figure 10.

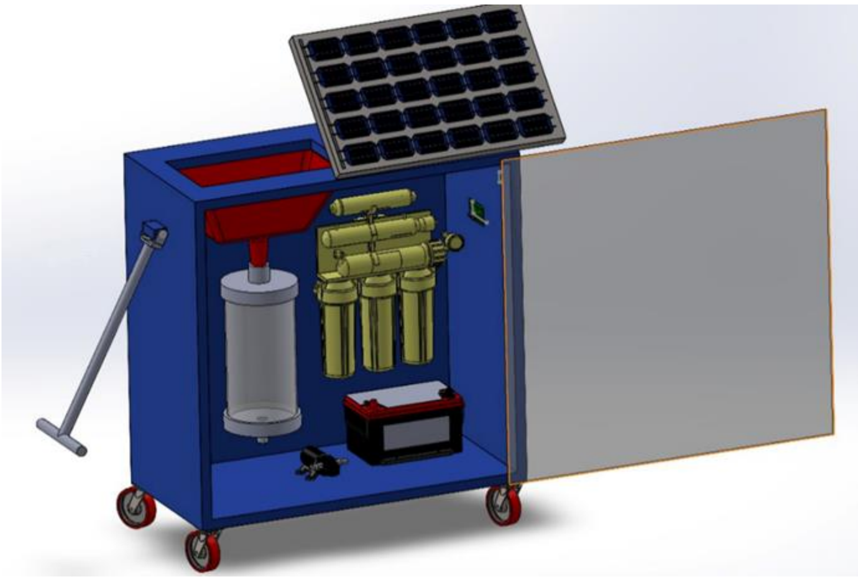


Figure 10: Iteration 2- Front View

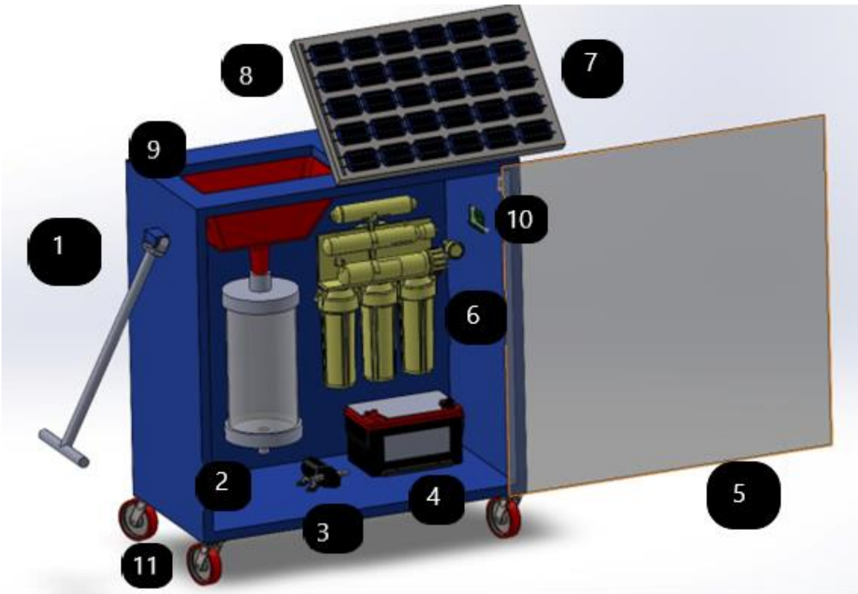



Figure 11: Iteration 2- Labeled Front View

| COMPONENT LABEL | COMPONENT NAME |
|---|---|
| 1 | Handle |
| 2 | Gravitational Filter |
| 3 | Pump |
| 4 | Battery |
| 5 | Slider |
| 6 | Reverse Osmosis |
| 7 | Solar Panel |

| | |
|---|---|
| 8 | Water Tank |
| 9 | Funnel |
| 10 | Microcontroller and Sensors |
| 11 | Caster Wheels |

Table 4: Component label and name of figure 11

### *2.1.3 Final Assembly Design*

Finally, while building our prototype, we faced some challenges and limitations which forced us to adjust some features of the design. Instead of a funnel, we opted for a stainless-steel sink. This is better than the previous design of a funnel since its dimensions, practicality, cost, and water storage capacity. It also has a drain hole that has a steel mesh filter which can filter out large particles. Also, we added more handles as well as an electrical box on top of the chassis to store the electronics. This is so that no water leakage can affect the sensitive electronics.  For the plumbing fittings, standard ½ male female, female male and male fittings were used, along with valves and hoses. It is important to note that the water lines of the RO system are 6mm and need 6mm to ½ inch adapters to connect to the pump and inlet water pipes. All fittings were sealed with Teflon tape to prevent leaking. The Final Design of our Water Desalination plant prototype is presented below in figures 12 and 13.

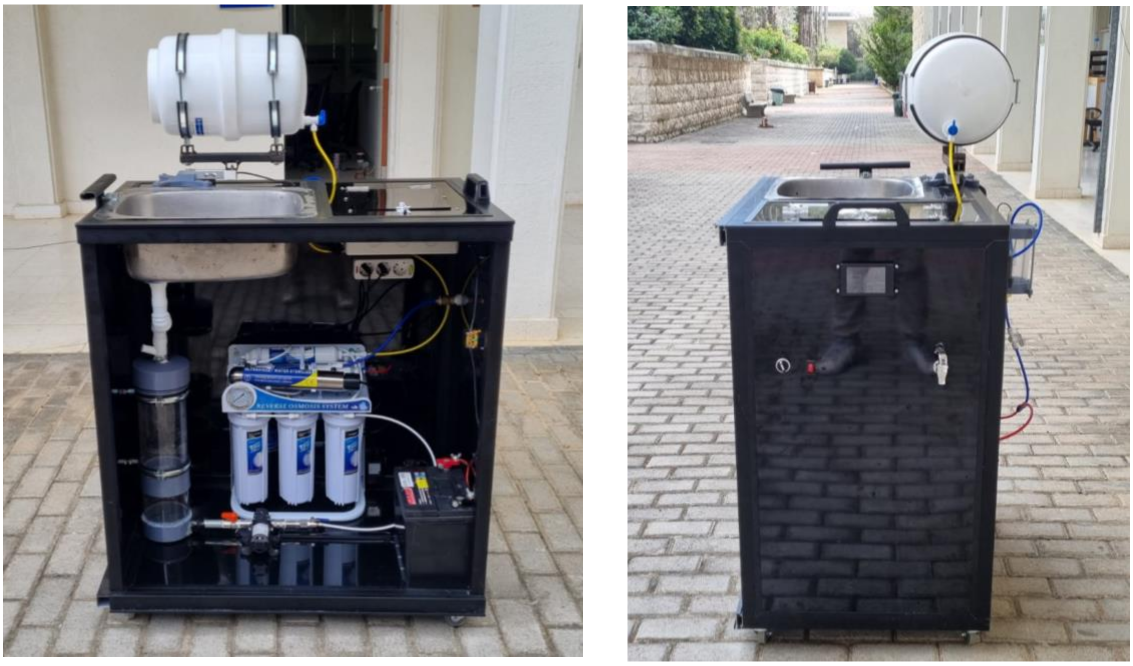


Figure 12: Final Design Front and Side View

Figure 13: Final Design Top and Back View

## 2.2 Components Design

### 2.2.1 Gravity Filter Design

The gravity filter is a natural filter that uses stones, sand, charcoal, and filter papers to remove large particles and debris from murky water making it instantly clear. A diagram showing how it works is shown in figure 14:

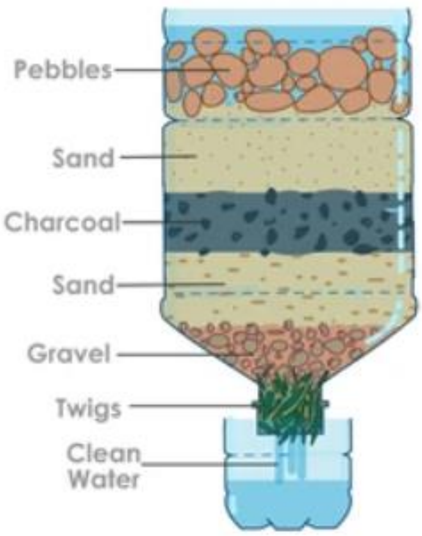



Figure 14: Gravity Filter Material

For this system, the gravity filter was custom made and designed on fusion 360. Its parts are composed of 3D printed parts, and 12cm acrylic piping. The top of the filter must be removable to access the internals so that the filter materials (stones, gravel, and sand) can be added. In addition, the top should accommodate a fitting for standard sink hoses so that it can be attached from the filter to the sink. One thing to note is that as water passes through the filter, it drips slowly with a low mass flow rate. Since the fittings of the piping are standard ½ inch fittings, water should be collected in a vessel before being pumped into the RO system. This is why a small buffer is added in the gravity filter as a collector. The design of the gravity filter is shown in figure 15:

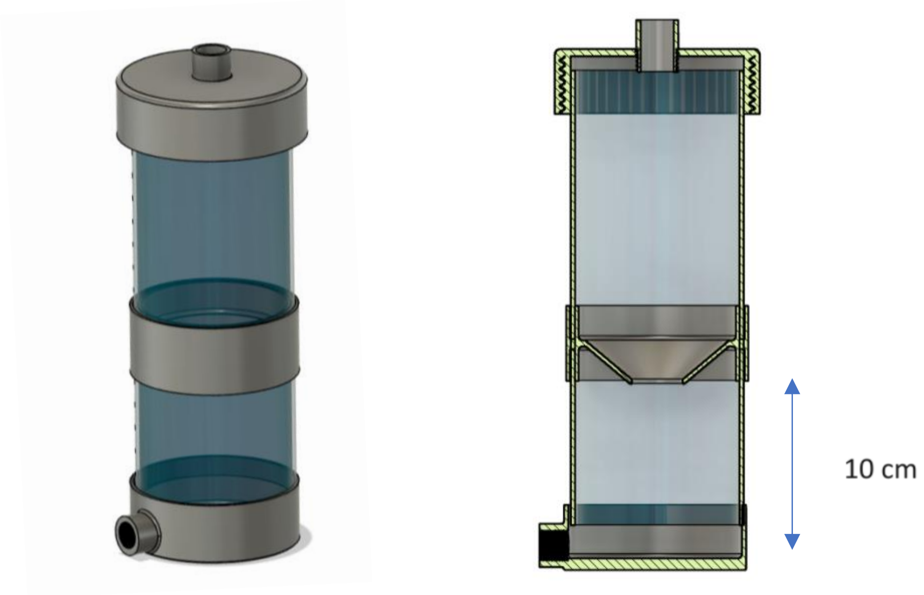



Figure 15: Gravity Filter Design

$$Volume\ of\ Buffer = \pi * r^{\wedge}2 * h = \pi * \ (12/2\ cm)\ ^{\wedge}2 * 10cm = 360\pi\ cm^{\wedge}3$$
$$= 1.13\ litres$$

$$So, Volume\ of\ buffer = \frac{360\pi}{1000} = 1.13\ liters\ of\ water\ can\ be\ in\ the\ buffer.$$

Assumptions:

-Inviscid Liquid

-Follows a streamline

-Incompressible

Using Bernoulli Equations:

$$\frac{P1}{\gamma} + \frac{v1^2}{2g} + z1 = \frac{P2}{\gamma} + \frac{v2^2}{2g} + z2 \rightarrow v1^2 = v2^2 + 2gh \rightarrow v2 \ll v1\ \&\ D1 \ll D2$$

So, $v1 = \sqrt{2}gh\ \ and\ v2 = -dh/dt \rightarrow v1A1 = v2A2$

<u>By substitution:</u>

Time needed to empty buffer= $\frac{2*Rbuffer^2*[\sqrt{h0}-\sqrt{hf}]}{\sqrt{2g}*rnozzle^2} = 63.26\ sec$

Flow Rate= Volume/time=0.01784 L/s **SO, Pump Should be used**

### *2.2.2 Pump Pressure Design*

The pressure buildup from the buffer can be calculated using equation 1 taking density of water to be 1000kg/m^3:

$$P_{buffer} = \rho \times g \times h$$

$$P_{buffer} = 1000 \times 9.81 \times 0.1 = 981\ Pa\ or\ 0.142\ PSI$$

This pressure is not enough as the threshold pressure for the RO pump to trigger is around 5 psi, and the ideal pressure entering the RO is specified to be around 60 PSI (from the manual). Therefore, an external pump is required. The Pump that will be used is shown in the figure below.

