Portable Water Purification System using Electrodialysis Reversal

Ira C. Valenzuela and Ronnie O. Serfa Juan

***Abstract* - The quality of drinking water is one of the factors that people consider before drinking it. Water is usually exposed to various organic and inorganic substances that are possibly harmful to one's health. The main objective of this study is to develop a water purification system using electrodialysis reversal that can be carried in remote or rural areas and can be powered either by AC supply or solar energy. This system provides an easy way to treat brackish water by using electrodes and current to mitigate the impurities, including the bacteria present in the contaminated water. It is mainly composed of the power supply, photovoltaic cell, battery, treatment and test tanks, electrodes, carbon and resin filters, LCD display, numeric keypad and microcontroller. Three (3) microbiological tests are performed to determine the quality of water produced namely: fecal coliform, total coliform test and heterotrophic plate count test. Through a series of experiments with the support of an accredited Department of Health (DOH) water testing laboratory, it is proven that an hour of treatment is enough to produce five (5) gallons of potable water.**

***Index Terms*: electrodialysis reversal, mobile water purifier, solar power, potable water**

I. Introduction

The surface of earth is comprised of about 70.9% of water [1]. Odorless, tasteless, and clear liquid are the characteristics of a pure water that is essential for mankind. Water also conttributes to good health because it is needed for the digestion and absorption of food. It also helps for proper toning of muscles, for supplying oxygen and nutrients to the cell, and for serving as a natural air conditioning system which is why the health personnel recommends drinking eight glasses of water daily.

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Drinking water is classified as potable water which is fit for consumption by human. Usually, water is naturally potable if it comes from unspoiled sources. But if one is not sure if the water is safe for drinking, laboratory tests should be done to see if there are contaminants present in the water.

There are people who drink water from inadequate sources due to desperation. Contaminated sources of drinking water which contains high level of pathogens and heavy metals are the main cause of illnesses and high risk of death. Water might contain unacceptable level of toxins since it is known for being a universal solvent. Drinking unsafe water is one of the world's major problems.

Several studies regarding water purification have been conducted to develop new water treatment techniques and methods that can provide clean drinking water to people living in remote areas such as Proportional-Integral-Derivative (PID) Control, Microwave Plasma UV Lamp, vacuum filtration, electric discharge and packed bed reactor. PID Control helps in regulating the pH of water, the clarity and the presence of micro-organisms in water [2]. Microwave Plasma UV Lamp emits light which destructs most waterborne bacteria and viruses. Conventional lamps are limited to a maximum output power of 30W per meter while MPUVL can deliver any amount of power per unit length and tube can any be of any shape, length, or diameter [3]. Two-dimensional graphene oxide (GO) membrane with their ultrafast permanence, outstanding mechanical properties, and high chemical stability is used for water purification process and fabricated by vacuum filtration [4]. Use of electric discharge and packed bed reactor is focused on removing *Escherichia coli* (E. coli) [5][6].

The main objective of this study is to develop a portable and solar-powered water purifier system using electrodialysis reversal. Specifically, it aims (1) to design a control system for an effective water purifier system; (2) to develop a water purifier system that can produce potable water; and, (3) to measure the

parameters required for the water output to be potable through an accredited DOH water testing laboratory.

Today, there is a global effort to keep the environment free of pollution. An adequate supply of pure water is absolutely essential to human existence. Therefore, maintaining and providing clean, purified and disinfected water is a top priority. This study presents the electrodialysis reversal as a process for water purification.

II. RESEARCH BACKGROUND

In the electro dialysis reversal process, an electrical current is transmitted directly between electrodes through the electrolytic channel: water. Electrical charge has been used to isolate minerals from other elements that are present in the water [7]. The resulting ions are transferred through the membranes from a less concentrated to a more concentrated solution. Varying the amount of electric charge causes the removal of the dissolved solids in the water. Using electro dialysis reversal, it can remove or separate sediments present in water. Periodically, the direction of ion flow is reversed by reversing the polarity applied electric current. The success of the study depends on having good and reliable electrodes. In this study, aluminum was used as electrode. Aluminum is non-corrosive, cheaper in price compared to others like graphite or nickel coated galvanized iron, and it has abundant supply in the market. The project has a timer to control how much time is needed for the water to undergo on the process of electrodialysis.

