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JOMO KENYATTA UNIVERSITY OF AGRICULTURE

AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

BSc Electronic and Computer Engineering

PROJECT REPORT

PROJECT TITLE:

SOLAR POWERED WATER FILTRATION AND PURIFICATION SYSTEM

Submitted by:

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PROJECT SUPERVISOR

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A Final Year Project submitted to the Department of Electrical and Electronic Engineering in partial fulfillment of the requirements for the Award of a Bachelor of Science Degree in Electronic Engineering.

NOVEMBER 2021

DECLARATION

This project report is my original work, except where due acknowledgement is made in the text, and to the best of my knowledge has not been previously submitted to Jomo Kenyatta University of Agriculture and Technology or any other institution for the award of a degree or diploma.

ACKNOWLEDGEMENT

Part of the project was used in the Energy for Efficiency for Access Design Challenge 2021.

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SUPERVISOR CONFIRMATION:

This project report has been submitted to the Department of Electrical and Electronic Engineering, Jomo Kenyatta University of Agriculture and Technology, with my approval as the University supervisor:

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ABSTRACT

Access to safe drinking water and improved health is a human right. In this project, we shall be designing a water purifier which works on solar energy. The main principle behind our project is ultra-violet water purification. The solar radiations are collected by the solar panel. The energy is then stored in a battery. The battery is then connected to a voltage regulator to control voltage to the ultra violet (UV) LED. The purification unit consists of water pump, ultrafiltration filter membrane and ultra-violet (UV-C) chamber. The pump creates a necessary pressure required for ultra-filtration. The microcontroller is used to control the operation of the pump and ultra-violet LED. The design of UV-C chamber has been covered in this project. The system comprises of main treatment stage and post-treatment stage. In the main treatment, the ultrafilter filters out unseen materials, biological contaminants and disease-causing microorganism while in post-treatment stage the UV-C LEDs inactivates them using electromagnetic radiation of wavelengths between 200-280 nm. The whole system is powered using solar energy which is a clean, cheap and renewable source with zero emissions.

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LIST OF ABBREVIATIONS AND ACRONYMS

DC	Direct Current
GPRS	General Packet Radio Service
LED	Light Emitting Diode
NF	Nano-filtration
PCB	Printed Circuit Board
POU	Point of Use
RO	Reverse Osmosis
SODIS	Solar for Water Disinfection
UF	Ultra-filtration
UV	Ultra-Viol

CHAPTER ONE

1. INTRODUCTION.

1.1 Background Information

Waterborne diseases in developing countries cause thousands of deaths and even more cases of diseases mostly affecting children. In the rural areas of developing countries boiling is the most often used method for purifying water for food preparation and drinking. However, boiling is relatively expensive, consumes substantial amount of fossil energy and the associated wood gathering causes depletion of forest cover. Among the available alternatives solar water purification is the most promising approaches for energy efficient, cost effective [1], robust and reliable solution to these problems.

There is a great and urgent need to supply environmentally friendly technology for the provision of drinking water in rural areas. Water is one of the most essential natural resources gifted to humankind. But the rapid development of the society, population growth and numerous human activities have sped up the contamination and deterioration of existing sources. Pure clean drinking water is necessary for survival. Water supply is either ground water or surface water sources. The water from each of these sources contains sediments and other solids.

Biological contaminants are of different types including different types of bacteria such as Escherichia coli [6] and Vibrio cholerae. The degree to which the biological contaminants may pose threats to environmental and human health is dependent on the type and concentration. There are many health risks associated with exposure to biological contaminants in water including diseases such as typhoid and cholera.

The search for clean water is a human endeavor as old as thirst itself. Many people in rural areas do not have access to clean water. The aim of our project is to filter and purify water using solar power in rural areas. The main theme is about using a customized water filtration and purification tower that incorporates a small DC pump and a UV Purification system. Ultraviolet purification is the most effective method for disinfecting bacteria from water. UV systems destroy 99.99% of harmful microorganisms without adding chemicals or changing the waters taste and odor.

Ultraviolet (UV) radiation treatment is an effective method for the disinfection of bacterial and viral contaminants present in water as it serves as an alternative technology to chemical disinfection techniques. It has the benefit of fast treatment, minimal hazards associated with chemical handling and disposal and reduced costs. The wavelength responsible for the treatment of water is generally shorter at around 280 nm which places it in the UV-C region (200-280 nm). UVC radiation absorption causes the inactivation of microbe contaminants in water by damaging their DNA [5]. UV based systems do not remove objects from the water but rather they kill organic material that causes illness.

UVC light-emitting diodes [3] are gaining popularity as an alternative technology which can overcome the limitations of conventional mercury-containing UV lamps. For instance, their small size makes them easy to incorporate into a sterilization system and since they don't contain mercury thus alleviating risks of human and environmental toxicity.

Ultrafiltration UF is a pressure-driven membrane separation mechanism that removes suspended particulate matter and some dissolved compounds with high molecular weight from contaminated water. UF is highly efficient in filtering out microorganisms from water making the technology ideal for water purification systems. Moreover, the UF treatment systems are also useful when applied as pre-treatment units before reverse osmosis and UV treatment systems as disinfection requirements are greatly reduced due to the reduction in suspended solids.

As for power the distributed nature of households in the rural communities without access to electricity makes the use of photovoltaic technology (PV) an appropriate option to power the water purifying systems. Solar is highly reliable and has a lifetime of more than 25 years and the resource they depend on(sunshine) is sufficiently available almost everywhere in the world making it a universal choice.

Solar water disinfection (SODIS) involves exposing water-filled plastic polyethylene terephthalate (PET) bottles to sunlight for several hours [27]. Exposure times vary depending on weather and climate from a minimum of six hours to two days during fully overcast conditions. The World Health Organization as a viable method for household water treatment and safe storage recommends it. Over two million people in developing countries use this method for their daily drinking water. However, it has many setbacks compared to our proposed solution. Some of the setbacks are dependency on high solar radiations, continuous cleansing of plastic bottles, low flow rates and inability to treat large amounts of water at a time.

The principle behind our project is UV purification and ultrafiltration. This project looks at the efficient combination of solar to power UV water purification systems and the advantages of UV LEDs over mercury lamps as sources of UV radiation. We are using solar energy which is a renewable source, abundant and cheap. We plan on using a microcontroller together with GSM module which monitors the treated water. A solar panel is used as source of energy that charges the battery. The battery will then power the microcontroller, UV led, flow meter and the pumps. An emphasis is placed on this solution that is effective, reliable, safe and sustainable for use in rural off-grid areas mainly in Kenya.

1.2 Problem statement

Approximately 9.4 million people in Kenya drink directly from contaminated water sources [29]. Approximately 19,500 Kenyans, including 17,100 children under five, die each year from water borne diseases [29]. These figures can be reduced with access to clean water and sanitation.

Access to safe water and sanitation contributes to improved health and helps prevent spread of infectious diseases. Many people do not have access to electricity or access to electric appliances that can operate off grid. Majority of the water purification systems do not operate off grid and therefore the need to provide an off-grid solution to guarantee access to clean water.

Improvements in point-of-use (POU) drinking water disinfection technologies for remote and regional communities are urgently needed and as such a decentralized system such point of use solar UV-C disinfection is a viable alternative which could be handy when incorporated with rainwater harvesting technologies.

1.3 Project justification.

The project is significant because it will assist to prevent the spread of water-borne diseases by providing communities in remote areas with safe drinking water. Water that has been disinfected with UV-C will be safe to drink. It is suited in places not linked to the grid by using solar energy through solar panels, and it is both inexpensive and easy.

1.4 Objectives

The objectives of this project are to come up with a water filtration and purification system that is powered by solar, portable and readily available to off-grid communities in rural areas who do not have access to clean drinking water.

1.4.1 Main objectives

To design and implement a solar based water filtration and purification system.

1.4.2 Specific objectives

1. To design a solar powered water filtration unit
2. To construct a solar powered water filtration unit
3. To design an ultra-violet purification system for water disinfection
4. To implement an ultra-violet purification system for water disinfection and purification
5. To develop a prototype for water filtration and purification

1.5 Division of roles

JOSEPHINE TARIYA ENE 212-0073/2016	CHARLES KARIRA ENE 212-0267/2016
Final report	
Literature Review – Ultrafiltration. Microcontroller research and implementation. Chapter 3	Literature Review – UV Disinfection. Design calculations of UV Chamber. Pump design, flow rates and integration Chapter 4 and 5
Implementation	
1. Fabrication of two raw water tanks with the sediment filter 2. Design of electrical circuit and PCB 3. ThingSpeak integration with microcontroller	1. Fabrication of the UV-C chamber and piping 2. Hardware implementation of the electrical circuit 3. Microcontroller programming

CHAPTER TWO

2. LITERATURE REVIEW

The development of efficient water treatment technologies especially inactivation of pathogenic microorganisms in drinking water is of great importance for human health and well-being. Also, power usage is crucial for such purification systems and with application of solar energy this increases efficiency and provides access to users not connected to the grid. Several methods can be used to purify and clean drinking water. Major focus is given to ultrafiltration and UV disinfection which will be used as the main treatment process in our project.

2.1 Existing methods of water purification

2.1.1 Boiling

Boiling is the most used point of use water treatment approach in most homes. Most people use firewood for boiling drinking water because this option kills majority of the microorganisms, it's simple and very widely accepted method. However, this method does not remove more contaminants that are dangerous. Also, use of biomass fuels (charcoal and firewood) is not sustainable as it is very dependent on natural resources leading to degradation of the environment.

2.1.2 Chemical methods

Different chemical methods are being used to purify drinking water. They include chlorine tablets and fluoride removal. These methods involve addition of chlorine in municipal water to kill pathogens effectively. However, this produces byproducts that cause some health concerns.

<u>Chlorine</u>

Chlorine is the most widely used primary disinfectant and is also often used to provide residual disinfection in the distribution system. Monitoring the level of chlorine in drinking water entering a distribution system is normally considered to be a high priority (if it is possible), because the monitoring is used as an indicator that disinfection has taken place. Residual concentrations of chlorine of about 0.6 mg/l or more may cause problems of acceptability for some consumers on the basis of taste. Monitoring free chlorine at different points in the distribution system is sometimes used to check that there is not an excessive chlorine demand in distribution that may indicate other problems in the system, such as ingress of contamination.

2.1.3 Solar water disinfection (SODIS)

This is a simple technology that relies on the use of sun's energy only and photo destruction to inactivate disease causing microorganisms in water making it safe for drinking. This is possible with oxidative effect of radials formed by UV radiation for 4-6 hours on a sunny day. In solar disinfection pathogens are killed by the combined action of UV radiation and heat. This method is cheap, simple and uses renewable energy. However, it has the disadvantage of being highly dependent on solar radiation and contamination of plastic bottles and inability to treat large amounts of water. Such concerns include health risks associated with plasticizers and other carcinogenic compounds which may leach from the bottles into the water.