Figure 16: Selected Pump

The pump shown in figure 10 is rated at 130 PSI at 12 volts at 6 Amps which is above the maximum rating of the RO system, which is said to be 80 PSI according to the standards for the plumbing fittings and the according to the RO kit manual. Therefore, the pump’s power must be regulated. To do this, we will be using a PWM motor controller to reduce the pump’s power. Assuming linearity, we will aim divide the motors power by half so that the pump’s pressure is reduced to 65 PSI. This is done by trial and error as the PWM controller is manually controlled with a knob.

$$P_{new} = \frac{P_{initial}}{2} + P_{buffer} = 65\ .142\ Psi$$

$$P_{min} \leq P_{new} \leq P_{max}$$

$$45\ Psi \leq 65.142\ Psi \leq 80\ Psi$$

### *2.2.3 Reverse Osmosis System*

The reverse osmosis system used was made to be installed under a sink. The way it works is as follows. Tap water enters the feed inlet tube and is forced through the filters using external pressure. Then, the RO pump pumps water through the RO membrane which then is directed into a 3-way valve. Water can either go directly to the faucet if the faucet is open, or it can go the tank and pressurize inside it until the faucet is open, then the water flows out of the tank witch pressure into the UV filter and odor filter into the faucet. The RO membrane has a drain where wastewater is exited. Its piping, flow, and wiring is shown in figures 17 and 18:

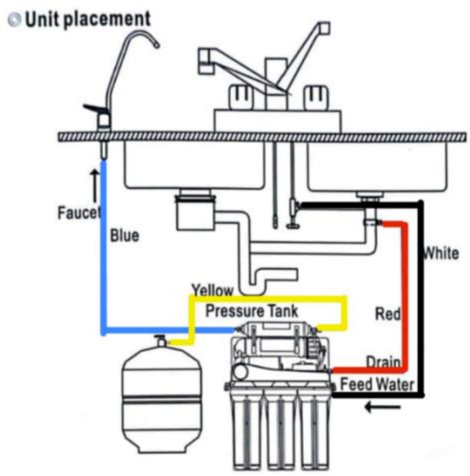
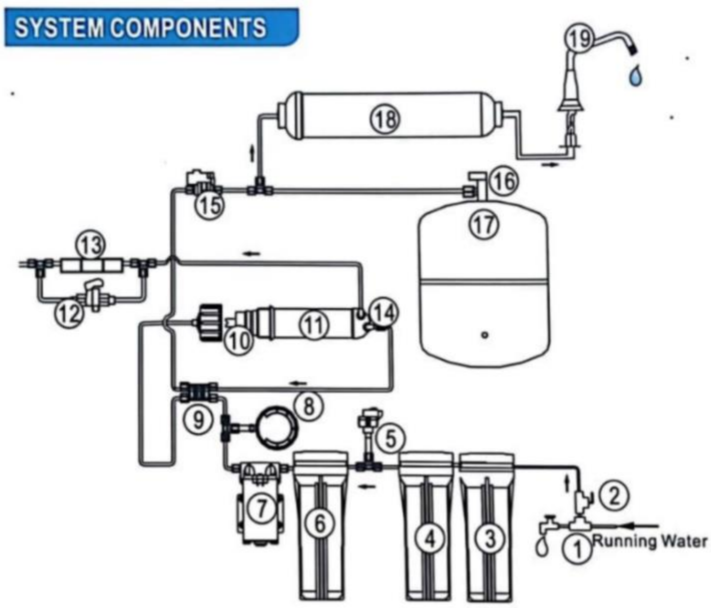



Figure 17: Installation Guide for Reverse Osmosis System



1. Tee Fitting
2. Feed Water Valve
3. PP Spun Fiber
4. Granular Carbon Filter
5. Low Pressure Switch
6. Block Carbon Filter
7. Booster Pump
8. Pressure Gage
9. Auto Shut Off Valve(option)
10. Membrane Housing
11. RO Membrane
12. By-pass flush Valve (option)
13. Drain Restrictor
14. Check Valve
15. High Pressure Switch
16. Ball Valve
17. Pressure Tank
18. Inline Carbon Filter
19. Faucet

Figure 18: System Component Guide of Reverse Osmosis System

To operate the RO system, a safety feature must be overcome, which is a low-pressure switch. This switch prevents the RO pump from turning on when there is low water pressure in the inlet port (Pressure less than 45 PSI). This is so that the RO system does not pump in air bubbles and cause cavitations inside the system. This system is meant to be used with residential water lines which are already pressurized from the buildings' water pumps. Since we are taking water from the gravity filter which does have enough pressure even when full, as calculated before, an external pump will be used to give us the ideal pressure (around 65 PSI) for the RO system. Increasing the pressure of the system is beneficial since the RO manual states that the higher the pressure, the better the water quality will be.

Before designing the reverse osmosis system, the manufacturer will perform mathematic analysis for better end results, below equations are displayed below:

| Terms | Equations of RO |
|---|---|
| Osmotic Pressure | $Posm = 1.19\ (Temp + 273) * \sum molal\ Concertation$ |
| Water transport through the membranes | $Qw = (\Delta P - \Delta Posm) * kw * \frac{s}{d}$ |
| Salt Transport | $Qs = \Delta C * ks * \frac{s}{d}$ |
| Salt Passage | $Sp = 100\% * (\frac{Cp\ (salt\ concentration)}{Cfm\ (mean\ salt\ conentration)})$ |

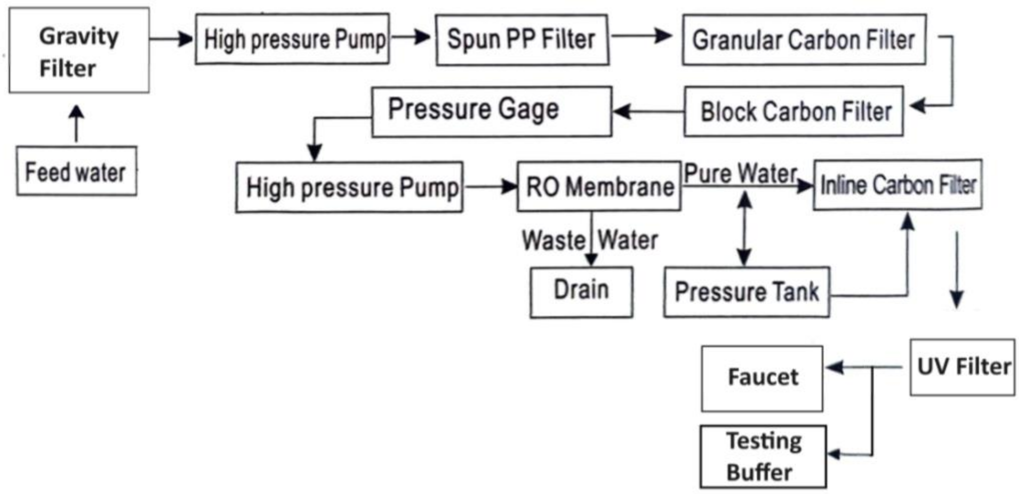
Table 5: Terms and Equations for RO system (1)

$$\Delta P = hydraulic\ pressure$$
$$Kw = membrane\ permeability\ coefficient\ of\ water$$
$$S = membrane\ area$$
$$d = membrane\ thickness$$
$$ks = membrane\ permeability\ coefficinet\ for\ salt$$

| Terms | Equation |
|---|---|
| Salt Rejection | $SR = 100\% - SP$ |
| Recovery Rate | $R = 100\% * [\frac{Qp(Product\ Flow\ Rate)}{Qf\ (feed\ water\ flow\ rate)}]$ |
| Concentration Polarization | $CPF = \frac{Cs\ (Membrane\ Surface)}{Cb\ (bulk\ concentration)}$ |

Table 6: Terms and Equations for RO system (2)

The flowchart of typical system after the iteration is found below:




Flowchart of the system 1

#### *2.2.4 Water Level Measurement*

For measuring the water stored in the tank, we will be using a load cell. This was the most convenient method of measurement as it does not require drilling through the tank to insert a water level sensor. From the difference of weight of the tank, we can calculate the amount of water in the tank. The tank weighs approximately 3.1kgs when empty. The calculations are shown in equation below:

$$W_{water} = W_{tank\ with\ water} - W_{tank\ no\ water}$$

A load cell is a block of aluminum that has a strain gauge attached to the center that detects small deflections in the block of metal when a load is attached to its end. This small variation in resistance can be converted to voltage using a Wheatstone bridge and an amplifier circuit. The challenging part is to come up with a mechanism that can be fixed to the chassis of the system and hold the large tank firmly. The design of this mechanism is shown in figure 19. In this system we will use a 100kg load cell.

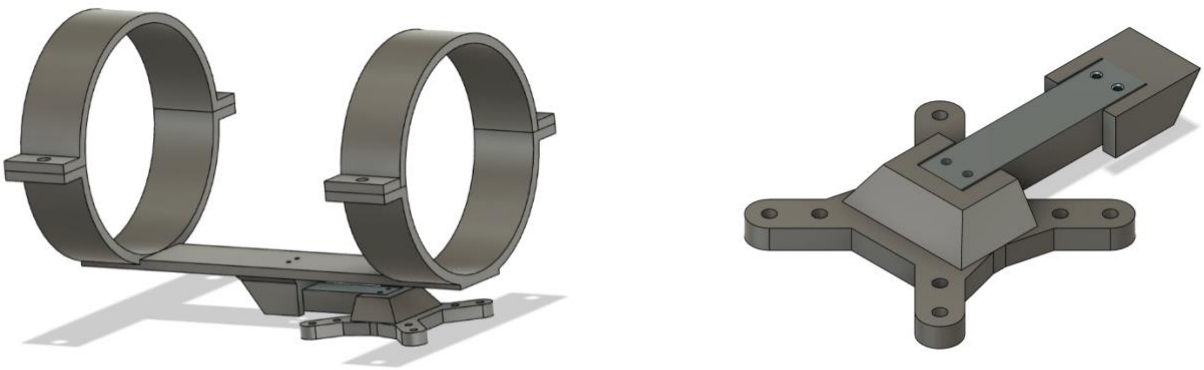


Figure 19: Load cell Mechanism

Figure 20: 100kg load cell.

### *2.2.5 PH and TDS Testing*

pH measures acidity or alkalinity on a scale from 0 to 14, with 7 being neutral. Lower values signify acidity, higher values alkalinity. It's determined by hydrogen ion concentration, crucial for chemical and biological processes. The pH of most drinking waters lies in the range of 6.8-8.5. Natural waters can be of lower pH because of acid rain or high pH in limestone areas.