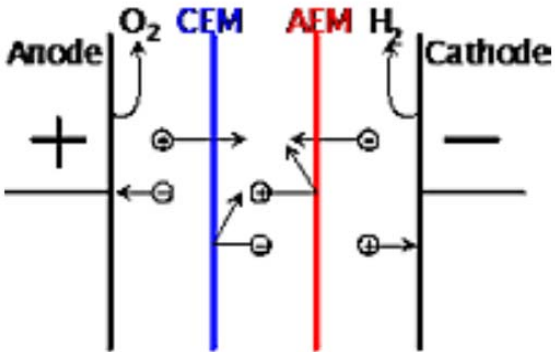

Fig. 1. Electrodialysis Reversal (EDR) process diagram [7]

In order for the electrodialysis reversal process to take place, non-corrosive rods are preferably used, such as aluminum and graphite. Aluminum is ideal to use due to low cost and are readily available in the market, Graphite rods are considerably expensive and hard to find in the market since graphite rods are scarce and consumers prefer Aluminum. Two electrodes will be used for the anode and cathode. These electrodes will be placed into the liquid. These electrodes are connected in a DC source such as a battery or a direct current generator. As the current flows through the electrolytic cell, chemical changes take place at the surface of the electrodes. At the cathode, the electrolyzed liquid combines with electrons supplied by the battery. This process is called reduction. At the anode, the liquid gives electrons to the anode. This process is called oxidation.

Electrodialysis reversal has been used in determining the effects of ion current rectification on energy harvesting [8]. Based on this study, the power efficiency from the electrolyte gradient has improved. For mixing waters with different salinity, reverse electrodialysis has been used [9]. It is noted that power generation is possible even in high concentration. Reduction of the discharge problem of polymer-flooding that produced water through electrodialysis reversal has been reported in the study of [10]. In a review conducted by [11], electrodialysis reversal has been considered economic when used in purifying water compared to reverse osmosis and electrodialysis. Also, clean microenergy generation has been possible with the use of electrodialysis reversal [12].

The study covers the development of a portable, solar and electric powered water purifier using electrodialysis reversal. It is designed in producing safe and reliable potable water for every individual. It also has a time circuitry system to control the process depending upon the source of the water. The system is to be restricted by some conditions, namely the system cannot use water from excessive dirt places like drainage, flood and septic systems. It is only intended to purify water coming from deep well and tap water. However, the system of the project does not recognize the pH of the water.

III. RESEARCH DESIGN

Figure 2 shows the block diagram on water purification system. Brackish water or deep-well water will be placed in the container. Then it will undergo electro-dialysis reversal to dissolve the unwanted solids in the water. The output produce a safe drinking water.

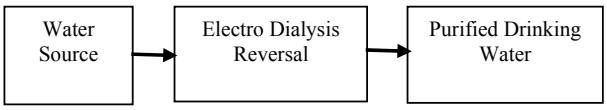

Fig. 2. Water Purification System using EDR

The block diagram of the system is shown in Figure 3. The system is solar-powered so that it can be moved in different places even if there is no available on-grid power supply. The microcontroller will control the overall function of the system to provide clean water.

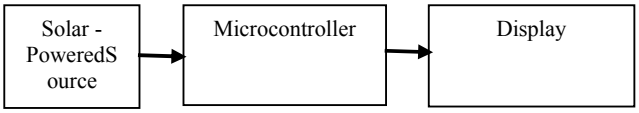

Fig. 3. Block Diagram of the System

A. Hardware Development

The circuit designing is one of the crucial steps in the development of the project because this is about interfacing the electronic components particularly, the six major devices which are PIC16F877A Microcontroller, Pumps, Electrodes, 16x2 LCD, battery and solar panel. After the circuit design is finalized, Trax Maker is used to fabricate the printed circuit board. The schematic diagram and the PCB layout for the PIC16F877A Microcontroller and Relay section are shown in Figure 4 and Figure 5 respectively.

