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Portable oceanic solutions for enhanced IoT-based desalination and salt extraction (POSEIDON)

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ABSTRACT

The clean water crisis remains a significant challenge in many remote areas, particularly on small islands in Indonesia where freshwater resources are limited. Desalination technology offers a promising solution; however, conventional methods often face obstacles such as high energy consumption, costly operations, and limited real-time water quality monitoring. This study aims to design and evaluate a distillation-based desalination device integrated with Internet of Things (IoT) technology, called POSEIDON. The system utilizes solar energy and heating elements to support the distillation process and is equipped with pH, TDS, ultrasonic, and water level sensors connected to the Blynk application for real-time monitoring and alert notifications. Testing was conducted over 10 hours under both daytime and nighttime conditions. Results show that the distilled water had pH values ranging from 7.01 to 7.51 and PPM values from 798 to 588.38. One-way ANOVA indicated no statistically significant variation ($p > 0.05$), demonstrating consistent system performance. The average volume of fresh water produced was 0.403 liters from 0.7 liters of seawater, with an average salt yield of 23.1 grams. POSEIDON exhibits good energy efficiency and portability, and it can operate at night. Nevertheless, improvements are needed in production capacity and water quality. Overall, POSEIDON presents a viable and sustainable solution to meet clean water needs in remote, water-scarce regions.

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1. INTRODUCTION

Water, as one of the natural resources, is needed to support life, the environment, and development (Putra R.E., & Zevi Y. 2021). Water is a vital source of life that is essential for all living beings, especially humans, to sustain their existence (Mardika et al., 2025). The rapid growth of the human population has led to an increased demand for freshwater in recent decades (Abuelnuor et al., 2020). About 97% of the world's water resources are in the form of seawater, which is not consumable, 2% is in the form of ice in polar regions, and only 1% is freshwater available for humans, animals, and plants (Kamran et al., 2020). According to a UNESCO report, 40% of the world's population will be affected by the water crisis by 2030 (Nejad et al., 2022). The availability of clean water is very important for society as a supply of water for industry, agricultural irrigation, and individual needs such as bathing, washing, cooking, and for consumption as drinking water, thus the quality of water needs to be considered (Fakhriyah et al., 2021). Based on the Regulation of the Minister of Health of the Republic of Indonesia No. 416/MENKES/IX/1990, clean water is water whose quality meets health standards, can be used for daily needs, and is safe for drinking after being boiled (Rolia et al., 2023). Although the availability of water in the world is very abundant, only a small fraction can be consumed by humans as drinking water. Currently, there is a tendency for the availability of clean water to decline over time (Ardilla et al., 2020). In Indonesia, it is estimated that around 60 percent of rivers, especially those in the regions of Sumatra, Java, Bali, and Sulawesi, have been polluted by various types of waste. Furthermore, it is projected that by 2025, nearly two-thirds of the world's population will live in areas experiencing water crises (Nisala et al., 2020).

Seawater is an abundant source of water, but it cannot be consumed directly due to its high salt content and failure to meet drinking water quality standards (Bela et al., 2022). One way to produce clean water by utilizing seawater is through the method of desalination. Seawater desalination is one of the main solutions that can be applied to address the water crisis (Mehrjerdi et al., 2021). Desalination is divided into two types: thermal desalination and membrane desalination. Thermal desalination includes Seawater Greenhouse, Multi-Stage Flash Distillation, Multi-Effect Distillation, and Vapor Compression Distillation, while membrane desalination includes Reverse Osmosis (Choukai O., & Zejli D. 2021). Thermal desalination and solar distillation work by utilizing heat energy to evaporate seawater and then condense it into fresh water. This method tends to require high energy consumption, ranging from 10 to 25 kWh per cubic meter of water, so it is generally used in areas with access to heat energy or industrial waste heat. (Mehrjerdi et al., 2021).

In contrast, membrane desalination such as Reverse Osmosis (RO) uses high pressure to filter salts through a semipermeable membrane. This technology is more energy-efficient with consumption of around 3–6 kWh per cubic meter of water, but requires regular maintenance as the membrane is sensitive to contamination. In terms of cost, RO technology tends to be more economical with operational costs ranging from approximately USD 0.5–1.2 per cubic meter, while MED or other thermal methods can reach USD 1.5–2.5 per cubic meter (Lemeshko, M., & Lemeshko, A. 2024).