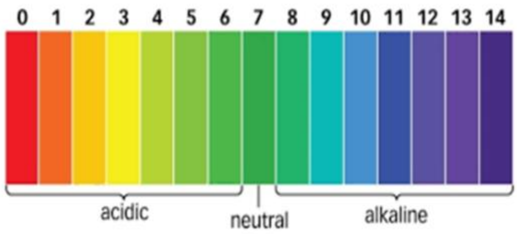



Figure 21: PH Scale

TDS typically stands for "Total Dissolved Solids." It refers to the combined content of all inorganic and organic substances contained in a liquid, usually water. These solids can include minerals, salts, metals, cations, and anions that are dissolved in the water. TDS is often measured in milligrams per litre (mg/L) or parts per million (ppm). High TDS levels can affect the taste and quality of water and may require treatment depending on its intended use, such as drinking water or industrial processes.


Figure 22: TDS Scale

To test the water turbidity and the hydrogen potential of the filtered water, TDS and PH sensors will be used. However, these sensors cannot be randomly placed as they are meant to be integrated into the system so that the user can easily test the filtered water before consumption. To do this, a buffer will be mounted on the side of the chassis where the user can fill the buffer with the treated water, and within the buffer, the sensors are fixed and can read the measurements of the filtered water. The user can then drain the buffer so that a new sample of water can be tested. The design of the buffer is shown in figure 23:

Figure 23: Sensor Buffer Design

### *2.2.6 Screen Display Design*

To display the recorded values of the sensor, and for the user to be able to interface with the device (i.e., control the pumps, monitor water level and quality) a touch screen will be used which is the ILI9488 OLED TFT touch screen. To mount the screen on the device, a custom mount was designed shown in figure 24.

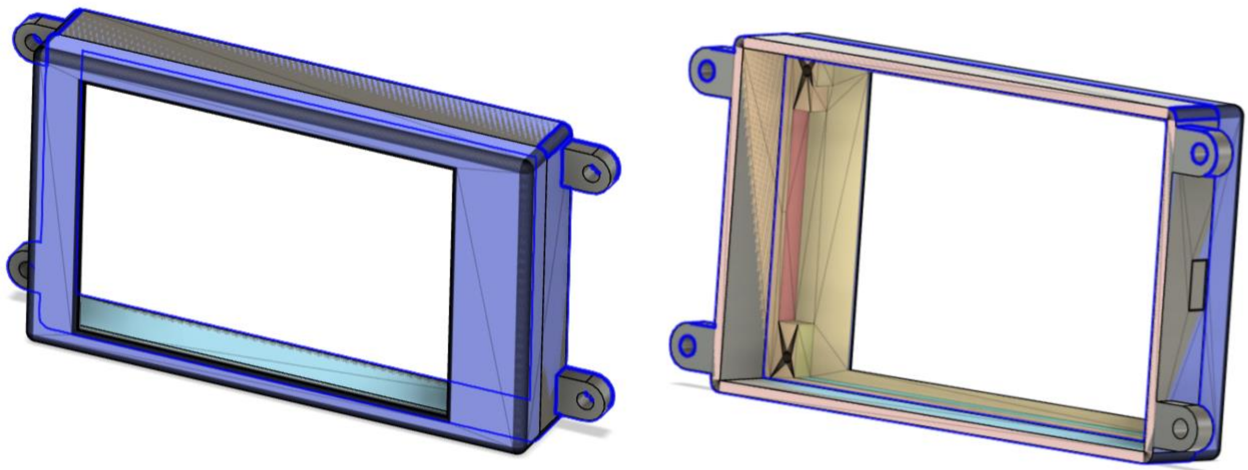


Figure 24: Touch Screen Mount

## 2.3 Electrical System Design

### *2.3.1 Power Calculations:*

The battery capacity calculated in Amp hours is known by calculating the power consumption of the circuit, and the amount of time desired for the system to operate which according to the set constraints is 6 hours.

The power consumption of the entire system is the sum of the power consumption of each component. The power of each component is indicated in their respective data sheet. The RO pump is rated at 28 Watts, 11 watts for the UV filter, and 20 watts for miscellaneous components including the inverter, ESP, sensors, and power supplies.

$$P_{total} = P_{pump} + P_{pumpRO} + P_{UV} + P_{misc}$$

$$P_{total} = 72 + 28 + 11 + 20 = 130\,Watts$$

The system voltage is chosen to be 12 Volts, since many components in the system require 12 volts, and since 12 volts is easily converted to 220 volts AC using a standard small inverter. To get the battery capacity in amp hours, we divide the energy required of the system and divide it by the system voltage:

$$Energy = Power\ (Watts) \times Time(hours)$$

$$Energy = 130 \times 6 = 780\,Watt\ hours$$

$$Battery\ capacity\ (Amp\ hours) = \frac{Energy(Watthours)}{Voltage(Volts)}$$

$$Power(Watts) = Voltage(Volts)\ \times Current(Amps)$$

$$Energy = Voltage(Volts)\ \times Current(Amps)\ \times Time(hours)$$

$$Battery\ capacity\ (Amp\ hours) = \frac{780\ (Watthours)}{12(Volts)} = 65\ Amp\ hours$$

A 65 Amp hour battery is available in the market and has been selected for this project. It will be sufficient to allow the system to run for 6 hours.

Now it is desired to select an appropriate solar panel such that it is compact enough to be carried with the system but powerful enough to charge the battery in a reasonable amount of time. A 50-watt solar panel is selected with dimensions of

55x67x3 cm. With a 50-watt 18V solar panel, it was calculated that approximately 15.6 hours of sunlight would be required to fully charge the 65Ah 12V battery.

$$Watthours\ (Wh) = Voltage\ (V) \times Capacity\ (Ah)$$

So, for the 12V, 65Ah battery:

$$Watthours = 12\ V \times 65\ Ah = 780\ Wh$$

Now, to find out how many hours the solar panel will take to charge the battery, we can use the formula:

$$Time\ (hours) = \frac{Battery\ capacity\ (Wh)}{Solar\ panel\ output\ (W)}$$

Therefore,

$$Time = \frac{780\ Wh}{50\ W}$$

$$Time = 15.6\ hours$$

***2.3.2 Wiring***

The wiring of the system is composed of two subsystems. A power distribution system to distribute power to the components from the 12-volt battery such as the ESP, RO, and pumps, and the electronic control system used to control the sensors, relays, and display screen. The power distribution diagram is shown in figure 25:

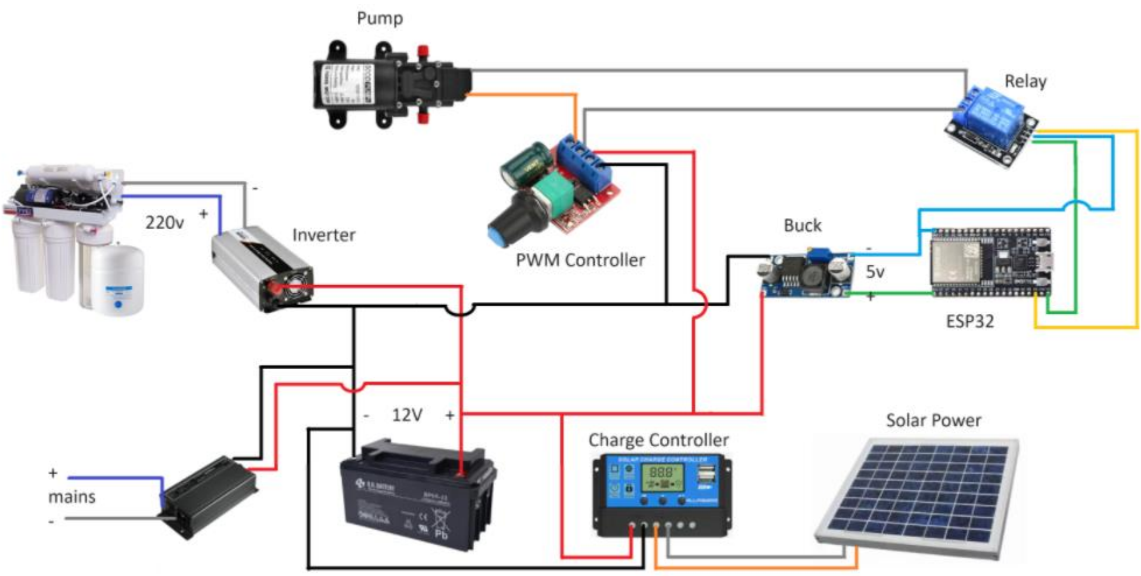



Figure 9: Power Distribution Circuit Diagram.

The 12-volt battery is charged by 2 methods. The first being using mains power where the battery is connected to a charger circuit which can be plugged into any 220-volt outlet. The charger automatically charges the battery and disconnects once the battery is full. The second method is by using a solar charge controller, which regulates the variable voltage and current coming from the solar panel and enables the battery to be charged steadily. To power the RO system, an inverter is used to convert 12 volts DC to 220 volts AC which is the rated voltage of the system. The ESP32 microcontroller cannot handle 12 volts as an input, therefore, the 12 volts must be reduced to 5 volts using a buck converter. This same converter will power all the other electronics which require 5 volts. Finally, a PWM controller is connected to the pump's power source (12 volts), to reduce the speed of the pump so that its pressure decreases to the desired pressure calculated before.

The portable plant is operated using an ESP Microcontroller, where multiple sensors such as PH, Turbidity, load cell, and water level sensors are used. In addition to a touch screen to allow the user to interact with the system. The water level sensor is used to detect when the gravity filter buffer is full. Once the buffer is full of water filtered from the gravity filter, the 1$^{st}$ booster pump is activated. This booster pump activates the RO pump since the RO system only activates when there is sufficient pressure in the inlet (low pressure switch is activated and allows the pump to turn on). The relay is responsible for controlling the 1st pump. The TDS and PH sensor are placed in their designated buffer and are wired to the ESP. All the information is monitored, controlled, and displayed on the OLED ILI9488 touch screen. The connection of each pin of the sensors and wiring codes are displaced in the figures below.