The aesthetics of the entire project is the least priority however, there is still a need for a new or innovated product to be out in the market for commercial purposes. Aesthetics is about making the project look good and presentable. Also, portability is a factor needed to be justified in this device since it is intended to be easily carried and brought anywhere. The image of the actual prototype is shown in Figure 6.

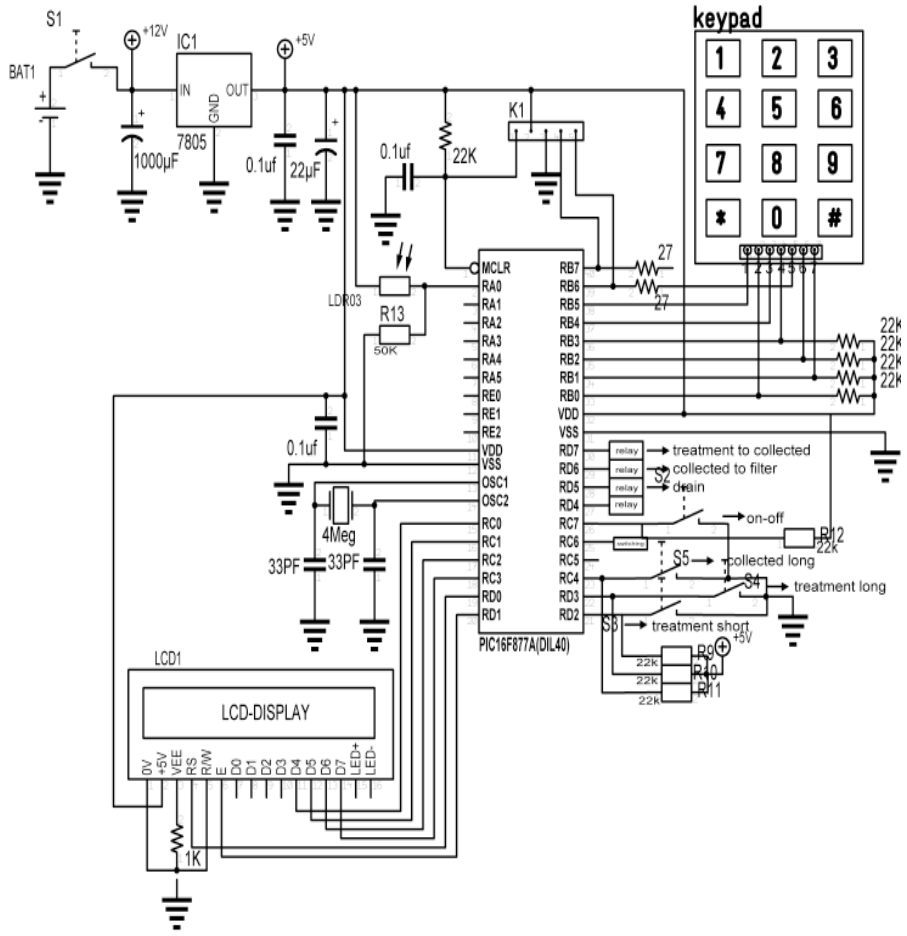

Fig. 4. MicrocoC2ntroller Circuit Design

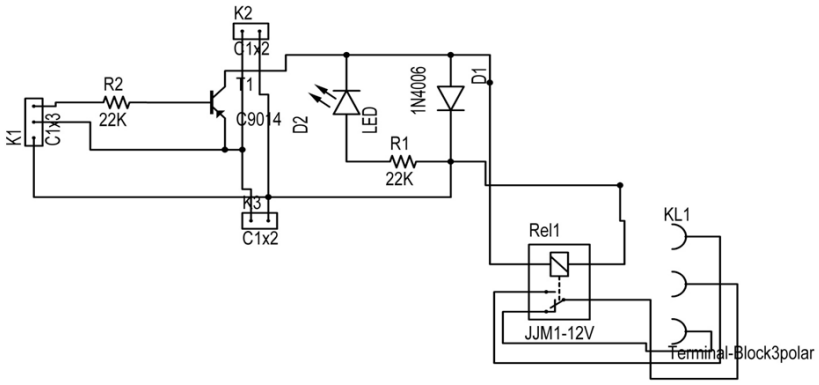

Fig. 5. Relay Schematic Diagram

Fig. 6. Actual Prototype

B. Software Development

PIC16F877A Microcontroller is used as the brain of the whole project. Assembly Language is used to control and regulate all the functions and behaviors of the electronic system of the project. Pic kit is the software used in encoding and burning the project's program codes.

Figure 7 shows the process flowchart. The first step to operate the project is to fill the container with five gallons first. Then a time option will appear in the LCD to set the time depending on the type of water (15mins, 30mins, 60mins, and custom time). It can also be interrupted by pressing the interrupt button and proceed to the next step with an option (Transfer water, treat again and Drain). If the transfer water is selected, the first pump will transfer the purified water to the other container. When the