WADI is a monitoring device developed to trace the progress of solar water disinfection in a PET-bottle by detecting and calculating the UV-A rays of the sun, indicated by a status bar and smiley face. It measures the UV-A radiation of sun and indicates the point of time at which at least 3log10 reduction of bacteria has taken place. The visualization of the progress of the solar disinfection process eliminates user uncertainty but it's still limited by dependence on solar radiation.

Figure 1-2.1.3 WADI from Engineering for Change Solutions Library

2.2 Filtration technology backgrounds

Membrane filtration is a technique used to separate particles from a liquid. A membrane is a thin layer of semi-permeable material that separates substances when a driving force is applied across the membrane. Membrane processes are used for removal of bacteria, microorganisms and particles. The membrane processes include ultra-filtration (UF), Nano-filtration (NF), and reverse osmosis (RO).

Table 1-2.2 Filtration technology comparisons

	Microfiltration	Ultrafiltration	Nanofiltration	Reverse osmosis
Size of particle	> 0.1 um	0.1- 0.01 um	0.01-0.001um	< 0.001um
Type of particle	Suspended particles	Macro molecules, bacteria	Micro molecular organic compounds	Ions

2.2.1 Ultrafiltration

Ultrafiltration is a separation process using membranes with pore sizes in the range of 0.1 to 0.001 micron. It removes high molecular-weight substances, colloidal materials, and organic and inorganic polymeric molecules. Low applied pressure is sufficient to achieve high flux rates for an ultrafiltration membrane. Flux of a membrane is defined as the amount of permeate produced per unit area of membrane surface per unit time. Generally, flux is expressed as gallons per square foot per day (GFD) or as cubic meters per square meters per day. Ultrafiltration membranes can have extremely high fluxes of between 50 and 200 GFD at an operating pressure of about 50 psig. Ultrafiltration is a cross-flow separation process. Here liquid stream to be treated (feed) flows tangentially along the membrane surface, thereby producing two streams. The stream of liquid that comes through the membrane is called permeate. The other liquid stream is called concentrate and gets progressively concentrated in those species removed by the membrane. In cross-flow separation, therefore, the membrane acts as a barrier to these species.

Conventional filters such as media filters or cartridge filters, on the other hand, only remove suspended solids by trapping these in the pores of the filter-media. These filters therefore act as depositories of suspended solids and have to be cleaned or replaced frequently. Conventional filters are used upstream from the membrane system to remove relatively large suspended solids and to let the membrane do the job of removing fine particles and dissolved solids. In ultrafiltration, for many applications, no pre-filters are used.

Ultrafiltration removes bacteria, protozoa and some viruses from the water. Nano-filtration removes these microbes, as well as most natural organic matter and some natural minerals, especially divalent ions, which cause hard water. Nano-filtration, however, does not remove dissolved compounds. Reverse osmosis removes turbidity, including microbes and virtually all dissolved substances. However, while reverse osmosis removes many harmful minerals, such as salt and lead, it also removes some healthy minerals, such as calcium and magnesium. This is why water that is treated by reverse osmosis benefits by going through a magnesium and calcium mineral bed. This adds calcium and magnesium to the water, while also increasing the pH and decreasing the corrosive potential of the water. Corrosive water may leach lead and copper from distribution systems and household water pipes [15].

Ultra-filtration has the following advantages the system operates at a low pressure, removes bacteria and viruses, keeps essential minerals in water, installs quickly and easily, does not generate waste water. An ultrafiltration system is eco-friendly [16]. Ultrafiltration has a 90-95% recovery rate and can be used to treat wastewater for reuse. Using a home ultrafiltration water system benefits the environment by reducing the amount of plastic water bottles discarded in landfills.

Some of the applications of ultrafiltration are in industries such as chemical and pharmaceutical manufacturing, food and beverage processing, and wastewater treatment, employ ultrafiltration in order to recycle flow or add value to later products. Blood dialysis also utilizes ultrafiltration.

The main disadvantage of ultrafiltration is the water from this procedure is not advisable for drinking by either human beings or animals. The reason for this is that the process does not separate soluble and therefore this soluble could be harmful to our health. One chemical that is very soluble in water is pesticides. Hence the need for purifying it.

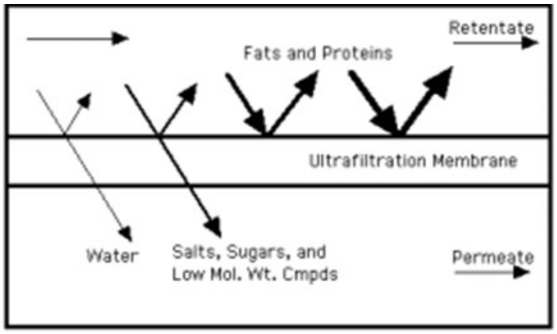


Figure 2-2.2.1 Ultrafiltration

2.2.2 Nanofiltration

Nano-filtration has a pore size range of 0.001-0.01um. Smaller than that used in microfiltration and ultrafiltration, but just larger than that in reverse osmosis. NF membranes can filter particles up to and including some salts, synthetic dies, and sugars, however, it is unable to remove most aqueous salts and metallic ions, as such; NF is generally confined to specialist uses. One of the main advantages of Nano-filtration as a method of softening water is that during the process of retaining calcium and magnesium ions while passing smaller hydrated monovalent ions, filtration is performed without adding extra sodium ions, as used in ion exchangers [17]. A main disadvantage associated with nanotechnology, as with all membrane filter technology, is the cost and maintenance of the membranes used [18].

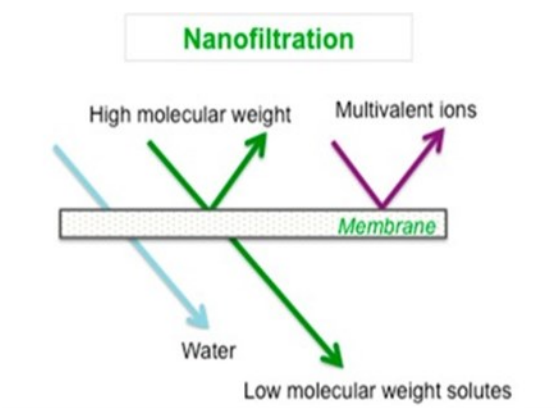


Figure 3-2.2.2 Nano filtration

2.2.3 Microfiltration

The pore size on micro-filtration membranes ranges from 0.1 – 5 ums, and has the largest pore size of the four main membrane types. Its pores are large enough to filter out such things as bacteria, blood cells, flour, talc and many other kinds of fine dust in solution. Because its pores are relatively large compared to other membranes, it can be operated under low pressures and therefore low energy. The main advantage is that the process requires little pressure. The main disadvantage is that there is insufficient quality of the treated water [19].

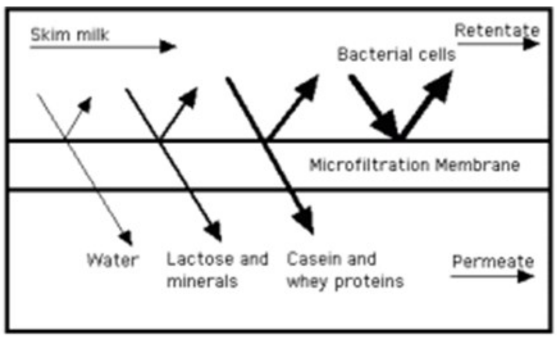


Figure 4-2.2.3 Microfiltration

2.2.4 Reverse osmosis RO

RO has a pore size range of 0.0001 – 0.001. It is by far the finest separation material available to the industry. This purification process removes particles 500,000 times smaller than a diameter of a single strand of a human hair. RO is successfully used for desalination and purification of water (or liquids) as it rejects everything but water molecules, with pore sizes approaching the radius of some atoms in many cases. This pore size means it is the only membrane that can reliably filter out salt and metallic ions from water. The small pore size of RO membranes means that a significant amount of osmotic pressure is required to force purification. Flow rates on RO membranes (36 GPD, 50 GPD, 75 GPD etc.) are limited to certain gallons per day rating. Some systems with high volume per day require pumps or flow restrictors to control volume, water pressure and flow rate within the system for maximum effectiveness [20]. The main advantage of RO is that it is a very effective way of water softening. In fact, it performs two functions, which are; water softening and water purification. It does not allow any particles except the water particles. The main disadvantage of RO is that lot of energy is required for the entire process and the water becomes acidic because it has been deionized of all its mineral content. It is not advisable drinking water from the process because naturally, the water must possess some minerals, which help in the functioning of the body. Hence, the water should be passed again through mineral beds of calcium and magnesium [21].

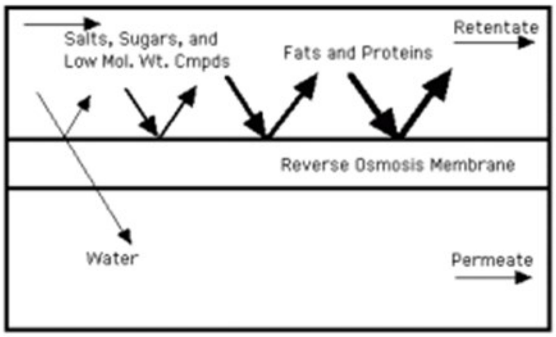


Figure 5-2.2.4 Reverse Osmosis

2.3 UV Purification

2.3.1 UV Disinfection

Ultraviolet (UV) radiation, an electromagnetic radiation with a wavelength from 100nm to 400nm can effectively inactivate various microorganism in water and is increasingly being applied for water disinfection [7].

The effect of UV radiation largely depends on wavelength due to the different energy levels of photons. Thus, the electromagnetic spectrum of UV radiation can be subdivided into different ranges: UVA (315-400) nm, UVB (280-315) nm and UVC (200-280) nm. Although there is UVA radiation in natural sunlight it is inefficient and impractical for disinfection due to its poor absorption by cells of the micro-organisms. In practice UV disinfection mostly relies on the artificial UV sources emitting UVC or UVB radiation. The shortest wavelength of UV radiation (UV-C) poses the maximum risk to disease causing microorganisms. This is considered the germicidal UV wavelength range.