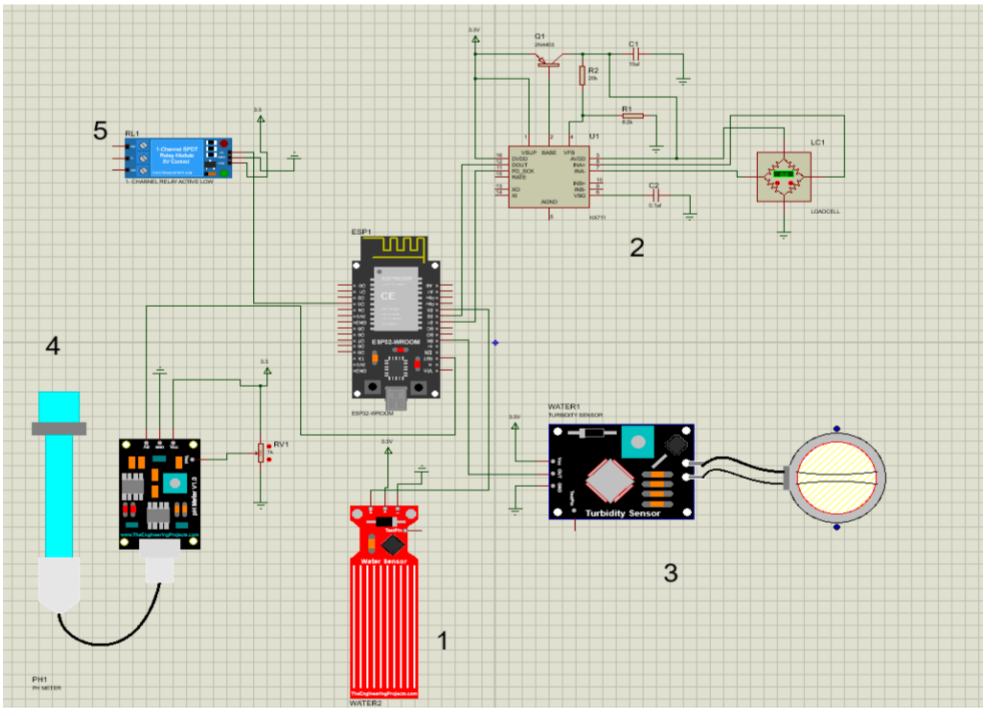



Figure 10: Schematic of Sensors and Relay Connected to ESP32

| Component's Number | Sensor Name | Sensor Pin(s) | Pin(s) Connection to Esp |
|---|---|---|---|
| **1** | Water Level Sensor | VCC | 3.3V |
| | | GND | GND |
| | | SIGNAL | D 34 |
| **2** | Hx711- Load Cell Sensor | VCC | 3.3 V |
| | | DOUT | D 33 |
| | | SCK | D 32 |
| | | GND | GND |
| **3** | TDS Sensor | VCC | 3.3 V |
| | | GND | GND |
| | | SIGNAL | D 12 |
| **4** | PH Sensor | VCC | VCC |
| | | GND | GND |
| | | SIGNAL | D 13 |
| **5** | Relay | VCC | 3.3 V |
| | | GND | GND |
| | | SIGNAL | D 26 |

Table 4: Wiring of Figure 26

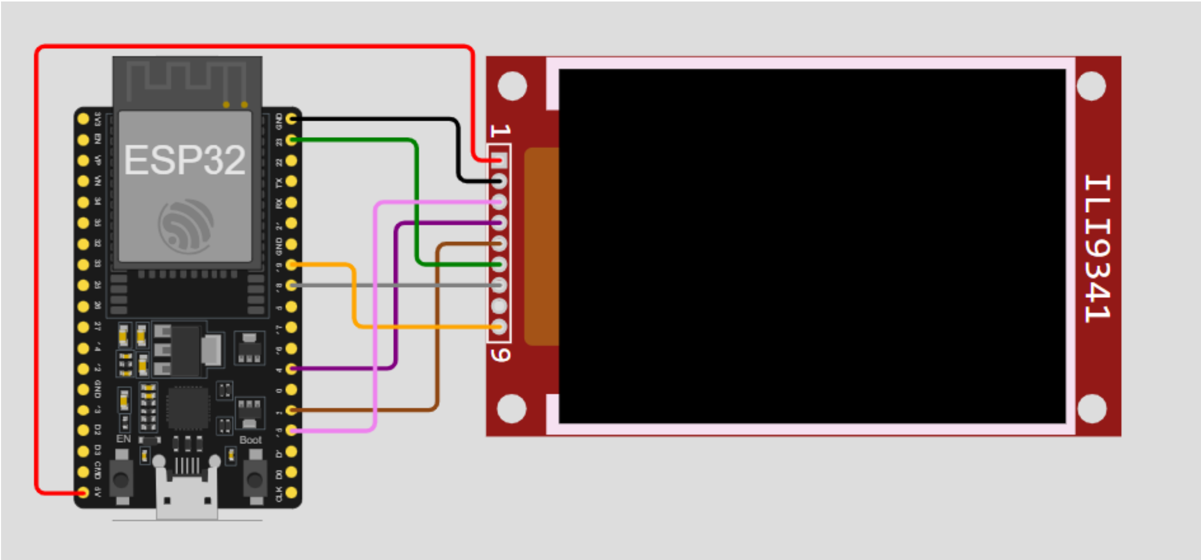



Figure 11: Schematic of ILI9488 with ESP32

| OLED Screen Pin | Pin Connection to the ESP32 |
|---|---|
| VCC | 3.3V |
| GND | GND |
| LED | 3.3V |
| MOSI | D 23 |
| SCK | D 18 |
| CS | D 15 |
| RESET | D 4 |
| DC | D 2 |
| T_DO | D 19 |
| T_DIN | D 23 |
| T_CS | D 21 |
| T_CLK | D 18 |

Table 5: OLED screen pin Connection to ESP32 (for Figure 27)

### *2.3.3 Flowchart of code*

The flowchart below shows a brief explanation of the code used for this project. The flowchart shows the control part of level sensor for the relay (for it to control the pump) and user interface found in the OLED screen and what it can display upon pressing on each button. Kindly note that the code is found in appendix D.

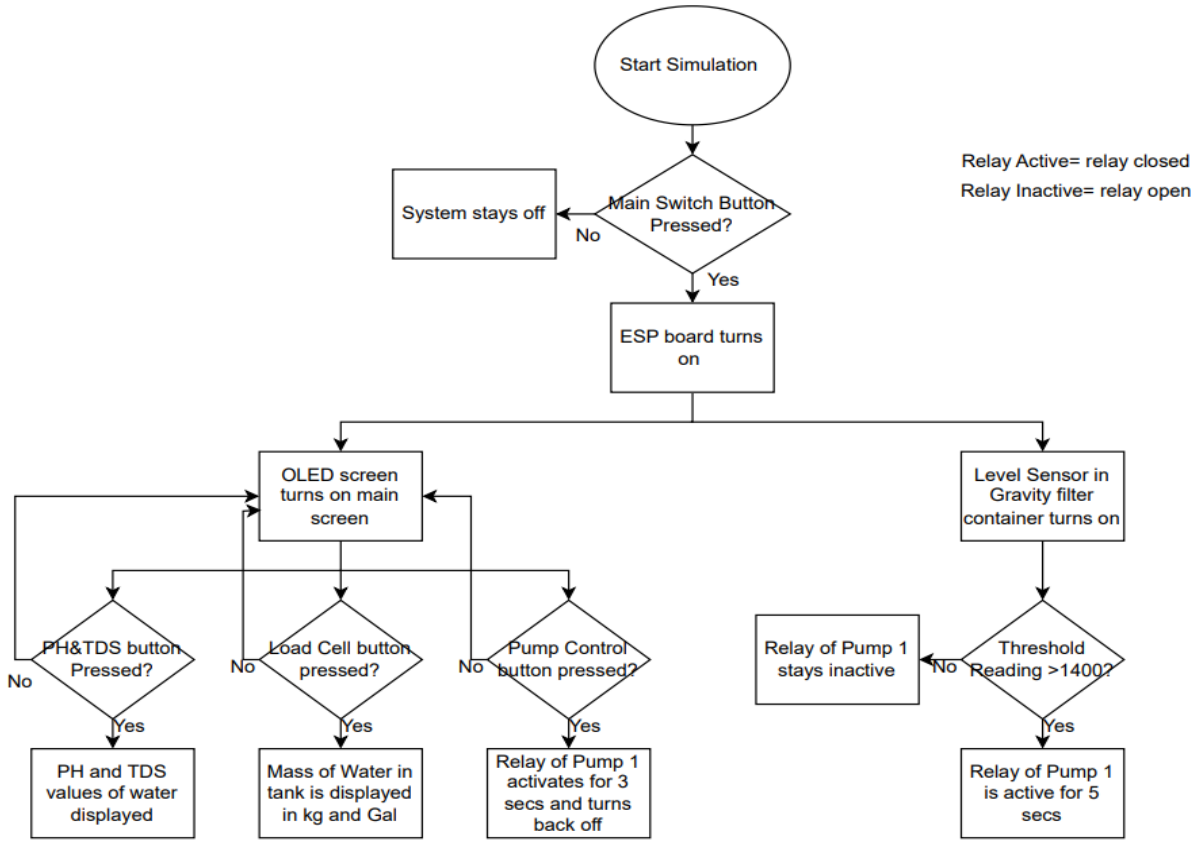



Figure 12: Flowchart of the Code

# CHAPTER 3

# FINAL DESIGN VALIDATION

## 3.1 Technical Validation of Final Prototype

### *3.1.1 PH and TDS values in the Chem Lab and Machine Sensors:*

For Tap Water:

| Experiment / Sensor | LAB Test | | With Sensor Test | |
|---|---|---|---|---|
| | **Before Desalination** | **After Desalination** | **Before Desalination** | **After Desalination** |
| **PH** | 8.06 | 8.12 | 8.06 | 7.9 |
| **TDS** | 325 ppm | 286ppm | 325 ppm | 213 ppm |

Table 6: Tap Water PH and TDS after and Before desalination measured in the Chemistry University lab and the sensors found in machine's buffer.

For Sea Water:

| Experiment / Sensor | LAB Test | | With Sensor Test | |
|---|---|---|---|---|
| | **Before Desalination** | **After Desalination** | **Before Desalination** | **After Desalination** |
| **PH** | 7.65 | 7.06 | __ | 6.9 |
| **TDS** | 1581 ppm | 469 ppm | __ | 453 ppm |

Table 7: Seawater PH and TDS after and Before desalination measured in the Chemistry University lab and the sensors found in machine's buffer.

### *3.1.2 Water Efficiency*

After testing, it was indicated that it took 5 Liters of supply water to give us 1 liter of Reverse Osmosis filtered water.

### *3.1.3 Gravity Filter Effectivity*

After testing the gravity filter, it indicated that the filter does indeed filter large contaminants from the water and makes the water significantly clearer.

Check the figure below:

Figure 13: Muddy water before and after gravity filter.

***3.1.4 Sensor Error***

Comparing the same sample of water with measurements done using the integrated sensors vs laboratory tested samples, the error of PH and TDS sensors doesn’t exceed 5%.

Also, the load sensor gives an error of less than 5% through measurement done between a weight meter found in the STC room and load cell sensor.

Validation of the desalination process was a critical aspect of the prototype testing. The reverse osmosis (RO) process was verified to effectively desalinate saline water, with the tank being fully filled within 2 to 3 hours. Testing of the RO kits confirmed that for every 2.5 to 3 liters of drain water produced, 1 liter of drinking water was obtained. The water temperature during testing was maintained at room temperature (20 degrees Celsius), ensuring consistent results.

Both software and hardware safety precautions were taken to keep the reverse osmosis safe from any unexpected error. A code was performed when the water tank is fully filled, all the pumps and valves should be closed; however, for hardware case, a shut off valve was used to stop the flow of water into the unit when the storage tank is full. To the shutoff valve, full means when the pressure in the tank reaches about ⅔ of the pressure of the tap water coming into the unit. In other words, if the water pressure is 60 psi, the RO unit will stop making water when the pressure in the storage tank reaches about 40 psi.

- <u>Quality Assurance and Control</u>

Quality assurance and control measures were implemented to guarantee the production of safe and high-quality potable water. A 3D-printed buffer containing pH and TDS meters was utilized to monitor the quality of the produced water. The pH values ranged between 6.8 to 7.2, while the TDS levels were below 300 ppm, consistent with the standards observed in water produced by reputable companies such as RIM, Tanourine, and Soha. These results affirmed the effectiveness of the desalination process in removing impurities and producing water of satisfactory quality.

### 3.2 Compliance of Final Design with Set Constraints

A wide range of constraints, from technological complexities to economic feasibilities, must be carefully taken into consideration when designing a portable water desalination plant. The final design must fall within the limitations, set in section 1.5, that provides the framework for the design and ensures the effectiveness and affordability of our product.

The implemented design has compact dimensions at 85cm x 57cm x 97cm which fits the dimension requirements.

The strict adherence to the specified 100 watts power consumption limit was not met but can be improved.

Due to the portability, low operating cost, and sustainability of the product it's considered an ecologically viable option.

A key component of the device's design is portability, which is possible by the addition of wheels and handles. This guarantees smooth motion and easy navigation on a variety of terrains.