second container is filled with the purified water, then it is ready to dispense and will flow in the filter for filtration process. If treat again is selected, the operation will start from the start again. And if Drain is selected, the second pump will transfer the water to the disposal container.

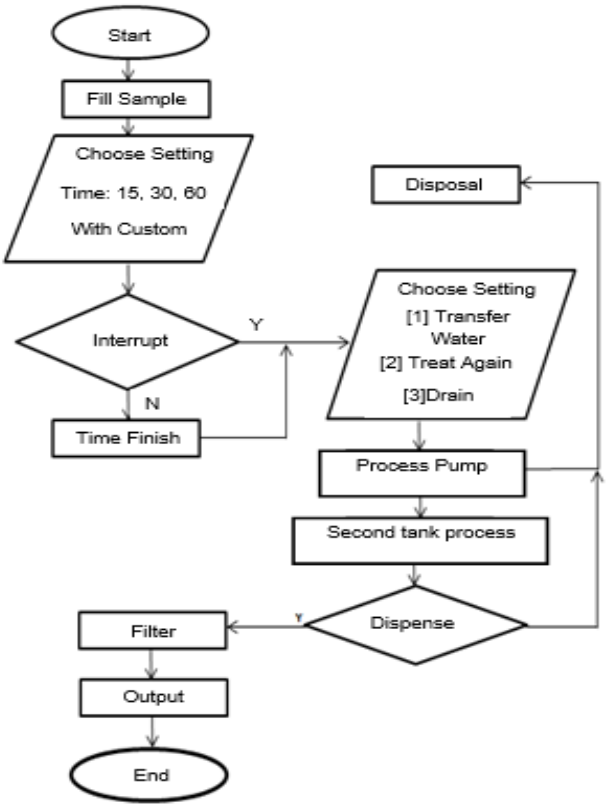

Fig. 7. Program Flowchart

C. Experiment Setup

The brackish water is obtained from the deep-well source. It was put in the container and the floater indicates if the water placed is about 5 gallons. Three

different water samples are treated under the changing polarity for 15 minutes, 30 minutes and 60 minutes. Then, it passed through carbon and resin filters for water softening. The produced water is brought in the Department of Health for laboratory testing. The tests performed are total coliform test, fecal coliform test and heterotrophic plate count. These was compared to the Philippine National Standard on Drinking Water standards.

Also, charging time and discharging time for battery are measured and compared with ac source.

IV. Results and Discussion

In order to compare and evaluate the performance of the project, several experiments have been made. Shown below are the results of all the experiments: All microbiological test results, over all system microbiological test results, and voltage measurement of battery using solar panel and alternating current.