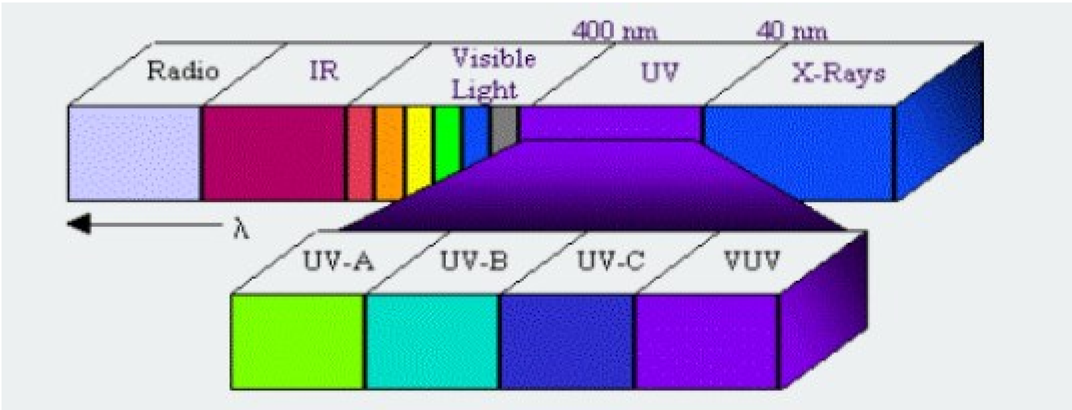


Figure 6-2.3.1 UV-C in spectrum of Electromagnetic radiation

The main UV sources for current UV disinfection systems are low or medium pressure mercury lamps [8]. Low pressure mercury lamps emit nearly monochromatic UV radiation with the peak wavelength at 254nm which is close to DNA absorption peak at around 260nm [13]. The UV radiation from the mercury lamps is strongly absorbed by the DNA of microorganisms leading to direct DNA damage by making them unable to reproduce.

Medium pressure mercury lamps MP emit a polychromatic spectrum with various wavelengths from UVC to UVA and visible light and have a much higher output than their low-pressure counterparts. Therefore, they disinfect water faster and have a greater penetration capability as compared to LP lamps.

All though these lamps are widely used for treatment there are still many issues with them. These lamps are very fragile and since they contain toxic mercury which is hazardous when improperly disposed [8]. UV lamps use a considerable amount of energy to operate with plug efficiency at around 15-35 % and have short lifetime of about 10,000 hours [9] [10].

2.3.2 Germicidal effect

UV-C radiation is considered germicidal and is gotten from mercury lamps and UV LEDs. UV-C effectively kills airborne pathogens, surface and water living bacteria, viruses and other cysts forms. Low doses of radiation may not produce any adverse effects on cells. The intensity of UV radiation is measured in the units of millijoules per square centimeters mJ/cm^2. For effective disinfection high intensity of radiation and longer exposure times is necessary.

Some viruses are resistant to conventional chlorination which can be effectively destroyed by UV radiation.

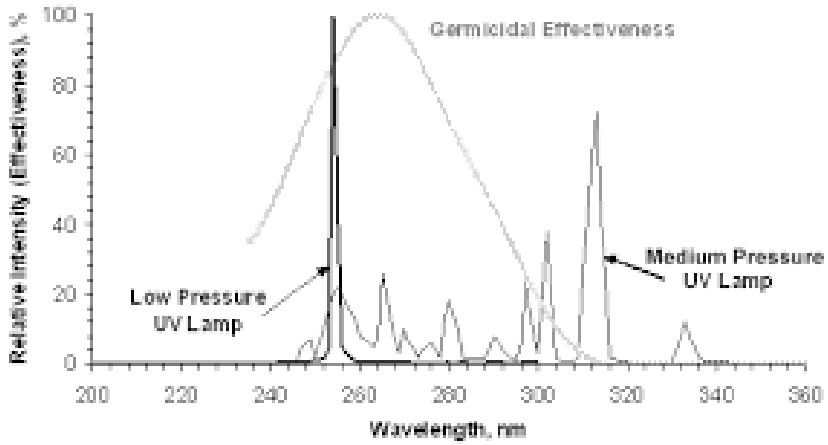


Figure 7-2.3.2 Germicidal effectiveness of UV lamps

The effectiveness of UV light on microorganism inactivation varies with different types of microorganisms. Generally, UV resistance by the microorganisms appears to follow microorganism size with the smallest microorganism being the most resistant. This is due to amount of UV light absorption per cell. Because viruses are the most resistant to UV disinfection dosing is controlled by log inactivation requirements of viruses.

The table below describes the UV dosage required to destroy the microorganism.

Table 2-2.3.2 UV Dosage requirements for microorganism's inactivation

Micro organisms	**Dosage of ultra-violet radiation (UV dose) in mW sec/cm^2 needed to kill the selected microorganism.**	
Bacteria	**90% (1 log reduction)**	**99% (2 log reduction)**
Bacillus subtilis	5.8	11
Escherichia coli	3	6.6
Pseudomonas aeruginosa	5.5	10.5
Pseudomonas fluorescens	3.5	6.6
Salmonella enteritidis	4	7.6
Salmonella paratyphi-enteric fever	3.2	6.1
Salmonella typhosa-typhoid fever	2.1	4.1
Salmonella typhimurium	8	15.2
Sarcina lutea	19.7	26.4

Shigella dysenteriae-dysentery	2.2	4.2
Shigella flexneri-dysentery	1.7	3.4
Shigella paradysenteriae	1.68	3.4
Staphylococcus aerus	2.6	6.6
Vibrio comma- cholera	3.4	6.5
Virus	90%	99%
Bacteriophage-E. coli	2.6	6.6
Infectious hepatitis	5.8	8
Poliovirus-poliomyelitis	3.15	6.6

2.3.3 LED Advantages

Recently with the development of semiconductor technology UV light emitting have emerged as new source to generate UV radiation. A LED is a semiconductor device that utilizes semiconductor materials p-type and n-type. The p for "positive" type contains excess holes while n type(negative) excess electrons. With a suitable voltage applied to a p-n junction electrons and holes recombine at the junction to emit radiation whose radiation depends on semiconductor materials. The most common lads are visible LEDs for lighting which are increasingly used because of higher efficiency and lower cost.

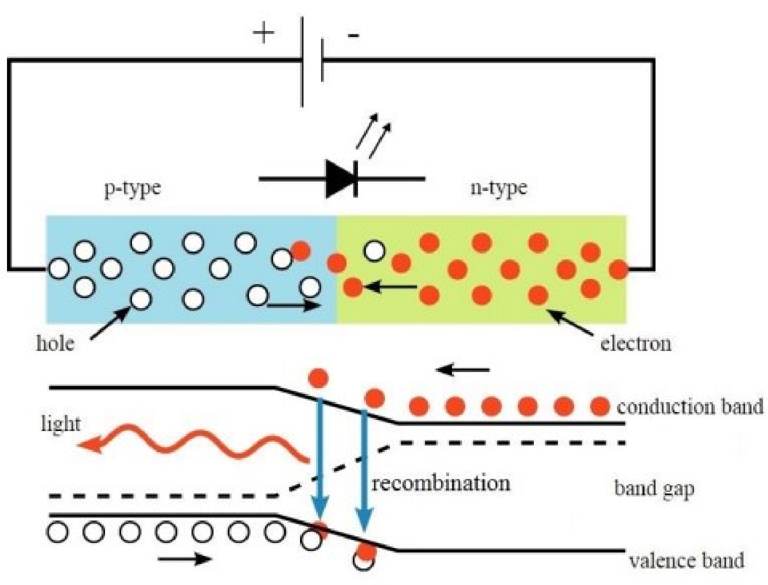


Figure 8-2.3.3 The circuit (top) and band diagram (bottom) on how an LED works

UV LEDs at various wavelengths can be manufactured using different semi-conductor materials. Mostly they are made using III-nitride, gallium nitride (GaN) and aluminum nitride (AIN) [11]. The wavelengths of UV-LEDs vary leading to its classifications. UVA range lies within 315-400nm, UV-C range is 200-280nm which is the shortest range among semiconductors [12].

The ability of UV-LEDs to offer a great variety of wavelengths is well aligned with need for efficient disinfection making it a potential option. UV LEDs can be designed to emit various wavelengths and offer the possibility to select a particular wavelength targeting a specific pathogen of concern. Since wavelengths of UV- LEDs can be customized polychromatic radiation can be easily achieved by the combination of UV-LEDs with the desired wavelengths. This provides an opportunity to construct the potentially optimal spectrum for more effective inactivation of target microorganisms.

UV-LEDs are semiconductor based enabling them to respond to electricity instantaneously. Pulsed radiation can be easily produced by connecting a pulse generator to the UV-LEDs and applying pulse voltage to turn on and off. Adjusting the duty cycle and different frequencies leads to improved inactivation as compared to continuous radiation [14].

2.4 Solar as a source of energy

Solar energy can be a major source of power. Solar is a renewable and efficient source that has no emissions. Its potential is 178 billion MW which is about 20,000 times the world's demands. Sun energy can be utilized as either thermal or photovoltaics'. The energy radiated by the sun on a bright day us approximately 1kw/m2, which can be used in driving the prime movers for the purpose of generation of electrical energy. Applications where solar energy is used include solar water heater and solar cookers.

In this project solar energy is being collected using a solar panel and through the solar controller to charge the battery. The collected solar energy is being stored in the battery. In cases of rural and remote areas without access to electricity, this stored energy can be used to run the solar powered water purification system.

CHAPTER THREE

3. METHODOLOGY

3.1 Design specifications of the water purifier

The solar-based water purifier has the following specifications

- Solar powered with a solar panel and battery. This provides the required electrical energy to power the ultra-violet LED.
- Control unit that houses electronic devices and microcontroller that initiates and controls the entire process.
- Two stages ultrafiltration filter with a pump that provides sufficient pressure for the filtration to take place on the filtration membrane.
- Uses ultra-violet LEDs in the ultra-violet chamber to provide for UV- disinfection enabling the purification of water for drinking purposes.
- Two raw water tanks with a sieve joined in between them. The first tank houses the dirty water that has large particles and has not gone through the sieve. The second tank houses dirty water that has passed through the sieve hence its free from large particles.
- A clean water tank with a pump that pumps water from the UV-C chamber to the tank for storing the purified water. Which is then dispensed for drinking.

3.2 Components of the Solar water purifier

Considering the necessary requirements, the following are the main components of the system:

- Two Ultrafiltration filters.
- Two water pumps (a submersible pump and an in-line pump).
- Three Ultra-violet LED
- Two Relays
- Microcontroller
- Three water tanks (two raw water tanks and one clean water tank).
- Dispenser.
- Solar panel

- Battery
- Flow meter
- Metallic frame that supports the entire system.

3.2.1 Ultrafiltration filters

This unit carries out the filtration process in order to filter out suspended particles in the water. It was done in two stages for maximum filtration to take place. Dirty water is pumped to the first filter then passes through the second filter for extra filtration to take place.