Furthermore, the device is capable of testing water quality using Total Dissolved Solids (TDS) tests, and PH level evaluations. This proves the usefulness of the device with different water sources.

The device can function autonomously for up to ***6*** hours, where the water level sensor in the buffer will switch on the pump and fill the tank when needed. This is made possible by integrating a 12 volts 65 Ah battery that supplies the device with the needed power to operate. Using the battery makes the device self-sufficient for off grid and rural areas.

Simple operation is ensured by user friendly interfaces and basic controls, through the OLED screen to display the amount of water stored in the tank and checking the result of the PH and TDS sensors. Maintenance procedures are made easier by using the sliding door to access all elements integrated in the system, and a hinge on the top of the device to access the electrical box which is the brain of the device that ensures everything runs autonomously.

Financial restrictions limit the range of features that can be incorporated into the device. However, the final design has a variety of features highlighting the cost-effectiveness without sacrificing performance. The final design's budget came out to a total of ***780*** $, which fits within the financial constraint of 1000$.

Due to financial size constraints, the gravity filter was designed and fabricated to fit in the device. The fabrication of this filter accompanied several iterations of the design. Leaking was the major problem when installing this element since the weight of this filter was stressing the fittings causing leaks and instability. After redesigning the filter, the outlet was relocated to the side of the filter where no stress was applied on the fittings, and clamping the filter into the chassis was enough to stabilize the filter.

The original design of the chassis included a wooden case since it's cheaper and reliable to use. However, this proves ineffective since the weight of the components will cause severe bending stress on the chassis and will cause relatively high deformation. As a solution we used an aluminum and fiber chassis which is more expensive than wood causing financial restraints on the project but on the other hand, the aluminum has greater young's modulus than wood minimizing deformation in the chassis. In addition, aluminum is less hygroscopic than wood, which in case of leaks will not cause damage or deterioration in the chassis, not to mention improved mobility by making the device lighter.

The system should undergo maintenance tasks for specific time intervals to ensure that the reverse osmosis kit perform in a well condition, kindly check the table below:

| Task/Component | Frequency | Description |
|---|---|---|
| Replace sediment filter | Yearly | If the supply water is heavily polluted with minerals, it is recommended to do this more often. |
| Replace carbon filter | Yearly | - |
| Replace RO membrane | 2-5 Years | Typical replacements range between 24-60 months. Replacement is necessary when the Water Safe Guard displays a red light, or when the capacity has dropped more than 10%. |
| Assess permeate water | Yearly | - |
| Inspect the buffer tank | Yearly | - |

Table 8 : RO kit maintenance list

### 3.3 Applicable Codes and Standards

ISO 22734: Desalination systems powered by renewable energy:

This standard provides comprehensive guidelines for the design, installation, operation, and maintenance of desalination systems powered by renewable energy sources such as solar power. It covers various aspects including system sizing, component selection, energy management, and performance monitoring to ensure efficient and reliable operation.

ISO 3696: Water for analytical laboratory use:

ISO 3696 specifies requirements and recommendations for the quality of water used in analytical laboratory applications. While not directly related to desalination, it may apply to ensure the quality of water produced by the desalination system meets analytical standards.

ISO 9001: Quality management systems:

ISO 9001 outlines requirements for establishing, implementing, and maintaining a quality management system (QMS) within an organization. While not specific to desalination, adherence to ISO 9001 ensures that the design, manufacturing, and operation of desalination systems meet consistent quality standards, leading to improved performance and customer satisfaction.

NSF/ANSI 58: Reverse osmosis drinking water treatment systems:

NSF/ANSI 58 establishes requirements for the performance, materials, and construction of reverse osmosis drinking water treatment systems. This standard ensures that RO systems effectively remove contaminants and produce high-quality drinking water that meets health and safety standards. Compliance with NSF/ANSI 58 is essential for ensuring the safety and reliability of portable water desalination systems.

NSF/ANSI 61: Drinking water system components - Health effects:

NSF/ANSI 61 sets criteria for evaluating the health effects of materials and products used in drinking water systems. This standard ensures that materials and components do not leach harmful contaminants into the treated water, thereby safeguarding public health and ensuring compliance with regulatory requirements.

IEEE 1547: Standard for Interconnecting Distributed Resources with Electric Power Systems:

IEEE 1547 provides requirements and guidelines for the interconnection of distributed energy resources (DERs), including solar power systems, with electric power systems. Compliance with IEEE 1547 ensures the safe and reliable integration of solar power systems into the electrical infrastructure of portable water desalination plants.

NFPA 70 (NEC): National Electrical Code:

The National Electrical Code (NEC), published by the National Fire Protection Association (NFPA), sets forth requirements for the safe installation and operation of electrical systems. Compliance with NEC ensures that electrical components and wiring within the desalination plant meet safety standards and minimize the risk of electrical hazards.

ASTM D4194: Standard Test Methods for Operating Characteristics of Reverse Osmosis and Nanofiltration Devices:

ASTM D4194 specifies procedures for testing the operating characteristics of reverse osmosis (RO) and nanofiltration devices. This standard provides standardized methods for evaluating the performance and efficiency of RO systems, including parameters such as permeate flux, salt rejection, and pressure drop.

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# APPENDIX A

# STUDENT OUTCOMES

| | ***How was it addressed in your SLP?*** | ***Where was it addressed in your SLP?*** |
|---|---|---|
| **1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics** | | |
| 1.1 Identify complex engineering problems | *Design, Assemble and operate a portable water desalination plant with the least cost and highest efficiency* | *2.1.2, 2.1.3* |
| 1.2 Formulate complex engineering problems by applying principles of engineering, science, and mathematics | *Applying the rules of physics related to water flow and Pressure Applied calculations for electronics power consumption, pumps, and 12V DC to 220V AC conversion.* | *2.3, 2.2.3* |

| | | |
|---|---|---|
| 1.3 Solve complex engineering problems by applying principles of engineering, science, and mathematics | *Using the formulas addressed in electric circuits, thermal fluids, and microcontrollers, we were able to develop our overall prototype that is fully powered using a 12V battery charged using a solar panel and controlled using an ESP microcontroller* | *2.3, 2.2.3* |
| **2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors** | | |
| 2.1 Design a system/component of a system or a process to meet specific needs while respecting safety, health and welfare of the public and adhering to cultural, social, environmental and economic factors | *Using an RO membrane system along with 2 pre filters and 3 post filters and a UV light we were able to design a water desalination* | *2.1.2, 2.1.3, 2.2.4, 2.2.5, 2.2.6* |

| | | |
|---|---|---|
| | *plant that produces highly purified safe drinkable water anytime especially to be used in emergencies* | |
| 2.2 Modify a system/component of a system or a process to meet specific needs while respecting safety, health and welfare of the public and adhering to cultural, social, environmental and economic factors | *Designing the water desalination plant with high standards. The Chassis is made of aluminum which is anti-rodent against water and long lasting with time. The project is fully powered using a solar panel, a renewable energy with 0 emissions. The produced water is a safe drinkable water* | *2.1.3, 2.2.4, 2.2.5, 2.2.6* |
| **3. An ability to communicate effectively with a range of audiences** | | |
| 3.1 Ability to write a well-structured formal report/technical document that addresses an assigned task | *Writing meeting* | *SLPI report (date* |

| | | |
|---|---|---|
| | *minutes, weekly reports/meeting with the advisor and presenting newly obtained information weekly with the advisor and among group members* | *December 2023) + SLPII Progress Report (beginning of April) + SLPII final report (end of April)+ meeting minutes for every meeting (once per weekly on average)* |
| 3.2 Ability to deliver a well-structured formal presentation that addresses range of audiences | *Delivering weekly presentations to advisor (word documents in SLP1) and on plant in (SLP2). In addition to Final presentation next to jury on April 17.* | *SLPI presentation (August-December) + SLPII Progress presentation (January - April) + SLPII final presentation (April 17)* |
| **4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts** | | |
| | | *1.2, 3.3* |

| | | |
|---|---|---|
| 4.1 Identify global, economic, environmental, and societal impact of implementing engineering solutions using applicable engineering code of ethics to differentiate between ethical/unethical behaviors | *Follow ASME standards in our design. In addition to Humanitarian standards stated by SPHERE for the water quality in case of emergencies.* | |
| 4.2 Identify global, economic, environmental, and societal impact of implementing engineering solutions using applicable engineering standards and codes to differentiate between professional/unprofessional behaviors | *We followed the ASME standards for professional conduct related to Integrity, Honesty, Competence, Conflict of Interest, and Environmental Responsibility* | *3.3 + Appendix C* |
| **5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives** | | |
| 5.1 Ability to plan and organize team tasks collectively to meet established goals | *Tasks were always divided equally among group members and based on their expertise* | *Appendix-C + Gantt chart in Time Plan* |

| | | |
|---|---|---|
| | *to best reach the ultimate project prototype. Team members were highly cooperative.* | |
| 5.2 Ability to carry out tasks assigned by the team to attain set objectives. | *Cooperating and team working led to finishing the work on time without any delays. Team members divided the tasks among them and went to university on off days to abide by the set plan and finish based on the desired plan* | *Progress was set on the Gantt Chart+ Appendix C+ in the knowledge, guidance and supervision of the advisor* |
| **6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions** | | |
| 6.1 An ability to design experiments | *Testing of the RO, filter and tank flushing. In addition to testing PH and TDS of* | *2.1.2, 3.1* |

| | | |
|---|---|---|
| | *previously tested water (Water bottles) to calibrate and optimize our sensors to be able to test our own water produced. Experimentation for water flow, vacuum, and leakages were done* | |
| 6.2 An ability to conduct experiments | *Different water samples were taken to check PH and TDS. In addition to testing the water in the laboratory to validate our work* | *3.1* |
| 6.3 An ability to draw apt evidence-based conclusions by analyzing and interpreting data | *Taking sample water from different bottle water sources and compare it to the results obtained* | *3.1* |
| | | |

| **7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.** | | |
|---|---|---|
| 7.1 Identify necessary skills and tools of contemporary engineering practice to solve a problem at hand | *Advanced features in SolidWorks were used to model the prototype and run a fatigue stress analysis.* *Arduino IDE was used to program our OLED, PH, TDS and relay control. Open sources such as research papers were used and cited below to acquire needed knowledge about multiple water desalination plants and choosing RO in our project.* | *2.1.2, 2.2.1,2.2.2.2. 2.4,2.2.6, 2.3.2,* |

| | | |
|---|---|---|
| 7.2 Apply self-learned skills and tools of contemporary engineering practice to solve a problem at hand | *Stress Analysis on the Chassis was done using Solid works and once checked and safe, it was implemented on the project. In addition, the desired PH and TDS expected were achieved* | *2.1.2, 2.2.1,2.2.2.2. 2.4,2.2.6, 2.3.2,* |

# APPENDIX B

# BILL OF MATERIALS

The following table shows all the components purchased by our team used while implementing the project, their quantities, and prices.