In addition to the five types of desalination mentioned above, there is one type of desalination that can be used to obtain clean water without requiring much electrical energy, namely solar-powered desalination. This process is called distillation or seawater distillation (Lemeshko, M., & Lemeshko, A. 2024). Distillation is a process of separating a liquid (seawater) from its mixture (salt) based on differences in boiling points or based on the ability of a substance to evaporate (Putranto et al, 2024). This vapor will be cooled and produce droplets of fresh water that can be collected as clean water (Irham et al, 2024).

However, traditional desalination processes often face several challenges, including high operational costs, low energy efficiency, and difficulties in monitoring water quality (Innaya et al, 2022). This is where the role of IoT becomes crucial. By integrating IoT technology into desalination systems, the systems can utilize smart sensors to collect and analyze real-time data, such as water levels, turbidity, and other environmental conditions (El-Kanj, H. G., 2024). This data can be transmitted to a cloud-based platform, enabling remote monitoring and more efficient management (Murugan, T. et al, 2023).

As time goes by, various technologies for seawater distillation have developed, and now they have entered a more modern phase (Siregar et al, 2021). One of the main advantages of IoT technology in the agricultural sector is its ability to optimize the use of resources such as water and detect seawater on each salt table. By using water detection sensors, farmers can accurately determine when and how much water is needed on each salt table (Nasution et al., 2024). Therefore, the application of the POSEIDON device is needed, utilizing solar heat and heating plates to accelerate the distillation process, and it can operate even when there is no sunlight, such as at night. POSEIDON is also integrated with IoT, allowing us to monitor the condition or amount of water in this device and is equipped with notifications for events such as when the seawater in the reservoir runs out, when the obtained freshwater is full, and when salt is available.

2. RESEARCH METHOD

In this study, we designed and implemented a system that utilizes Internet of Things (IoT) technology to extend the functionality and efficiency of the distillation device. We describe the flow of this research in the form of a flowchart as follows:

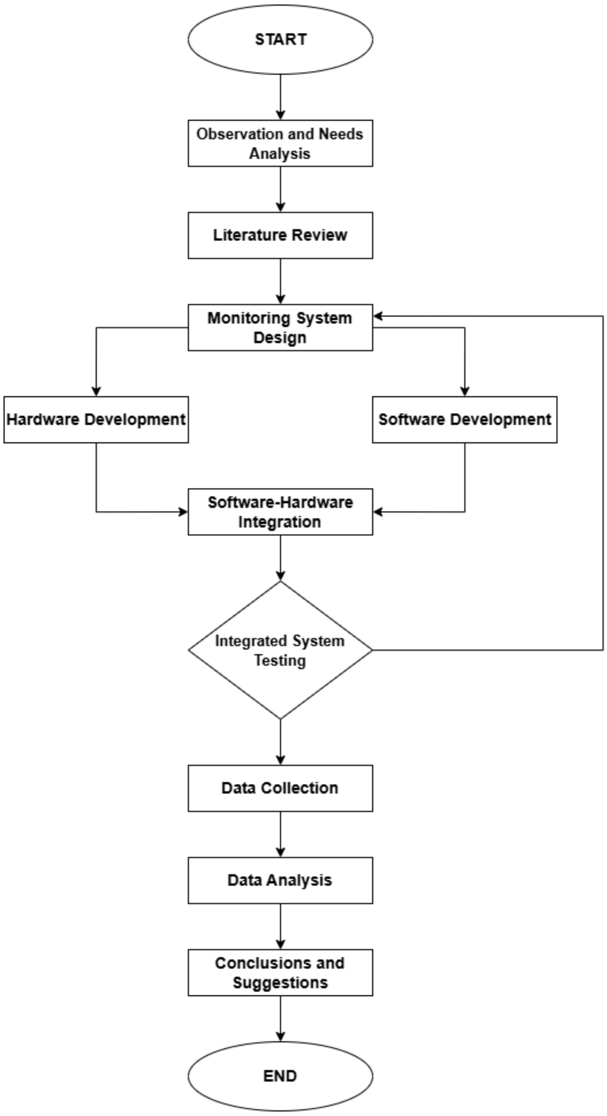

Figure 1. Research Flowchart

The diagram above illustrates the stages of developing a monitoring system, beginning with observation and needs analysis to understand the problem and determine the appropriate solution. This is followed by a literature review to gather relevant references and theoretical foundations. Based on this information, a monitoring system design is created, covering both hardware and software aspects.