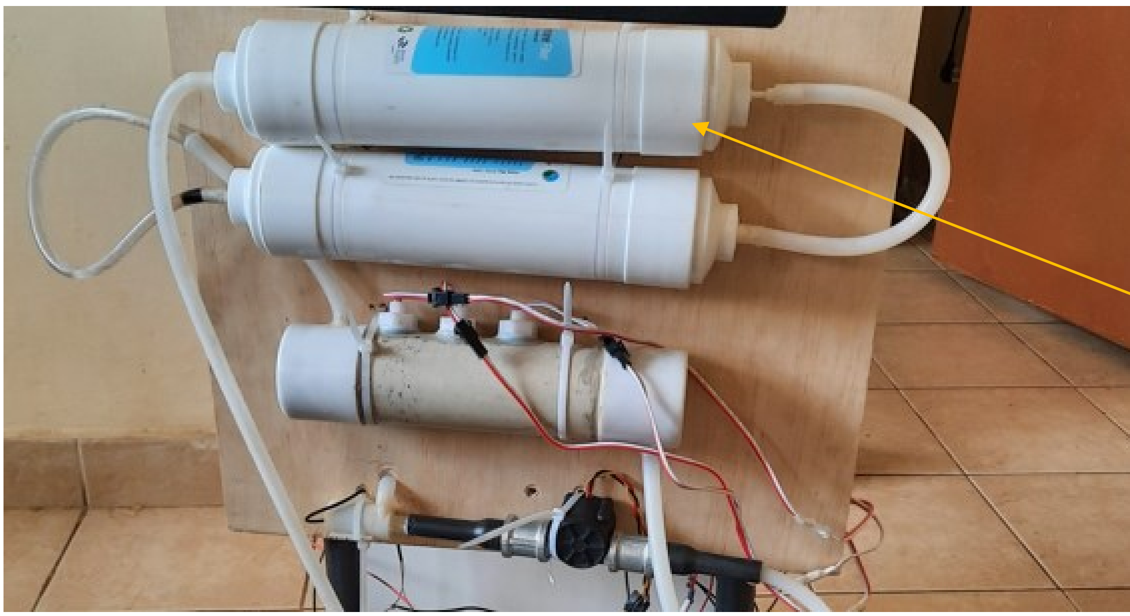


Figure 9-3.2.1 Ultrafiltration filter

3.2.2 Submersible Water pump

This pump is inside the second raw water tank and provides the necessary pressure to force water across the ultrafilter membrane.

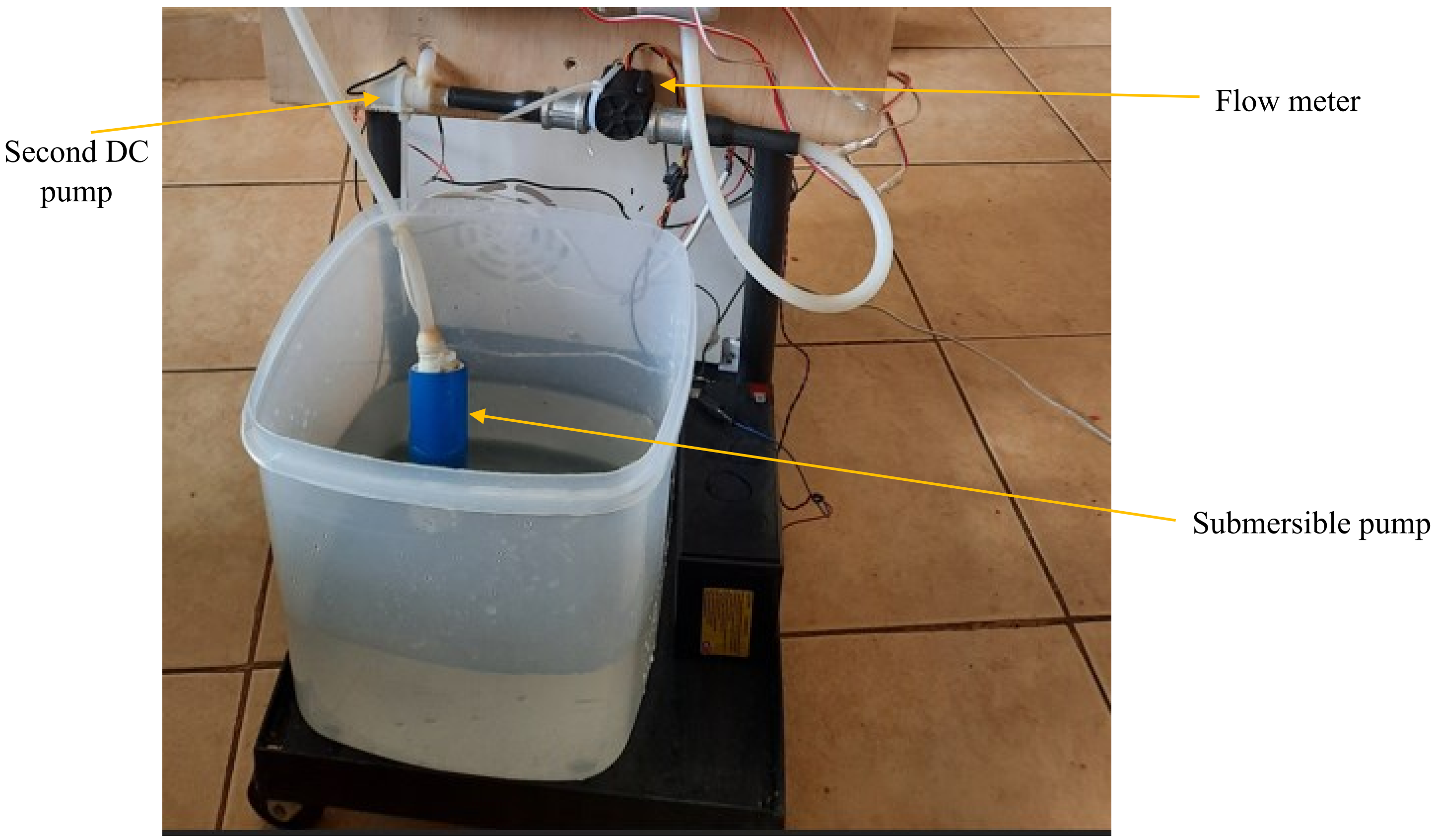


Figure 10-3.2.2 Submersible pump

3.2.3 UV-C LED

This is a semiconductor-based LED that produces radiation in the UV-C range when powered. The emitted radiation was used to disinfect the water. The three UV-LEDs each are rated at 40mA, 12V and 3mW power output at wavelength of 270-285nm. It has a 10000hrs life span.

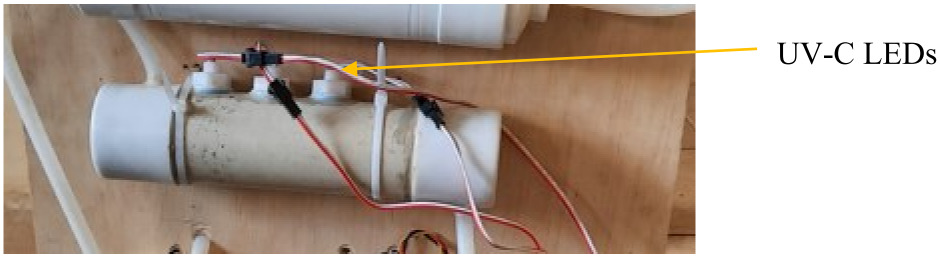


Figure 11-3.2.3 UV-C LED chamber

The three LEDs are housed in the UV-C Chamber.

3.3 Design of UV-C chamber

The placement of UV-LEDs within the chamber depends on both how far the LED is from the radiation surface. As the LED moves away from the target, the intensity of the resulting UV-C light decreases.

The intensity of the UV-C power is inversely proportional to the distance between the LED and the target object.

UV dose = irradiance x time

For most UV LEDs they are rated at 5mm irradiation distance for 10 seconds to 60 mins

Validity of 1/r2 law is valid for all case that lateral dimension dx and dy of the spot light source are far much smaller than r: dx << r and dy << r

In our case diameter or pipe is far much smaller than length of pipe

$$1/_{r^2}\ law$$

The further away the light source is the lesser the intensity

$$intensity = \frac{radiation\ output\ W/m2}{1/_{r^2}}$$

Conversion metric **1mW/cm2 = 10W/m2**

Since we are targeting e-coli we need radiation output of 6mWsec/cm2 = 6mW = 60W/m2

Our radiation from 3 UV-LEDs is 90W/m2 but we need to achieve 60W/m2 at a given radiation distance r (how much distance the UV-light travels).

$$\frac{90W/m2}{\frac{1}{r}^{2}} = 60W/m2$$

$$r = 0.81m$$

Since r is quite large, we can approx. to 0.5m = 50cm so that light travels lesser distance so intensity increases.

Also remember 6mWsec -> 1 cm2 for E-coli

Assuming we use a steel pipe with radius 1.5cm

Total area of contact of UV radiation on the pipe = circumference of pipe x length (radiation distance)

$$total\ area\ of\ contact = 2\pi * 1.5 * 50cm = 470cm2$$

But for the LED 6mW –> 1 sec –> 1cm2

So, for 470cm2 we will need $\frac{470}{9} * 6 = 300\ seconds \rightarrow approx\ to\ 5min$

The total volume of water in this chamber = $\pi * 1.5^2 * 50 = 350cm3$

The maximum flow rate to ensure that all the water in UV chamber with volume of 700cm3 will be

$$\frac{350cm3}{5mins} = 0.07Litres\ per \min = 4.2\ L/hour$$

Any other flow rate Less than 4L/hour will increase time of exposure hence it can work, but not greater than 4L/Hour.

3.4 Control Mechanism

For the control process we used a SIM900L microcontroller. The microcontroller controls the switching of the pump as well as the powering of the UV-LED.

3.4.1 Block diagram

We used a 10W solar panel for getting electrical supply which is the fed to charge controller which charges the battery up to 12V. There's a voltage regulator in the circuit which ensures there's stability of input voltage in the circuit, the supply from the battery is fed to the pump. The entire process is being controlled by the microcontroller. The relay acts a switch for opening and closing the circuit so that the water is purified only upon demand. The input water in the raw water tank was fed to the ultrafilter, using the pump, which removes particles. The water is then fed into the UV-C chamber which kill bacteria form in the water and then pumped to the clean water tank and we get purified water upon dispensing.

The block diagram for solar power water purification and filtration filter is given below in Fig 12-3.4.1 (a).