| Material | Specification | Link | Price | Expected time for delivery |
|---|---|---|---|---|
| Sink | Stainless steel kitchen sink | Link | 70 | |
| Acrylic pipe | 12 cm diameter 2meters | Link | 35 | |
| Pipe Access cap for gravity filter | 12*12*5cm<br>120 gram<br>2 per pack | Link | 14 | |
| Male NPT External thread brass | Hex Nipple<br>3/8’’ to ½’’<br>For brass fitting and piping<br>2 per pack | Link | | |
| Reverse Osmosis Kit | 5 stage Reverse Osmosis Filtration system<br><br>With: Nickel Faucet, Tank, Booster pump, Post Carbon Filter and under sink replacement filters<br><br>Micron layer that is 0.0001 TFC membrane layer | Link | 300 | |

| | | | | |
|---|---|---|---|---|
| | High Contaminant rejection, High Efficiency Absorption | | | |
| Analog TDS Sensor | Arduino Compatible<br><br>Waterproof 0-1000ppm<br><br>Measures liquid quality (conductive substance)<br><br>Measures TDS value of water, reflecting the cleanliness of water | Link | 15 | |
| Battery | 12V/45AH<br>Lead Acid | Link | 60 | |
| Solar Panel Kit | 50 Watts Mono Crystalline<br>12V<br>Waterproof<br>With: Photocell 10A solar charge controller+ SAE Connection Cable kit | Link | 60 | |
| | | | | |

| | | | | |
|---|---|---|---|---|
| | | | | |
| PH Sensor | Arduino Compatible Liquid PH (0-14) With: PH Electrode probe | Link | 68.5 | |
| | | | | |
| Battery Charger (Optional) | 12V 8Amp/24V 4Amp smart battery charger | Link | 7 | |
| Braided Reinforced PVC Hose | | | 150$ | |
| Fittings/ miscellaneous screws/ | | | | |
| Aluminum chassis | | | | |
| Total | | | 780$ | |

Table 9: BILL OF MATERIALS

# APPENDIX C

# MEETING MINUTES

**MINUTES OF MECH 595A MEETING (1)**

**COLLEGE OF ENGINEERING – MME Department – RHU**

**Solar Powered Portable Water Desalination Plant**

**ON SEPTEMBER 28th, 2023 AT 8:00 AM**

---

**Present:** Mahmoud Al Wattar, Malek Itani, Adnan Ramlawi, Dr. Ahmad Koubeissi

**Absent:** Karim Braidi, Mohammad Sabaa Aayon

---

The meeting came to order at 08:00 am.

## 1. *Discussions and Updates*

- Attendees discussed the importance of collecting research of different water desalination plants in the industries worldwide.
- Attendees agreed to hold future meetings on campus.

## 2. *Advisor Comments and Recommendations*

- Team members should divide their research into 3 parts (Process, Technology, and expectations).
- Team members should do research to have detailed knowledge about the project.

## 3. *Expected Deliverables for Next Meeting*

The team members are expected to deliver three outcomes:

1. Get research about types of water desalinations used in the industry (which one is efficient, advantages, drawbacks) and process of each type.
2. Research about the technologies (and history) of the water desalination plant (Industries):
   - How much water does the desalination plant need to produce one litter of drinking water.
   - How much power it needs (Industrial and for the project)
   - Restrictions of locations.
   - At what sea level will the desalination plant withdraw water from.
3. Team members expectations about the project and hardware specifications.
   - Battery/ Solar
   - Features
   - Design Material, etc....

The meeting was adjourned at 8:30 AM.

Minutes taken by: Mahmoud Al Wattar

**MINUTES OF MECH 595A MEETING (1)**

**COLLEGE OF ENGINEERING – MME Department – RHU**

**Solar Powered Portable Water Desalination Plant**

**ON October 5$^{th}$, 2023 AT 9:00 AM**

---

**Present:** Mahmoud Al Wattar, Malek Itani, Adnan Ramlawi, Dr. Ahmad Koubeissi, Karim Braidi, Mohammad Sabaa Aayon

**Absent:** No one

---

The meeting came to order at 09:00 am.

## 4. Discussions and Updates

- Attendees discussed the importance of collecting research of different water desalination plants in the industries worldwide.
- Attendees agreed to hold future meetings on campus.

## 5. Advisor Comments and Recommendations

- Team members should divide their research into 3 parts (Process, Technology, and history).
- Team members should do research to have detailed knowledge about the project and start preparing for the literature review.

## 6. Expected Deliverables for Next Meeting

The team members are expected to deliver three outcomes:

- Write a 2-page research contains block diagram, explanation, description, schematic diagram Get of different types of water desalinations used in the industry (which one is efficient, advantages, drawbacks) and process of each type.
- Summarize the history of the desalination plants in chorological order (2-page research):
- Write a 2-research paper about the technologies and features of each water desalination plants (large scale, medium scale, and portable)
  - Weight, Features
  - Design Material, Cost
  - How much water does the desalination plant need to produce one liter of drinking water. How much power it needs (Industrial and for the project)
  - Restrictions of locations. At what sea level will the desalination plant withdraw water from.

## 7. Assessment

The meeting was adjourned at 9:30 AM.

Minutes taken by: Mahmoud Al Wattar

**MINUTES OF MECH 595A MEETING (1)**

**COLLEGE OF ENGINEERING – MME Department – RHU**

**Solar Powered Portable Water Desalination Plant**

**ON October 12th, 2023 AT 8:00 AM**

---

**Present:** Mahmoud Al Wattar, Malek Itani, Adnan Ramlawi, Dr. Ahmad Koubeissi, Karim Braidi, Mohammad Sabaa Aayon

**Absent:** No one

---

The meeting came to order at 08:00 am.

## 8. *Discussions and Updates*

- Attendees discussed the importance of collecting research of different water desalination plants in industries worldwide.
- Attendees agreed to hold future meetings on campus.

## 9. *Advisor Comments and Recommendations*

- Team members should divide their research into 3 parts (Process, Technology, and history).
- Team members should do research to have detailed knowledge about the project and start preparing for the literature review.

## 10. *Expected Deliverables for Next Meeting*

The team members are expected to deliver three outcomes:

- Modification of the block diagram in the process research by adding description, components, and technical information per the advisor requirements.
- Summarize the history of the desalination plants in chorological order (2-page research).
- Write a 2-research paper about the technologies and features of each water desalination plants (large scale, medium scale, and portable) by:
  - Talk/Elaborate about the parameters in each water desalination.
  - Technology used in water desalination.
  - Technology, common practices (Process), Block diagram.
  - Scale at which water desalination is conducted.
  - Introduction to scale, how we will scale the industries, where you expect to find these scales.
  - Literature includes quantity output per time.
  - Summary in Table: Parameters, projects, technology, mechanism, output.

The meeting was adjourned at 8:30 AM.

Minutes taken by: Mahmoud Al Wattar

**MINUTES OF MECH 595A MEETING (1)**

**COLLEGE OF ENGINEERING – MME Department – RHU**

**Solar Powered Portable Water Desalination Plant**

**ON Nov 10th, 2023 AT 8:00 AM**

---

**Present:** Mahmoud Al Wattar, Malek Itani, Adnan Ramlawi, Dr. Ahmad Koubeissi, Karim Braidi, Mohammad Sabaa Aayon

**Absent:** No one

---

The meeting came to order at 08:00 am.

## *11. Discussions and Updates*

- Attendees discussed the importance of collecting research of different water desalination plants in industries worldwide.
- Attendees agreed to hold future meetings on campus.

## *12. Advisor Comments and Recommendations*

- Do research about material and how much each one costs.

## *13. Expected Deliverables for Next Meeting*

The team members are expected to deliver three outcomes:

- Do research into the type of materials used and how much they cost.
- How much it takes time to deliver the materials.
- Identify which materials is found locally.
- Identify which materials are found outside of Lebanon.
- Determine the budget of the project.

The meeting was adjourned at 8:30 AM.

Minutes taken by: Mahmoud Al Wattar

**MINUTES OF MECH 595A MEETING (1)**

**COLLEGE OF ENGINEERING – MME Department – RHU**

**Solar Powered Portable Water Desalination Plant**

**ON Nov 20$^{th}$, 2023 AT 8:00 AM**

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**Present:** Mahmoud Al Wattar, Malek Itani, Adnan Ramlawi, Dr. Ahmad Koubeissi, Karim Braidi, Mohammad Sabaa Aayon

**Absent:** No one

---

The meeting came to order at 08:00 am.

## *14. Discussions and Updates*

- Attendees discussed the importance of collecting research of different water desalination plants in industries worldwide.
- Attendees agreed to hold future meetings on campus.

## *15. Advisor Comments and Recommendations*

- Software Design.

## *16. Expected Deliverables for Next Meeting*

The team members are expected to deliver three outcomes:

- Draw a prototype of water desalination project.
- Check for design constraints.
- Determine the dimensions of each material.
- Make the design portable.
- Make the design easy for maintenance.

The meeting was adjourned at 8:30 AM.