Tables 1 and 2 are the qualitative results of the water testing laboratory that tested the untreated water and the processed water of the prototype. It comprises of the three analysis that are prescribed by the Philippine National Standard for Drinking Water (PNSDW) to determine the potability of the water.

The first test is the Total Coliform test. This test determines the presence of coliform bacteria such as E.coli, as well as other types of harmful bacteria that are naturally found in soil.

Secondly, the Fecal Coliform test. This test indicates the potential presence of pathogens as well as human wastes and animal wastes that has been dissolved on the water.

Lastly is the HPC test or the Heterotrophic Plate Count test. It determines the ability of the water to culture colony formation of the bacteria. From the data that has been gathered upon performing experiments, it can be concluded that the longer the time the water is treated by using the prototype, it eradicates harmful elements that are present on the water and the prototype is efficient and has the capability to produce processed water that can meet the standards of the Philippine National Standard for Drinking Water.

TABLE 1
All Microbiological Tests

		Results (MPN/100mL)					
Analysis	PNSDW Limit (MPN/100mL)	Raw Water	Filter	OS @ 15 mins.	OS @ 30 mins.	OS1 @ 60 mins.	OS2 @ 60 mins. (EDR)
Total Coliform	less than 1.1	>8.0	2.6	4.6	<1.1	<1.1	<1.1
Fecal Coliform	less than 1.1	>8.0	2.6	4.6	<1.1	<1.1	<1.1
HPC	less than 500 CFU/ mL	> 6 0 0 0 CFU/ ml	>3000 CFU/ ml	> 6 0 0 0 CFU/ ml	> 3 0 0 0 CFU/ ml	4 CFU/ml	20 CFU/ml

TABLE 2
Over All System Microbiological Test Results

Time (mins.)	Total Coliform	Fecal Coliform	HPC
15	4.6	4.6	>6000 CFU/ml
30	<1.1	<1.1	>3000 CFU/ml
60	<1.1	<1.1	4 CFU/ml

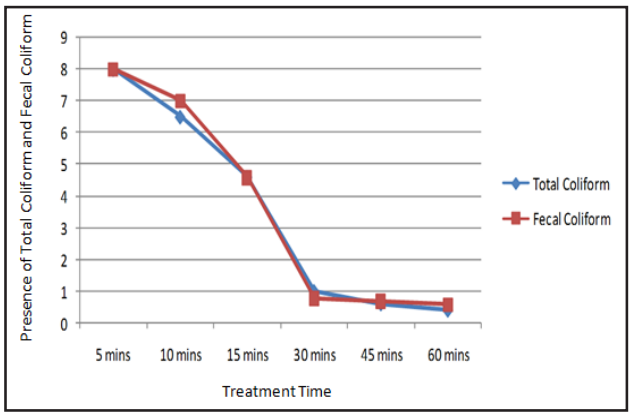

Fig. 8. Total Coliform and Fecal Coliform Comparison versus time

Figure 8 illustrates that the treatment time is indirectly proportional to Total Coliform and Fecal Coliform. It shows that the longer the electrodialysis reversal treatment process is applied to the raw water, the bacteria present on the water can be further removed.

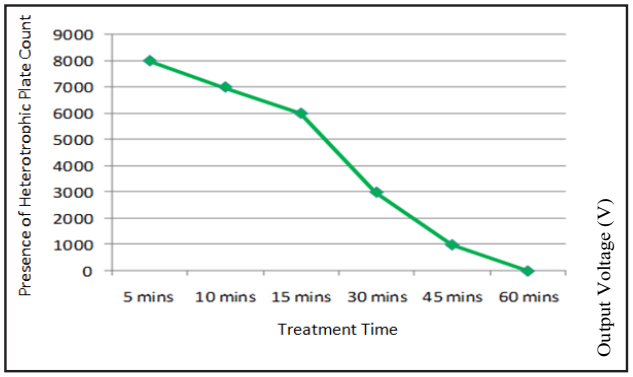

Fig. 9. Heterotrophic Plate Count versus time

Figure 9 shows that the longer the electrodialysis reversal treatment process is applied to the raw water, the accumulation of the colony or the Heterotropic Plate Count of the bacteria present on the water can be further removed. Heterotropic Plate Count is the ability of the water to culture colony formation of the bacteria.