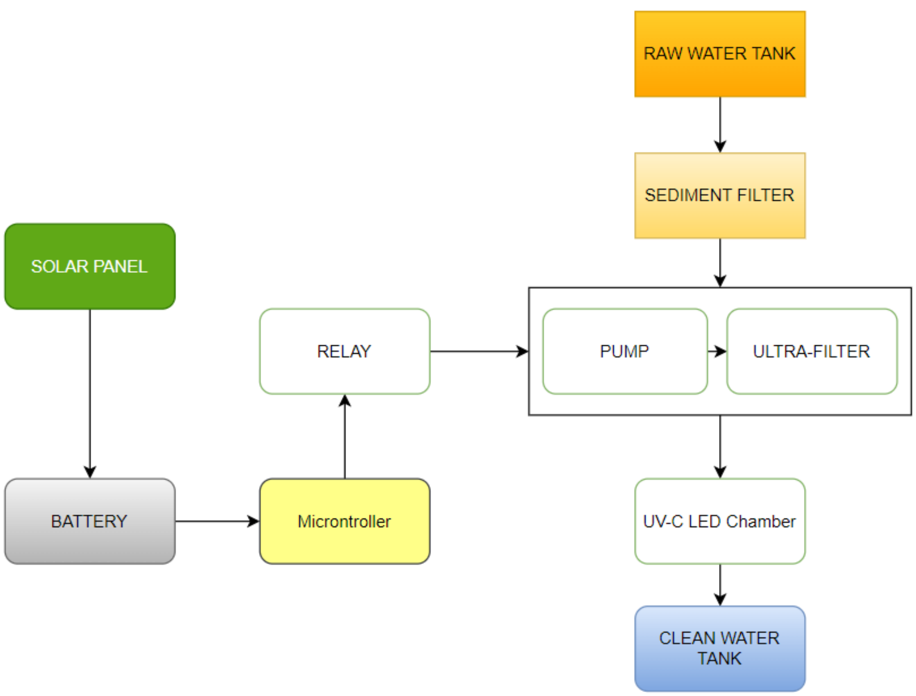
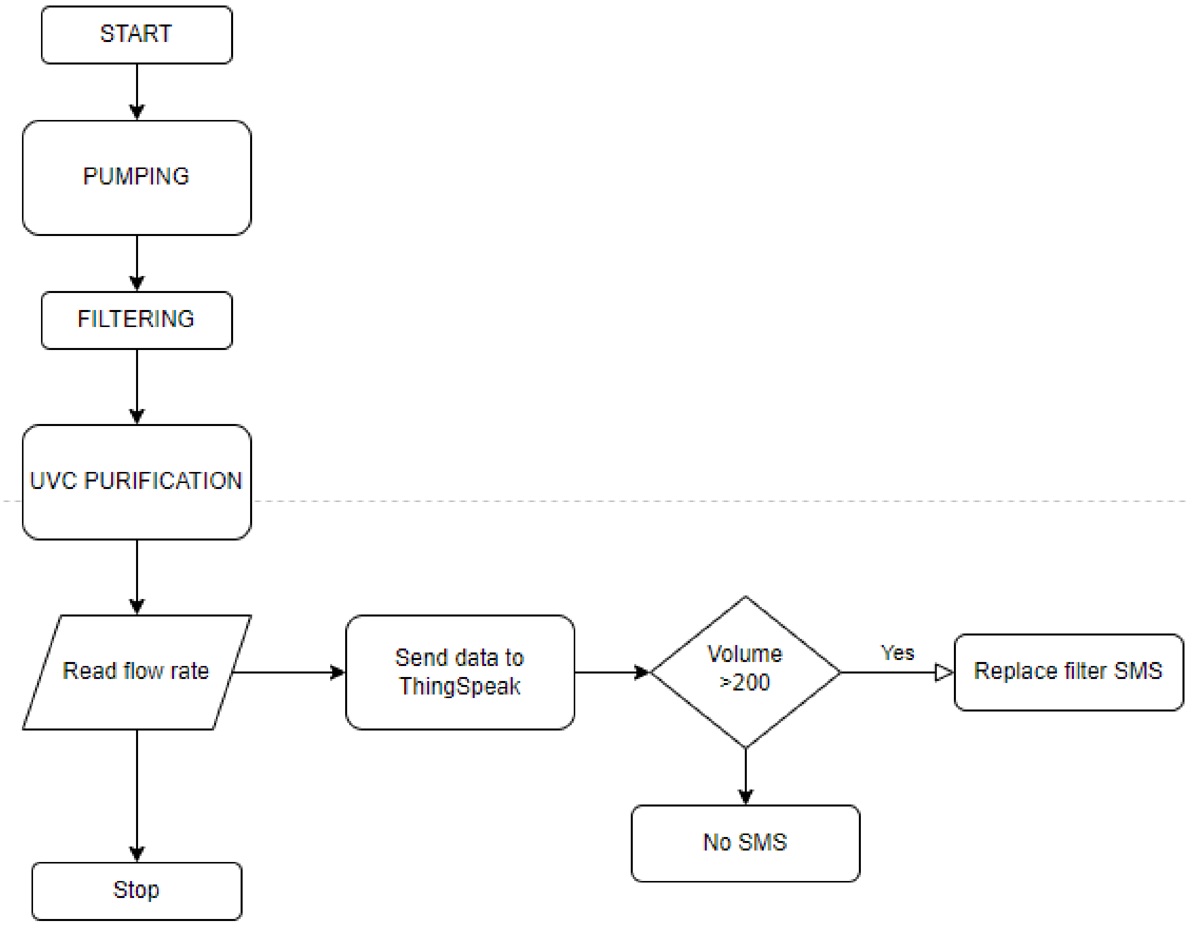


Figure 12-3.4.1 (a) Block diagram

The Fig 13-3.4.1(b) below shows flow chart of the whole system.



The overall process controlled by microcontroller is described in Fig 14-3.4.1 (c) below:

Figure 13-3.4.1 (b) Flow chart

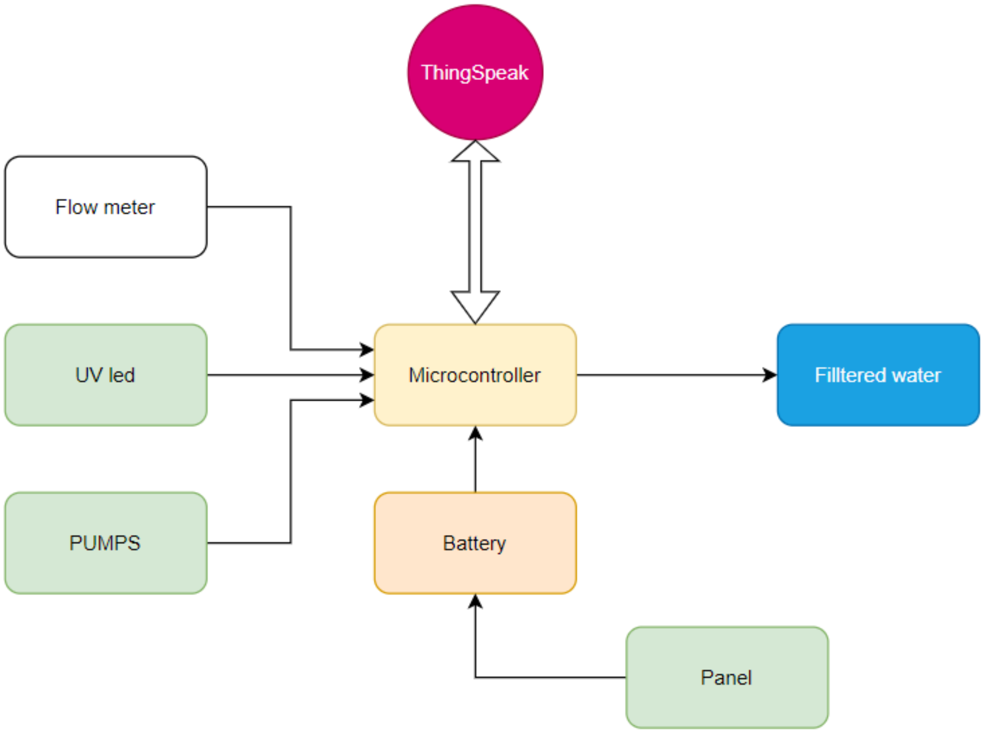


Figure 14-3.4.1 (c) Overall operation

3.5 Microcontroller

T-Call sim800L esp32 board is a microcontroller board with Bluetooth, Wi-Fi, SMS and connect to internet using data Plan on the sim card.

Figure 15-3.5 SIM800L Microcontroller

This microcontroller has an inbuilt Nano sim card connection and has a power requirement of 5V via USB-C or 3.3V via 3.3V pin. The microcontroller can be programmed via Arduino ide to control the purification process.

3.6 Water filtration and purification process

The process flow diagram for the purification process is given below in Fig.15-3.6

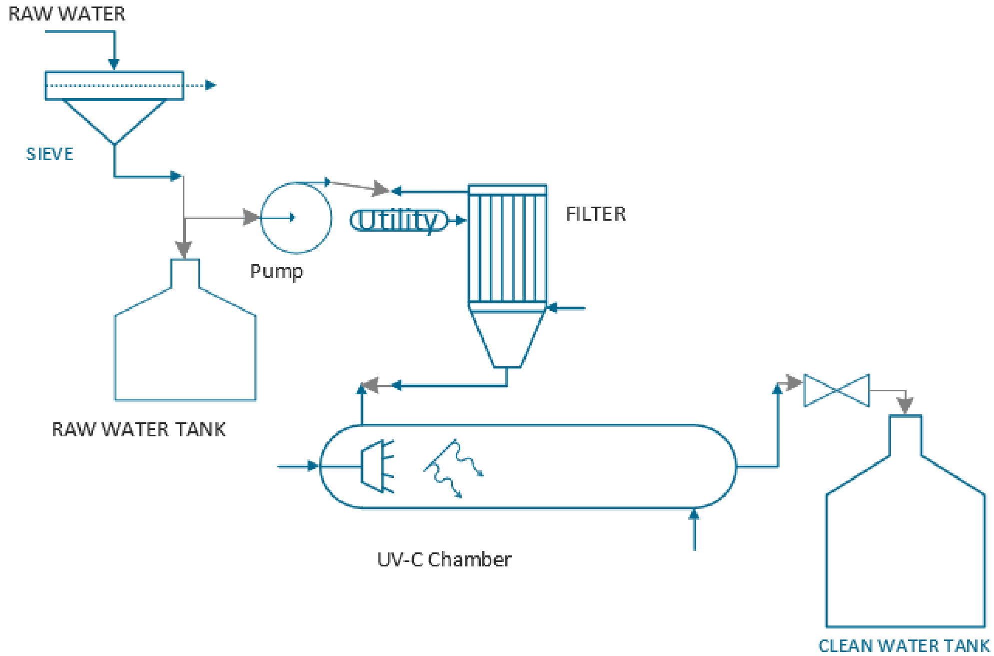


Figure 16-3.6 Process Flow diagram

People fetch water from a cloudy water source using a water container. The water is then poured into the first storage container of our device. It is pre-filtered using the sieve attached in between the two containers. It then settles in the second container ready to be pumped to the first ultra-filter membrane. The user presses the push button in the control unit box to initiate the purification process. The microcontroller then turns on the submersible pump, which in turn pushes water across the first ultrafiltration membrane. The water flows through a pipe into the second ultrafiltration membrane, which is further filtered. Water flows through the pipe into the UV LED chamber for purification. There is an in-line pump across the pipe that is fitted between the UV chamber and clean water tank. It pumps water from the UV chamber into the clean water tank which is then dispensed for drinking.