Minutes taken by: Mahmoud Al Wattar

# Appendix D

# Code

```
#include "FS.h"
#include <SPI.h>
#include <TFT_eSPI.h> // Hardware-specific library
#include <Wire.h>

TFT_eSPI tft = TFT_eSPI();       // Invoke custom library

#define RED2RED 0
#define GREEN2GREEN 1
#define BLUE2BLUE 2
#define BLUE2RED 3
#define GREEN2RED 4
#define RED2GREEN 5
#define TFT_GREY 0x2104 // Dark grey 16 bit colour

#define CALIBRATION_FILE "/TouchCalData3"
#define REPEAT_CAL false
char currentPage, selectedUnit;

// Constants for pH sensor
const int pHsensorPin = 13;
float calibration_value = 52.4;
int phval = 0;
unsigned long int avgval;
int buffer_arr[10], temp;

// Constants for TDS sensor
#define TdsSensorPin 12
#define VREF 3.3      // analog reference voltage(Volt) of
the ADC
#define SCOUNT  30           // sum of sample point
int analogBuffer[SCOUNT];    // store the analog value
in the array, read from ADC
int analogBufferTemp[SCOUNT];
int analogBufferIndex = 0, copyIndex = 0;
float averageVoltage = 0, tdsValue = 0, temperature =
25;

#include "HX711.h"
#include <Arduino.h>
const int LOADCELL_DOUT_PIN = 33;
const int LOADCELL_SCK_PIN = 32;
HX711 scale;

uint32_t runTime = -99999; // time for next update
int d = 0;       // Variable used for the sinewave test
waveform
boolean range_error = 0;

//Relay Control
const int RELAY_PIN = 26;
const unsigned long eventInterval_1 = 5000;
unsigned long previousTime_1 = 0;
const unsigned long eventInterval_2 = 3000;
unsigned long previousTime_2 = 0;

//Water Level Sensor
#define sensorPin 34
int state=0;

void setup(void)
{
  Serial.begin(9600);
  tft.init();
  // Set the rotation before we calibrate
  tft.setRotation(1);
  touch_calibrate();
  tft.fillScreen(TFT_BLACK);
  drawHomeScreen();
  currentPage = '0';
  selectedUnit = '0';
  scale.begin(LOADCELL_DOUT_PIN,
LOADCELL_SCK_PIN);
  scale.set_scale(-45.8046875);                    // this value
is obtained by calibrating the scale with known weights;
see the README for details
  scale.tare();              // reset the scale to 0
  pinMode(RELAY_PIN, OUTPUT);
}

void loop()
```

```
{
  unsigned long currentTime_1 = millis();
  unsigned int sensorValue = analogRead(sensorPin);



  if (sensorValue <1400){
    if ((scale.get_units(10)/1000, 1) <= 15.0){
    if (currentTime_1 - previousTime_1 >=
eventInterval_1) {
    digitalWrite(RELAY_PIN, LOW);
    previousTime_1= currentTime_1;
    state=0;
      }
    }
  if ((scale.get_units(10)/1000, 1) >= 15.0){
   digitalWrite(RELAY_PIN, LOW);
   }
  }

 if (sensorValue >1400){
  state=1;
 }

 if (state==1){
  digitalWrite(RELAY_PIN, HIGH);
 }
  if ((scale.get_units(10)/1000, 1) >= 15.0){
   digitalWrite(RELAY_PIN, LOW);
   }

   uint16_t X, Y;

  if (currentPage == '0'){
   if (tft.getTouch(&X, &Y)){

    if ((X>=120) && (X<=260) && (Y>=90) &&
(Y<=130)) {
      currentPage = '1'; // Indicates that we are the first
example
      tft.init();
      tft.fillScreen (TFT_BLACK);
      drawPH_TDS_SENSOR();
      }

    if ((X>=120) && (X<=260) && (Y>=150) &&
(Y<=190)) {
      currentPage = '2'; // Indicates that we are the first
example
      tft.init();
      tft.fillScreen (TFT_BLACK);
      LOADCELL_SENSOR();
      }

    if ((X>=120) && (X<=260) && (Y>=210) &&
(Y<=250)) {
      currentPage = '3'; // Indicates that we are the first
example
      tft.init();
      tft.fillScreen (TFT_BLACK);
      pumpControl();
      }
   }
  }

  if (currentPage=='1'){
    static unsigned long analogSampleTimepoint =
millis();
  if(millis() - analogSampleTimepoint > 40U) {
    analogSampleTimepoint = millis();
    analogBuffer[analogBufferIndex] =
analogRead(TdsSensorPin);
    analogBufferIndex++;
    if(analogBufferIndex == SCOUNT)
      analogBufferIndex = 0;
  }

  static unsigned long printTimepoint = millis();
  if(millis() - printTimepoint > 800U) {
    printTimepoint = millis();
    for(copyIndex = 0; copyIndex < SCOUNT;
copyIndex++)
      analogBufferTemp[copyIndex] =
analogBuffer[copyIndex];
    averageVoltage = getMedianNum(analogBufferTemp,
SCOUNT) * (float)VREF / 1024.0;
    float compensationCoefficient = 1.0 + 0.02 *
(temperature - 25.0);
    float compensationVolatge = averageVoltage /
compensationCoefficient;
```

```
    tdsValue = (133.42 * compensationVolatge * compensationVolatge * compensationVolatge - 255.86 * compensationVolatge * compensationVolatge + 857.39 * compensationVolatge) * 0.5;

  }

  // pH sensor readings
  for(int i = 0; i < 10; i++) {
    buffer_arr[i] = analogRead(pHsensorPin);
    delay(30);
  }

  for(int i = 0; i < 9; i++) {
    for(int j = i + 1; j < 10; j++) {
      if(buffer_arr[i] > buffer_arr[j]) {
        temp = buffer_arr[i];
        buffer_arr[i] = buffer_arr[j];
        buffer_arr[j] = temp;
      }
    }
  }

  avgval = 0;
  for(int i = 2; i < 8; i++)
    avgval += buffer_arr[i];

  float volt = (float)avgval * 5.0 / 1024 / 6;
  float ph_act = -5.70 * volt + calibration_value;

  Serial.print("pH Value:");
  Serial.println(ph_act);

 if (millis() - runTime >= 0L)
  { // Execute every TBD ms
    runTime = millis();

    // Test with a slowly changing value from a Sine function
    d += 4;
    if (d >= 360)
      d = 0;

    // Set the the position, gap between meters, and inner radius of the meters
    int xpos = 0, ypos = 5, gap = 4, radius = 52;

    xpos = 60, ypos = 90, gap = 50, radius = 80;

    //reading = 800 + 150 * sineWave(d + 90);
    xpos = gap + ringMeter(ph_act, 0, 14, xpos, ypos, radius, "ph", BLUE2RED); // Draw analogue meter

    //reading = 15 + 15 * sineWave(d + 150);
    xpos = gap + ringMeter(tdsValue,50, 1200, xpos, ypos, radius, "ppm", BLUE2RED); // Draw analogue meter
    }
     if (tft.getTouch(&X, &Y)){
      if ((X>=0) && (X<=480) && (Y>=0) && (Y<=320)) {
      currentPage = '0'; // Indicates that we are the first example
      tft.init();
      tft.fillScreen (TFT_BLACK);
      drawHomeScreen();
        }
      }

  }

  if (currentPage=='2'){

  if (tft.getTouch(&X, &Y)){
      if ((X>=15) && (X<=88) && (Y>=156) && (Y<=188)) {
      selectedUnit ='1';
        }
      }

   if (tft.getTouch(&X, &Y)){
     if ((X>=15) && (X<=88) && (Y>=200) && (Y<=232)) {
      selectedUnit ='2';
        }
      }

   if (tft.getTouch(&X, &Y)){
     if ((X>=0) && (X<=220) && (Y>=0) && (Y<=50)) {
```

```
      currentPage = '0'; // Indicates that we are the first
example
      tft.init();
      tft.fillScreen (TFT_BLACK);
      drawHomeScreen();
      selectedUnit='0';
        }
      }
   if (selectedUnit=='1'){
    tft.fillRect(400,210,50,30,TFT_BLACK);
    tft.fillRect(280,200,280,30,TFT_BLACK);
    tft.fillRect(240,280,140,40,TFT_BLACK);
    tft.setTextColor(TFT_DARKGREEN);
    tft.setCursor(280,200);
    tft.setTextFont(4);
    tft.print(scale.get_units(10)/1000, 5);
    tft.setCursor(400,210);
    tft.setTextFont(2);
    tft.print("in Kg");
    tft.setTextColor(TFT_WHITE);
    tft.setCursor (0, 250);
    tft.setTextFont(2);
    tft.print("The load cell is measuring the weight of the
tank, and its now filled to ");
    tft.setTextFont(4);
    tft.setTextColor(TFT_BLUE);
    tft.setCursor (240,280);
    tft.print((scale.get_units(10)/15000)*100, 5);
    tft.print("%");
    delay(500);
   }
   if (selectedUnit=='2'){
    tft.fillRect(280,200,280,30,TFT_BLACK);
    tft.fillRect(400,210,50,30,TFT_BLACK);
    tft.fillRect(240,280,140,40,TFT_BLACK);
    tft.setTextColor(TFT_DARKGREEN);
    tft.setCursor(280,200);
    tft.setTextFont(4);
    tft.print(scale.get_units(10)/3785.41, 5);
    tft.setCursor(400,210);
    tft.setTextFont(2);
    tft.print("in Gal");
    tft.setTextColor(TFT_WHITE);
    tft.setCursor (0, 250);
    tft.setTextFont(2);
    tft.print("The load cell is measuring the weight of the
tank, and its now filled to ");
    tft.setTextFont(4);
    tft.setTextColor(TFT_BLUE);
    tft.setCursor (240,280);
    tft.print((scale.get_units(10)/15000)*100, 5);
    tft.print(" %");
    delay(500);
   }
   delay (500);
  }
  if (currentPage=='3'){
    unsigned long currentTime_2 = millis();
     if (tft.getTouch(&X, &Y)){
     if ((X>=0) && (X<=220) && (Y>=0) && (Y<=50))
{
      currentPage = '0'; // Indicates that we are the first
example
      tft.init();
      tft.fillScreen (TFT_BLACK);
      drawHomeScreen();
        }
  }
  if (tft.getTouch(&X, &Y)){
     if ((X>=122) && (X<=250) && (Y>=152) &&
(Y<=188)) {
     tft.fillRect(174,220,150,20,TFT_BLACK);
     tft.fillRect(145,250,250,20,TFT_BLACK);
     tft.setTextFont (2);
     tft.setTextColor(TFT_RED);
     tft.setCursor (174,220);
     tft.print("Button OFF is Activated");
     digitalWrite(RELAY_PIN, LOW);
     }
  }

   if (tft.getTouch(&X, &Y)){
     if ((X>=250) && (X<=378) && (Y>=152) &&
(Y<=188)) {
     tft.fillRect(174,220,150,20,TFT_BLACK);
     tft.fillRect(145,250,250,20,TFT_BLACK);
     tft.setTextFont (2);
     tft.setTextColor(TFT_GREEN);
     tft.setCursor (174,220);
     tft.print("Button ON is Activated");
```

```
    if ((scale.get_units(10)/1000, 1) >= 15.0){
    digitalWrite(RELAY_PIN, LOW);
    tft.setTextFont (2);
    tft.setTextColor(TFT_YELLOW);
    tft.setCursor (180,250);
    tft.print("Caution: Tank is FULL");
    state=0;
     }

    if ((scale.get_units(10)/1000, 1) <= 15.0){
    state=3;
    tft.setTextFont (2);
    tft.setTextColor(TFT_YELLOW);
    tft.setCursor (180,250);
    tft.print("Processing...");
    }
   }
   }
    if (state==3){
    if (currentTime_2 - previousTime_2 >=
eventInterval_2) {
      digitalWrite(RELAY_PIN, LOW);
      previousTime_2= currentTime_2;
      state=0;
       tft.fillRect(145,250,250,20,TFT_BLACK);
       }
      if (currentTime_2 - previousTime_2 <=
eventInterval_2) {
      digitalWrite(RELAY_PIN, HIGH);
      }
     }
     if(state==0){
    digitalWrite(RELAY_PIN, LOW);
     }

  }
}


void touch_calibrate()
{
  uint16_t calData[5];
  uint8_t calDataOK = 0;

  // check file system exists
  if (!SPIFFS.begin()) {
    Serial.println("Formatting file system");
    SPIFFS.format();
    SPIFFS.begin();
  }

  // check if calibration file exists and size is correct
  if (SPIFFS.exists(CALIBRATION_FILE)) {
    if (REPEAT_CAL)
    {
      // Delete if we want to re-calibrate
      SPIFFS.remove(CALIBRATION_FILE);
    }
    else
    {
      File f = SPIFFS.open(CALIBRATION_FILE, "r");
      if (f) {
        if (f.readBytes((char *)calData, 14) == 14)
          calDataOK = 1;
        f.close();
      }
    }
  }

  if (calDataOK && !REPEAT_CAL) {
    // calibration data valid
    tft.setTouch(calData);
  } else {
    // data not valid so recalibrate
    tft.fillScreen(TFT_BLACK);
    tft.setCursor(20, 0);
    tft.setTextFont(2);
    tft.setTextSize(1);
    tft.setTextColor(TFT_WHITE, TFT_BLACK);

    tft.println("Touch corners as indicated");

    tft.setTextFont(1);