TABLE 3
VOLTAGE MEASUREMENT OF BATTERY USING SOLAR PANEL AND ALTERNATING CURRENT

Medium Of Charging	Measured Voltage		Charging Duration
	Before	After	
Solar Panel	4.2	12	12hours
	3.4	12	12 hours 14mins.
AC	4.2	12.3	8hours 30 mins.
	3.4	12.1	7 hours 50mins.

Table 3 are the parameters acquired by performing experiments on how long the average charging time of the battery using the solar panel source versus the Alternating Current (AC) source. From the results acquired, it shows that the battery can be charged faster than by using the Alternating Current (AC) source.

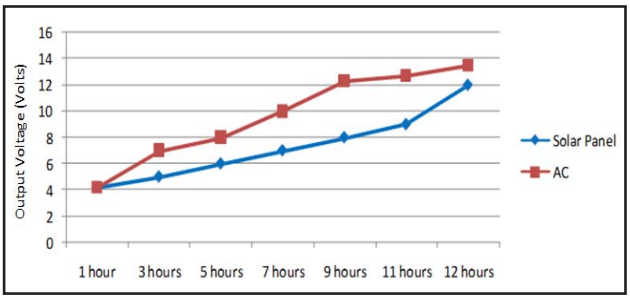

Fig. 10. Trial No. 1 - Solar Panel and AC Charging Comparison

Figure 10 is the first trial of the comparison of the charging time of the battery. It illustrates the graphical representation of the charging time of the battery by using the Alternating Current (AC) source and the Solar Panel. The graph depicts that when it comes to charging time, the Alternating Current (AC) source is much faster than the Solar Panel. By charging the battery using the Alternating Current (AC) source, the maximum output voltage of the battery can be obtained much faster compared to solar panel.

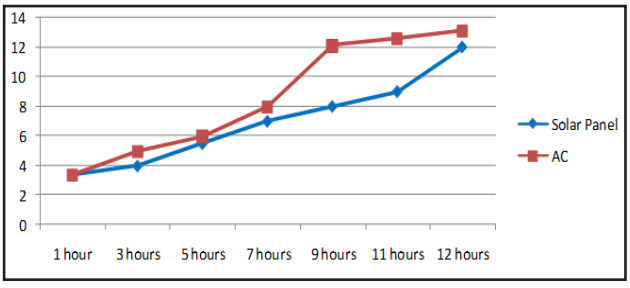

Fig. 11 Trial No. 2 – Solar Panel and AC Charging Comparison

Figure 11 is the second trial of the comparison of the charging time of the battery. Same results have also been acquired as compared to the 1st trial. It still shows that the battery can be charged much faster by using the Alternating Current (AC) source as compared to the Solar Panel.

V. CONCLUSION

Based on the results of the study, the following conclusions were derived. A portable, solar and electric powered water purifier system using Electrodialysis Reversal was developed and proved experimentally that the whole system works well with the help of a water testing laboratory that is accredited by the Department of Health. The project has successfully met the parameters required by the Department of Health and the Philippines National Standard for Drinking Water. The reliability and efficiency of the project has also been successfully verified with the help of these parameters. The PIC16F877A microcontroller was effectively interfaced to the relays, numeric keypad and to the whole circuitry. The microcontroller was proven effective given that the whole system worked well and no problems were encountered. The control system was also proven to be effective in view of the fact that the water purifying process worked well and produced water that can be consumed by humans.

ACKNOWLEDGMENT

The authors would like to thank all the scientists that extended their help in the completion of this study.

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