The dirty water undergoes three processes as shown in the table below;

Table 3-3.6 Water Treatment stages

Pre-treatment	Sediment filter which removes dirt, and solid particles
Main-treatment	Two Ultrafiltration membrane filters each of pore size 0.01 micron. Removes bacteria (E. Coli which can cause diarrhea, urinary tract infections, respiratory illness, pneumonia and other illnesses.), protozoa and some viruses
Post-treatment	Ultraviolet light from LEDs. This further eliminates bacteria, viruses and protozoa (like giardia lamblia cysts which cause stomach bloating, nausea and diarrhea) from the water.

3.6.1 System layout design

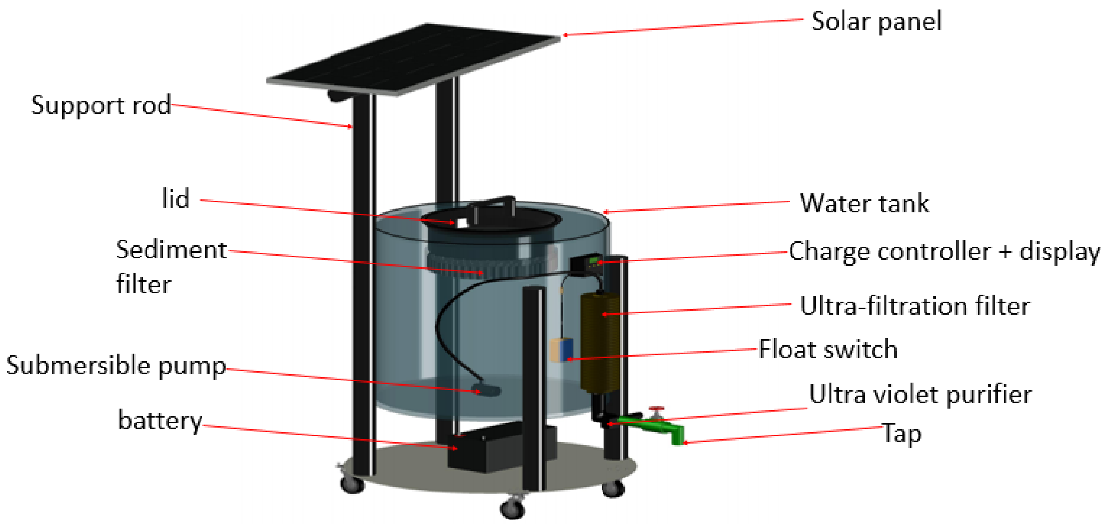


Figure 17- 3.6.1 Design layout

3.7 Power ratings and calculations

Led each is 3mW = 9mW

5V pump at 0.2A = 1W

12V pump at 1A = 12W

Controller 5v 30mA = 150mW

Total load: 14W

Battery rated at 7Ah 12V

Assuming 90% efficiency: $\frac{12 \times 7Ah \times .9}{14} = 5.4\ hours$

The unit can run for around 5hours dispensing water while on battery supply.

Maximum pressure = 120psi

Amount of time required to expose the cloudy water to UV-c rays is 3min in order to obtain a 3log10 reduction of coliform bacteria.

3.8 Circuit design

A layout of the circuit was designed using KiCAD.

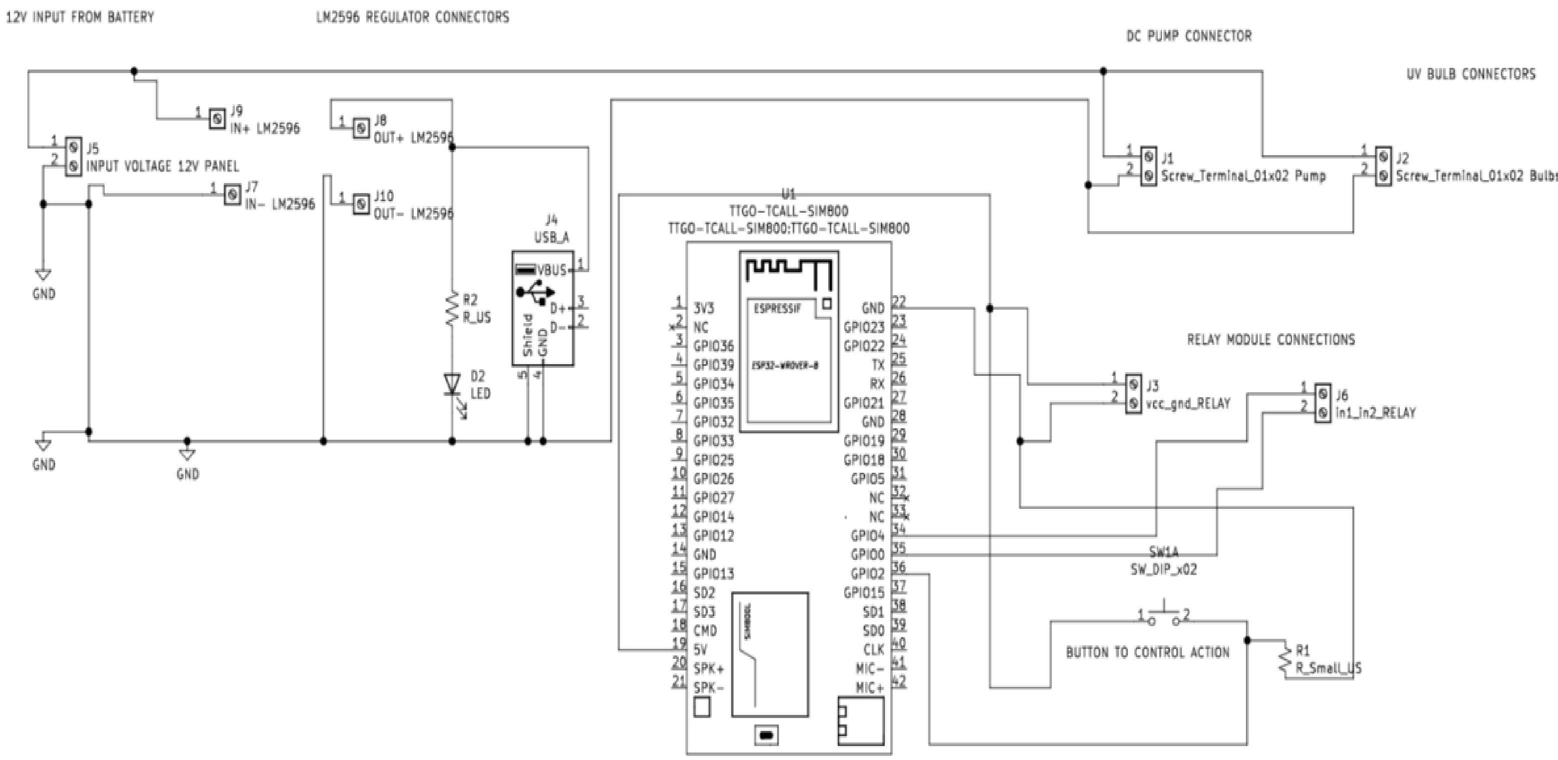


Figure 18-3.8 Circuit design

3.9 PCB design

After the circuit was functional from the breadboard a PCB was designed using KiCAD. The component footprints were installed and actual traces were created and run. The design was then printed on paper and transferred to the copper board after which it was etched.

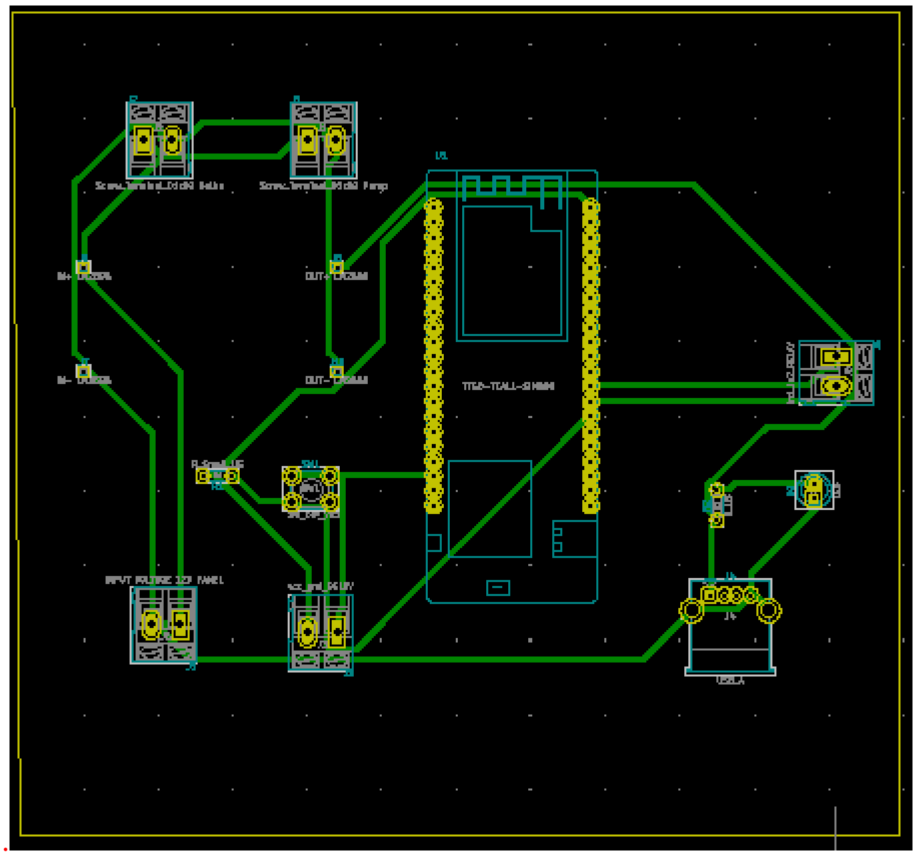


Figure 19- 3.9 PCB layout

We designed a layout of the circuit using KiCAD. After the circuit was functional from the breadboard a PCB, layout was designed using KiCAD. The layout was printed out using the laser printer and the A4 glossy paper. The copper board was cut according to the size of the layout. The copper side of the PCB was rubbed using steel wool; this removed the top oxide layer of copper as well as the photo resists layer. The copper surface of the board was placed on the printed layout. And tape was put along the two sides of the non-copper side of the board. This helped to hold the board and the printed layout in position. An electronic iron was heated to maximum temperature and the image on the glossy paper was ironed down to the copper side. This was done for around 7 minutes. After ironing, the printed plate was placed in Luke warm water for around 10 minutes. The paper got dissolved and it was gently removed. Some of the tracks got fainted while removing the paper hence a white chalk was used to highlight the tracks. A plastic container was filled up with some water. Two teaspoons of ferric chloride powder was dissolved in the water. The PCB was dipped into the etching solution for around 30 minutes. The etchant reacted with the unmasked copper and removed the unwanted copper from the PCB. Pliers was used to take out the PCB from the solution. The PCB was dried with a clean cloth.