Next, hardware and software development are carried out separately. Once both components are ready, the integration of hardware and software is performed to form a complete system. The integrated system then undergoes testing to ensure its functionality and reliability. Testing was conducted for 10 hours with testing conditions carried out outdoors and indoors to simulate the conditions of using the device during the day and at night.

If the system operates properly, data collection is conducted based on the testing or field implementation results, followed by data analysis. Finally, the results of the analysis are used to compile conclusions and suggestions, marking the end of the system development process.

Hardware Development

At this stage, the researcher develops the system hardware by designing a block diagram that uses the ESP32 module, where the NodeMCU ESP32 is a microcontroller module based on ESP32 with Wi-Fi and Bluetooth connectivity features, high performance, many I/O pins, and is suitable for various IoT applications such as home automation, environmental monitoring, and industrial projects (Sakthimohan et al, 2021). NodeMCU is used as the main controller for the water quality monitoring system in the desalination process. This design aims to automatically and real-time monitor water conditions through the integration of various sensors and wireless connectivity. The operational block diagram of the system is shown in Figure 2

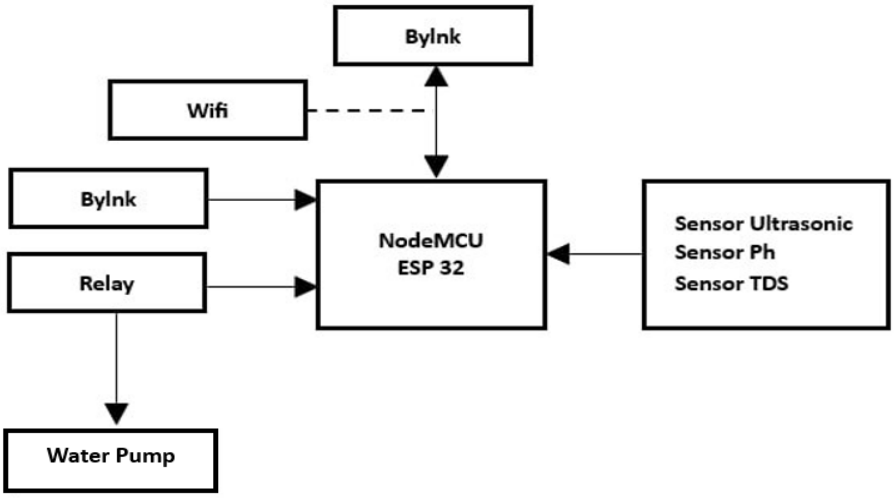

Figure 2. Diagram Block

This diagram shows an automatic monitoring and control system based on the NodeMCU ESP32 that uses an ultrasonic sensor to measure the level or presence of objects (Jia K., 2024), a pH sensor to measure the acidity or alkalinity of water (Bayusari et al., 2021), and a TDS (Total Dissolved Solids) sensor to measure the level of dissolved solids in water (Chakkaravarthe et al., 2024); data from these three sensors is sent to the ESP32 for processing and then transmitted to the Blynk application via a WiFi connection for real-time monitoring. If the water conditions do not meet the standards, the ESP32 will activate a relay to automatically turn the water pump on or off, making it suitable for use in automatic irrigation applications or water quality monitoring.