    tft.println();

    if (REPEAT_CAL) {
      tft.setTextColor(TFT_RED, TFT_BLACK);
      tft.println("Set REPEAT_CAL to false to stop this
running again!");
```

```
    }

    tft.calibrateTouch(calData, TFT_MAGENTA,
TFT_BLACK, 15);

    tft.setTextColor(TFT_GREEN, TFT_BLACK);
    tft.println("Calibration complete!");

    // store data
    File f = SPIFFS.open(CALIBRATION_FILE, "w");
    if (f) {
      f.write((const unsigned char *)calData, 14);
      f.close();
    }
  }
}

void drawHomeScreen() {
  tft.setTextColor(TFT_WHITE);
  tft.setTextFont(2);
  tft.setTextSize(1);
  tft.setCursor(100, 10);
  tft.print("Solar Powered Portable Water Desalination
Plant");
  tft.drawLine(20,36, 440,36, TFT_RED);
  tft.setTextColor(TFT_WHITE);
  tft.setTextFont(2);
  tft.setTextSize(1);
  tft.setCursor(189, 41);
  tft.print("Final Year Project");
  tft.setTextColor(TFT_WHITE);
  tft.setTextFont(2);
  tft.setTextSize(1);
  tft.setCursor(204, 64);
  tft.print("Select Option");

  // Button - PH AND TDS Sensor
  tft.fillRect(120,90,260,40,TFT_WHITE);
  tft.fillRect(122,92,256,36,0x008080);
  tft.setTextFont(2);
  tft.setCursor(195,102);
  tft.print("PH & TDS SENSOR"); // Prints the string

   // Button - Load Cell
  tft.fillRect(120,150,260,40,TFT_WHITE);
  tft.fillRect(122,152,256,36,0x008080);
  tft.setTextFont(2);
  tft.setCursor(195,162);
  tft.print("LOADCELL SENSOR"); // Prints the string

  // Button - PUMP CONTROL
  tft.fillRect(120,210,260,40,TFT_WHITE);
  tft.fillRect(122,212,256,36,0x008080);
  tft.setTextFont(2);
  tft.setCursor(204,222);
  tft.print("PUMP CONTROL"); // Prints the string

}


void drawPH_TDS_SENSOR(){
  tft.setTextColor(TFT_WHITE);
  tft.setRotation(1);
  tft.fillScreen(TFT_BLACK);
  tft.fillRect (0, 0, 30, 30, 0x008080);
  tft.setTextFont (1);
  tft.setCursor(5,5);
  tft.print("<--");
  tft.setTextFont (2);
  tft.setCursor(70,5);
  tft.print("Back to Main Menu");
  tft.setTextFont (4);
  tft.setCursor(120,30);
  tft.print("PH and TDS sensor Reading");
  tft.setTextFont (2);
  tft.setCursor(80,270);
  tft.print("PH Sensor");
  tft.setTextFont (2);
  tft.setCursor(320,270);
  tft.print("TDS Sensor");
}

void LOADCELL_SENSOR(){
  tft.setTextColor(TFT_WHITE);
  tft.setRotation(1);
  tft.fillScreen(TFT_BLACK);
  tft.fillRect (0, 0, 30, 30, 0x008080);
  tft.setTextFont (1);
  tft.setCursor(5,5);
  tft.print("<--");
```

```
  tft.setTextFont (2);
  tft.setCursor(70,5);
  tft.print("Back to Main Menu");
  tft.setTextFont (4);
  tft.setCursor(135,50);
  tft.print("Load Cell Sensor");
  tft.setTextFont(2);
  tft.setCursor(225,76);
  tft.print("HX-711");
  tft.drawLine(0,100, 480,100, TFT_RED);
  tft.setTextFont(4);
  tft.setCursor(10,114);
  tft.print("Select Unit");
  tft.setTextFont (4);
  tft.setCursor(300,120);
  tft.print("Weight: ");
  tft.fillRect(15,156,72,32,TFT_WHITE);
  tft.fillRect(18,159,66,26,0x008080);
  tft.setCursor(30,157);
  tft.setTextFont (4);
  tft.print("Kg");
  tft.fillRect(15,200,72,32,TFT_WHITE);
  tft.fillRect(18,203,66,26,0x008080);
  tft.setCursor(30,201);
  tft.setTextFont (4);
  tft.print("Gal");
}

void pumpControl(){
  tft.setTextColor(TFT_WHITE);
  tft.setRotation(1);
  tft.fillScreen(TFT_BLACK);
  tft.fillRect (0, 0, 30, 30, 0x008080);
  tft.setTextFont (1);
  tft.setCursor(5,5);
  tft.print("<--");
  tft.setTextFont (2);
  tft.setCursor(70,5);
  tft.print("Back to Main Menu");
  tft.setTextFont (4);
  tft.setCursor(204,30);
  tft.print("Pump Control");
  tft.fillRect(120,150,260,40,TFT_WHITE);
  tft.fillRect(122,152,128,36,TFT_RED);
  tft.fillRect(250,152,128,36,TFT_GREEN);
  tft.setTextFont(2);
  tft.setCursor(177,162);
  tft.print("OFF"); // Prints the string
  tft.setCursor(308,162);
  tft.print("ON"); // Prints the string
  tft.setCursor(0, 270);
  tft.print("The Pump will automatically turns off when
water is fully Filled (100%).");
}
//  Draw the meter on the screen, returns x coord of
righthand side
//
##############################################
###########################
int ringMeter(int value, int vmin, int vmax, int x, int y,
int r, const char *units, byte scheme)
{
  // Minimum value of r is about 52 before value text
intrudes on ring
  // drawing the text first is an option

  x += r;
  y += r; // Calculate coords of centre of ring

  int w = r / 3; // Width of outer ring is 1/4 of radius

  int angle = 150; // Half the sweep angle of meter (300
degrees)

  int v = map(value, vmin, vmax, -angle, angle); // Map
the value to an angle v

  byte seg = 3; // Segments are 3 degrees wide = 100
segments for 300 degrees
  byte inc = 6; // Draw segments every 3 degrees, increase
to 6 for segmented ring

  // Variable to save "value" text colour from scheme and
set default
  int colour = TFT_BLUE;

  // Draw colour blocks every inc degrees
  for (int i = -angle + inc / 2; i < angle - inc / 2; i += inc)
  {
    // Calculate pair of coordinates for segment start
```

```
float sx = cos((i - 90) * 0.0174532925);
float sy = sin((i - 90) * 0.0174532925);
uint16_t x0 = sx * (r - w) + x;
uint16_t y0 = sy * (r - w) + y;
uint16_t x1 = sx * r + x;
uint16_t y1 = sy * r + y;

// Calculate pair of coordinates for segment end
float sx2 = cos((i + seg - 90) * 0.0174532925);
float sy2 = sin((i + seg - 90) * 0.0174532925);
int x2 = sx2 * (r - w) + x;
int y2 = sy2 * (r - w) + y;
int x3 = sx2 * r + x;
int y3 = sy2 * r + y;

if (i < v)
{ // Fill in coloured segments with 2 triangles
  switch (scheme)
  {
  case 0:
    colour = TFT_RED;
    break; // Fixed colour
  case 1:
    colour = TFT_GREEN;
    break; // Fixed colour
  case 2:
    colour = TFT_BLUE;
    break; // Fixed colour
  case 3:
    colour = rainbow(map(i, -angle, angle, 0, 127));
    break; // Full spectrum blue to red
  case 4:
    colour = rainbow(map(i, -angle, angle, 70, 127));
    break; // Green to red (high temperature etc)
  case 5:
    colour = rainbow(map(i, -angle, angle, 127, 63));
    break; // Red to green (low battery etc)
  default:
    colour = TFT_BLUE;
    break; // Fixed colour
  }
  tft.fillTriangle(x0, y0, x1, y1, x2, y2, colour);
  tft.fillTriangle(x1, y1, x2, y2, x3, y3, colour);
  //text_colour = colour; // Save the last colour drawn
}
```

```
  else // Fill in blank segments
  {
    tft.fillTriangle(x0, y0, x1, y1, x2, y2, TFT_GREY);
    tft.fillTriangle(x1, y1, x2, y2, x3, y3, TFT_GREY);
  }
 }
 // Convert value to a string
 char buf[10];
 byte len = 3;
 if (value > 999)
   len = 5;
 dtostrf(value, len, 0, buf);
 buf[len] = ' ';
 buf[len + 1] = 0; // Add blanking space and terminator,
helps to centre text too!
 // Set the text colour to default
 tft.setTextSize(1);

 tft.setTextColor(TFT_WHITE, TFT_BLACK);
 // Uncomment next line to set the text colour to the last
segment value!
 tft.setTextColor(colour, TFT_BLACK);
 tft.setTextDatum(MC_DATUM);
 // Print value, if the meter is large then use big font 8,
othewise use 4
 if (r > 84)
 {
   tft.setTextPadding(55 * 3);   // Allow for 3 digits each
55 pixels wide
   tft.drawString(buf, x, y, 8); // Value in middle
 }
 else
 {
   tft.setTextPadding(3 * 14);   // Allow for 3 digits each
14 pixels wide
   tft.drawString(buf, x, y, 4); // Value in middle
 }
 tft.setTextSize(1);
 tft.setTextPadding(0);
 // Print units, if the meter is large then use big font 4,
othewise use 2
 tft.setTextColor(TFT_WHITE, TFT_BLACK);
 if (r > 84)
   tft.drawString(units, x, y + 60, 4); // Units display
 else
```

```
    tft.drawString(units, x, y + 15, 2); // Units display

  // Calculate and return right hand side x coordinate
  return x + r;
}

//
##############################################
############################
// Return a 16 bit rainbow colour
//
##############################################
############################
unsigned int rainbow(byte value)
{
  // Value is expected to be in range 0-127
  // The value is converted to a spectrum colour from 0 =
blue through to 127 = red

  byte red = 0;   // Red is the top 5 bits of a 16 bit colour
value
  byte green = 0; // Green is the middle 6 bits
  byte blue = 0;  // Blue is the bottom 5 bits

  byte quadrant = value / 32;

  if (quadrant == 0)
  {
    blue = 31;
    green = 2 * (value % 32);
    red = 0;
  }
  if (quadrant == 1)
  {
    blue = 31 - (value % 32);
    green = 63;
    red = 0;
  }
  if (quadrant == 2)
  {
    blue = 0;
    green = 63;
    red = value % 32;
  }
  if (quadrant == 3)
  {
    blue = 0;
    green = 63 - 2 * (value % 32);
    red = 31;
  }
  return (red << 11) + (green << 5) + blue;
}

//
##############################################
############################
// Return a value in range -1 to +1 for a given phase angle
in degrees
//
##############################################
############################
float sineWave(int phase)
{
  return sin(phase * 0.0174532925);
}

//========================================
========================================
=====
// This is the function to draw the icon stored as an array
in program memory (FLASH)
//========================================
========================================
=====

// To speed up rendering we use a 64 pixel buffer
#define BUFF_SIZE 64

// Draw array "icon" of defined width and height at
coordinate x,y
// Maximum icon size is 255x255 pixels to avoid integer
overflow

void drawIcon(const unsigned short *icon, int16_t x,
int16_t y, int8_t width, int8_t height)
{

  uint16_t pix_buffer[BUFF_SIZE]; // Pixel buffer (16
bits per pixel)
```

```
  tft.startWrite();

  // Set up a window the right size to stream pixels into
  tft.setAddrWindow(x, y, width, height);

  // Work out the number whole buffers to send
  uint16_t nb = ((uint16_t)height * width) / BUFF_SIZE;

  // Fill and send "nb" buffers to TFT
  for (int i = 0; i < nb; i++)
  {
    for (int j = 0; j < BUFF_SIZE; j++)
    {
      pix_buffer[j] = pgm_read_word(&icon[i *
BUFF_SIZE + j]);
    }
    tft.pushColors(pix_buffer, BUFF_SIZE);
  }

  // Work out number of pixels not yet sent
  uint16_t np = ((uint16_t)height * width) %
BUFF_SIZE;

  // Send any partial buffer left over
  if (np)
  {
    for (int i = 0; i < np; i++)
      pix_buffer[i] = pgm_read_word(&icon[nb *
BUFF_SIZE + i]);
    tft.pushColors(pix_buffer, np);
  }

  tft.endWrite();
}

int getMedianNum(int bArray[], int iFilterLen) {
  int bTab[iFilterLen];
  for (byte i = 0; i < iFilterLen; i++)
    bTab[i] = bArray[i];
  int i, j, bTemp;
  for (j = 0; j < iFilterLen - 1; j++) {
    for (i = 0; i < iFilterLen - j - 1; i++) {
      if (bTab[i] > bTab[i + 1]) {
        bTemp = bTab[i];
        bTab[i] = bTab[i + 1];
        bTab[i + 1] = bTemp;
      }
    }
  }
  if ((iFilterLen & 1) > 0)
    bTemp = bTab[(iFilterLen - 1) / 2];
  else
    bTemp = (bTab[iFilterLen / 2] + bTab[iFilterLen / 2 -
1]) / 2;
  return bTemp;
}
```