Actual fabrication of the PCB was implemented as shown below in Figure 20-3.9.

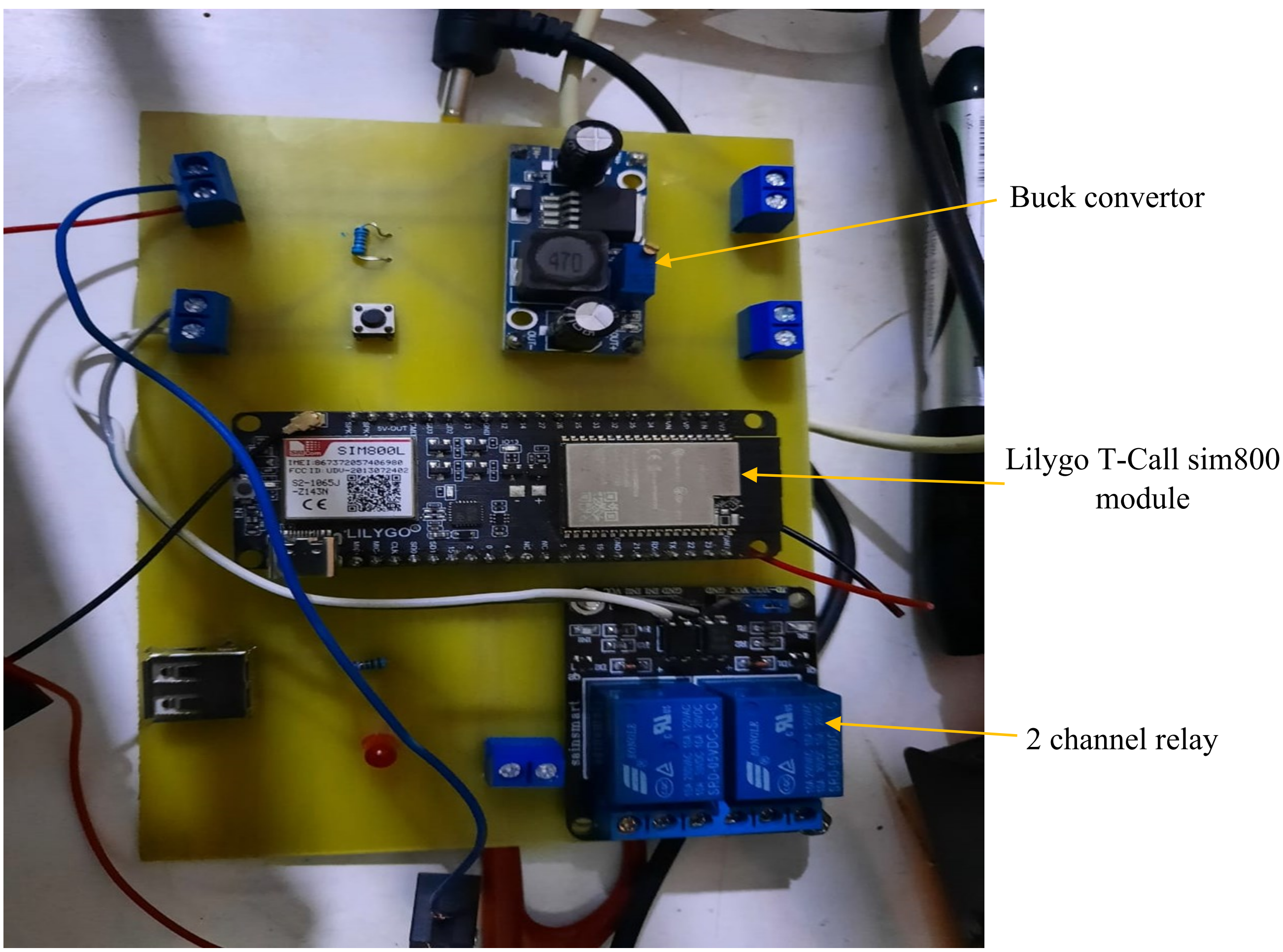


Figure 20-3.9 Actual PCB mounted

3.10 Assembly

After designing the model. All the components and materials were purchased. Wires were soldered onto the pin 14 and 0 of the microcontroller that would be connected to the relay pins. The relays and microcontroller were fixed on top of the PCB. The PCB was housed inside a pattress box that has a push button. Metallic rods were cut into specific dimensions and the metallic frame for supporting the entire system was built. A wooden frame was mounted in between the rods of the metallic frame. The two filters and UV-C chamber were mounted on it and were interconnected with rubber pipes. A circular shape was cut at the bottom of the first raw water tank and the pre-filter was mounted then it was placed on top of the second water tank. The submersible water pump was placed inside the second water tank and a small hole was drilled on the side that allows the passage of the pipe that connects the raw water tank and the first ultra-filter. The two tanks were now placed on the metallic frame. The in-line pump was mounted on the wooden frame and a pipe was connected in between the UV-C chamber and the pump. A hole was drilled on the clean water tank and a pipe was connected from the in-line pump to the clean tank to bring in clean water. The tank was placed on top of a dispenser. The solar panel was placed at the top most part of the metallic frame and the battery was placed at the bottom just next to the tanks.

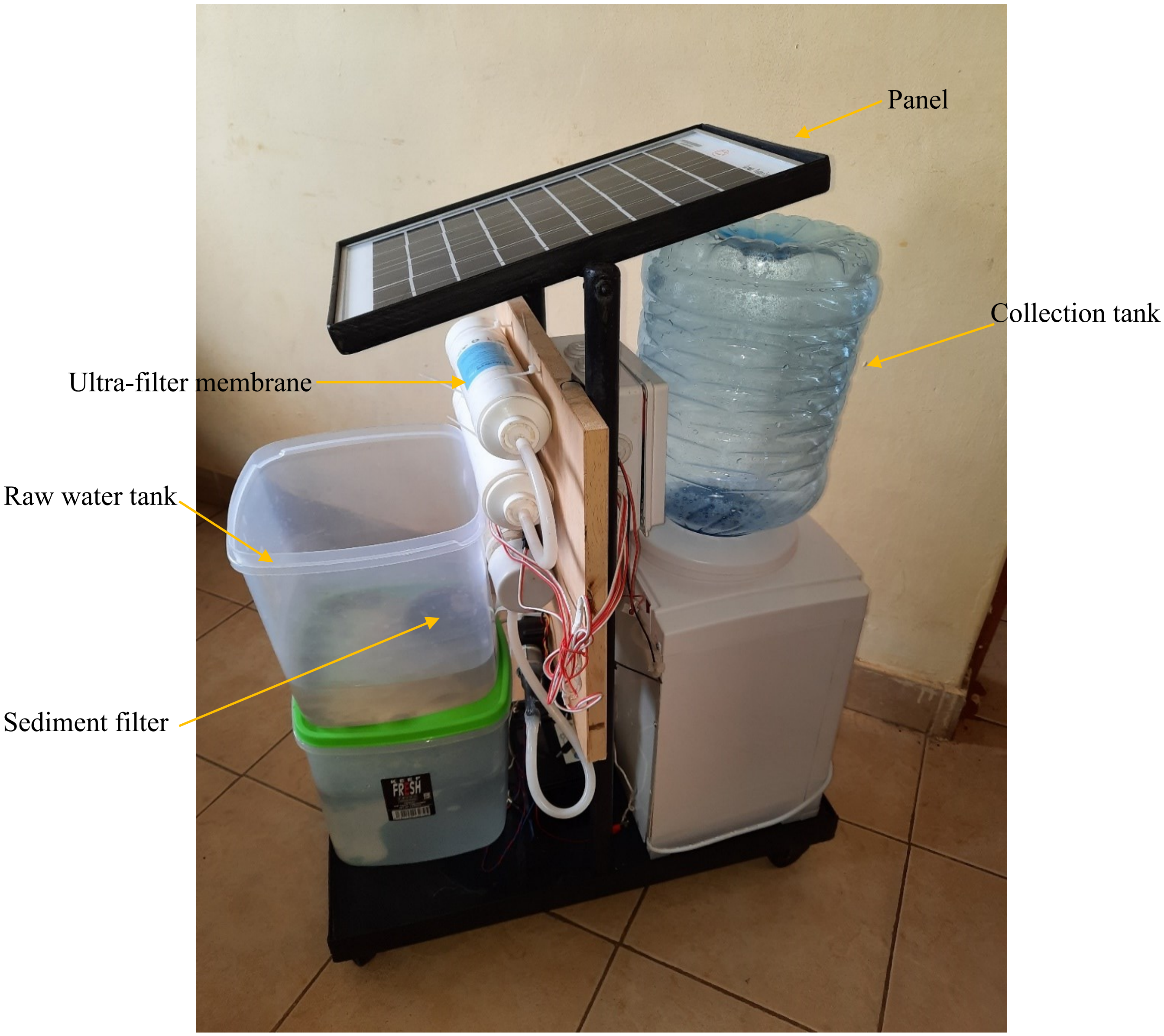


Figure 21-3.10 (a) Sideview

Figure 22- 3.10 (b) Front view

CHAPTER FOUR

4. RESULTS

4.1 Prototype

A working prototype of the solar powered water filtration and purification system was constructed.

4.2 Purified water

The system was able to filter and purify dirty water and make it suitable for drinking. According to our prototype, the flow rate was found to be 0.4L/min thereby dispensing around 20L per hour of continuous operation.

The water was filtered and is shown in Figure 24-4.2 below.

Figure 23-4.2 Water before and after filtration

4.3 Flow statistics

Using the micro-controller, the flow data was sent to ThingSpeak via cellular data where it was analyzed. The average flow rate was found to be 0.4L per min that translates to around 20L per hour on continuous operation.

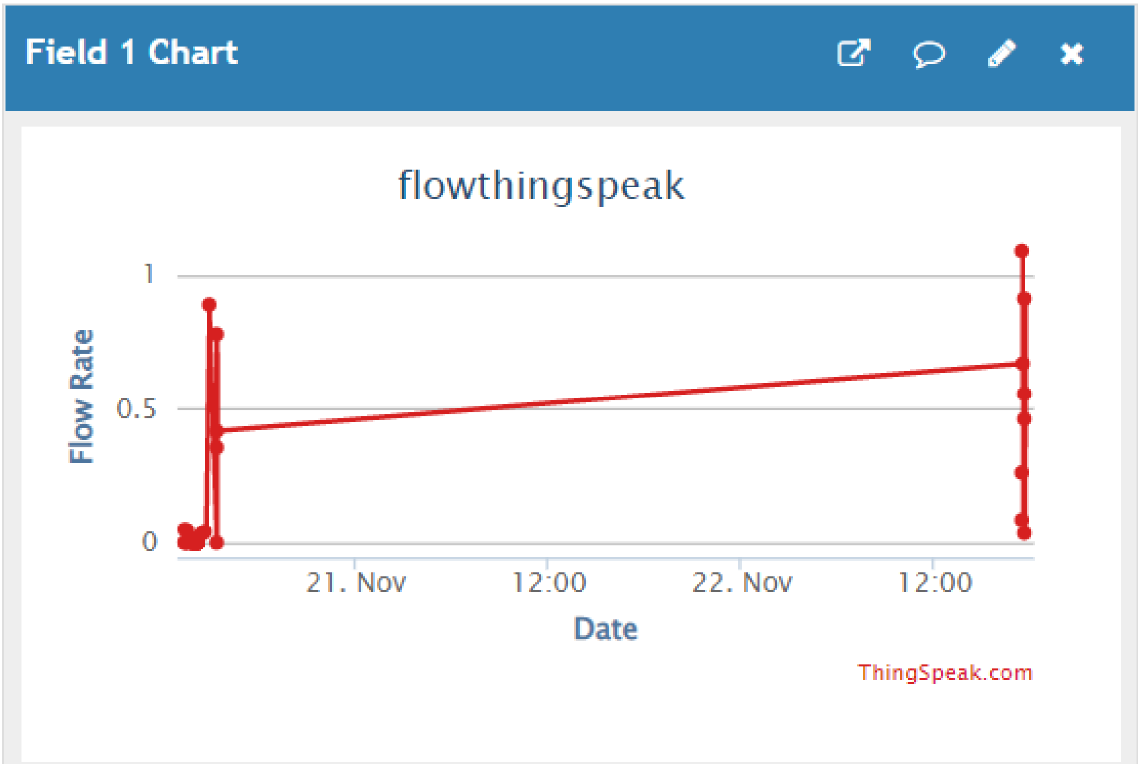


Figure 24-4.3 Flow rate statistics

The amount of purified water will depend on the usage of water by the user. With the volume of water purified being updated to ThingSpeak, a reminder to the user to change the filter upon exceeding filtration set limits was implemented via SMS. The total volume of purified water was visualized in real time from ThingSpeak channel as shown below.

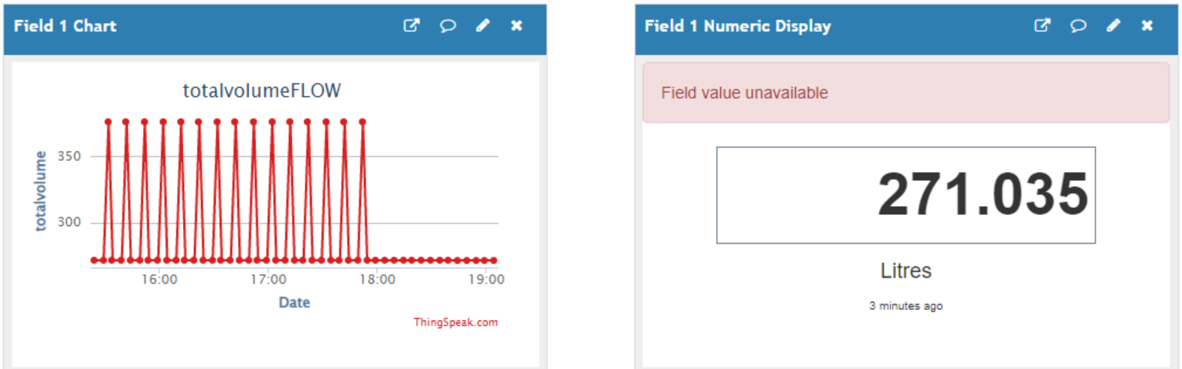


Figure 26-4.3 Sampled volume of water purified

For demonstration purposes, the water purifier limit was set to 200 liters and would trigger an SMS to the user to change the filter periodically. This notification is of importance as it ensures the filters do not exceed their rated lifetime making them ineffective in filtration.

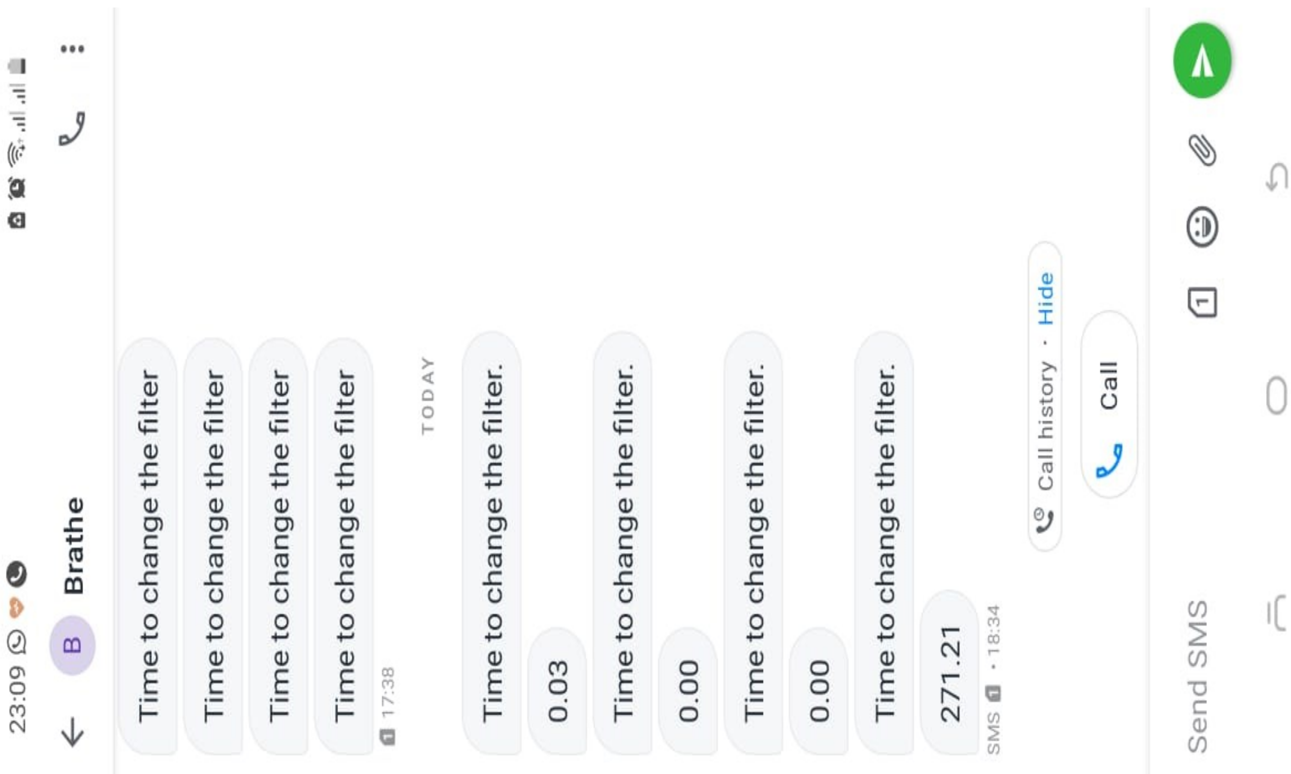


Figure 25 4.3 Reminder to change filter via SMS

4.4 Power consumption

The water filtration and purification unit runs on battery and can run for 5 hours of continuous operation. This allows for the device to be accessed without the need of connection to the electrical grid.

CHAPTER FIVE

5 RECOMMENDATION AND CONCLUSION

A working prototype of a solar powered water filtration and purification unit was successfully constructed. The dispensed water was suitable for drinking.

5.1 Challenges faced

- The assembled prototype was bulky than expected though it has wheels, it will be tiresome for a user to push it for long distances.
- COVID-19 has been the major challenge during the implementation phase of the project leading to delays in shipping and delivery of some of the components.
- Numerous wires on the control unit box made the prototype less appealing and unfortunately, there was no way to eliminate them since they were necessary.
- The pre-filter did not filter as expected hence most filtration was done by the ultrafilter.
- The microcontroller malfunctioned in the cause of testing the prototype hence we had to purchase another one within a short period.
- Diameter differences between the pipes and flow meter posed a challenge during fabrication.

5.2 Recommendations

- Use material that are lighter in weight to reduce bulkiness.
- Use a bio-filter for pre-filtration to ensure first stage filtration is done as expected.
- Read the data sheet comprehensively and do more research on the microcontroller to ensure you use the right pins to avoid shorting of the device.
- Use shorter wires instead of long ones to make the circuit more appealing.
- Consider and verify component diameters with actual pipe diameters in the market to ensure smooth interconnection.

5.3 Conclusion

The construction of water filtration and purification unit can really help in improving access to clean water. With the use of solar energy, it makes the project cheaper and suitable to be used in remote locations. The unit is also portable, compact and robust.

Additionally with the integration of GPRS through sim card water usage statistics as well as reminders on when to service the filters can be timely issued to the users of the water purification unit.

DIVISION OF ROLES

<table>
<tr><td>JOSEPHINE TARIYA

ENE 212-0073/2016</td><td>CHARLES KARIRA

ENE 212-0267/2016</td></tr>
<tr><td>Final report</td><td></td></tr>
<tr><td>Literature Review – Ultrafiltration.
Microcontroller research and implementation.
Chapter 3</td><td>Literature Review – UV Disinfection.
Design calculations of UV Chamber.
Pump design, flow rates and integration

Chapter 4 and 5</td></tr>
<tr><td>Implementation</td><td></td></tr>
<tr><td>1. Fabrication of two raw water tanks with the sediment filter
2. Design of electrical circuit and PCB
3. ThingSpeak integration with microcontroller</td><td>1. Fabrication of the UV-C chamber and piping
2. Hardware implementation of the electrical circuit
3. Microcontroller programming</td></tr>
</table>

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BUDGET

Item	Description	Quantity	Rate	Amount
1	Ultrafiltration filter	2	833	1666
2	Water tank	3	500	1500
3	5V Dc pump	1	600	600
4	12v Submersible Dc pump	1	3000	3000
5	Solar panel	1	3000	3000
6	UV-C LED	3	1200	3600
7	Battery charger	1	1000	1000
8	Battery	1	3000	3000
9	Microcontroller	1	4000	4000
10	Metallic sheets	1	3000	3000
11	Pre-filter	1	1300	1300
12	Relay	1	500	500
13	PCB and etching	1	2000	2000
14	Flow meter	1	800	800
15	Wooden block	1	1000	1000
16	Buck Convertor	1	300	300
17	Water dispenser	1	2000	2000
18	Jumper and wires	10	25	250
19	Miscellaneous			3600
TOTAL				36116

TIME PLAN FOR YEAR 2021

ACTIVITIES	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Documentation								
Proposal Writing								
Literature Review								
Proposal Presentation								
Design and coding								
Hardware configuration, testing and adjustment								
Final Report writing								
Final Presentation								

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