Software Development

This diagram shows an automatic monitoring and control system based on the NodeMCU ESP32 that uses an ultrasonic sensor to measure the level or presence of objects (Jia K., 2024), a pH sensor to measure the acidity or alkalinity of water (Bayusari et al., 2021), and a TDS (Total Dissolved Solids) sensor to measure the level of dissolved solids in water (Chakkaravarthe et al., 2024); data from these three sensors is sent to the ESP32 for processing and then transmitted to the Blynk application via a WiFi connection for real-time monitoring. If the water conditions do not meet the standards, the ESP32 will activate a relay to automatically turn the water pump on or off, making it suitable for use in automatic irrigation applications or water quality monitoring.

```
fixcobapresentasi §
#define BLYNK_PRINT Serial
#include <WiFi.h>
#include <WiFiClient.h>
#include <BlynkSimpleEsp32.h>
#include <SPI.h>


char auth[] = "qtx1u_LyzKaDtcRTwJZpXBAgljqLS0TT";
char ssid[] = "POSEIDON";
char pass[] = "poseidon1";


//TIMER
int mili = 0, detik = 0, menit = 0, jam = 0;
hw_timer_t *My_timer = NULL;
void IRAM_ATTR onTimer() {
  mili++;
  if (mili >= 1000) {
    mili = 0;
    detik++;
  }
  if (detik >= 60) {
    detik = 0;
    menit++;
  }
  if (menit >= 60) {
    menit = 0;
    jam++;
  }
  if (jam >= 24) {
    jam = 0;
  }
}
```

Figure 3. Source Code Display

Design of Water Quality Monitoring Application

Researchers in this study used Blynk for an IoT application that allows users to control and monitor devices in real-time via a smartphone (Alfarisy & Hadiwandra, 2024). In the context of this research, Blynk is used to display data related to water quality, including several important parameters. The application efficiently presents information regarding the Clean Water level in the tank, indicating how high the available clean water level is. The accuracy of the data from the sensors used has been calibrated with their respective measuring instruments. For example, the pH sensor used has been calibrated with a pH meter, and the TDS sensor has been calibrated with a TDS meter. This is to ensure a high level of data accuracy. The sea water level data in the Blynk application provides information about changes in the amount of sea water in the tank. The sea water height in the desalination device will be displayed in the application, providing data on the availability of sea water in that device. Water turbidity is the last data displayed, it indicates the extent to which particles in the water can affect water quality. This data is crucial for assessing potential health risks from contaminated water.

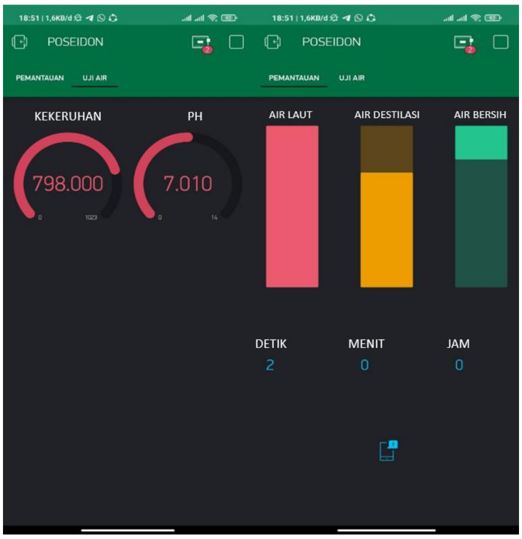

Figure 4. Display on the Blynk Application

Smartphone Alert Notification System

In this research, an alert notification system integrated with the Blynk app serves to provide real-time information to users about water quality conditions. The system is designed to monitor several important parameters and provide notifications when significant changes occur. The reliability of the notifications was tested until the system consistently provided alerts when predefined parameters were met, such as when the water level in the seawater storage tank was full or beginning to run low, when the freshwater supply was full, and when the salt residue could be harvested. Water level notification will be sent if the water level in the tank reaches the specified minimum limit, allowing users to ensure a sufficient water supply and prevent shortages. In addition, the system will provide alerts if the seawater level in the tank experiences a drastic increase or decrease, helping users understand the dynamics of changes in the amount of seawater that can affect the seawater desalination process. If the seawater level in the desalination device reaches a critical level, the user will also receive a notification, which is important for maintaining the availability of seawater required for the desalination process and ensuring the system operates efficiently. In addition, the system will provide alerts if the water turbidity level exceeds a predetermined threshold, allowing users to identify potential health risks due to contamination and take the necessary actions to ensure water quality remains safe. With this alert notification system in place, users can quickly and appropriately take the necessary steps to maintain water quality and availability, as well as reduce risks that may arise from changing water conditions.

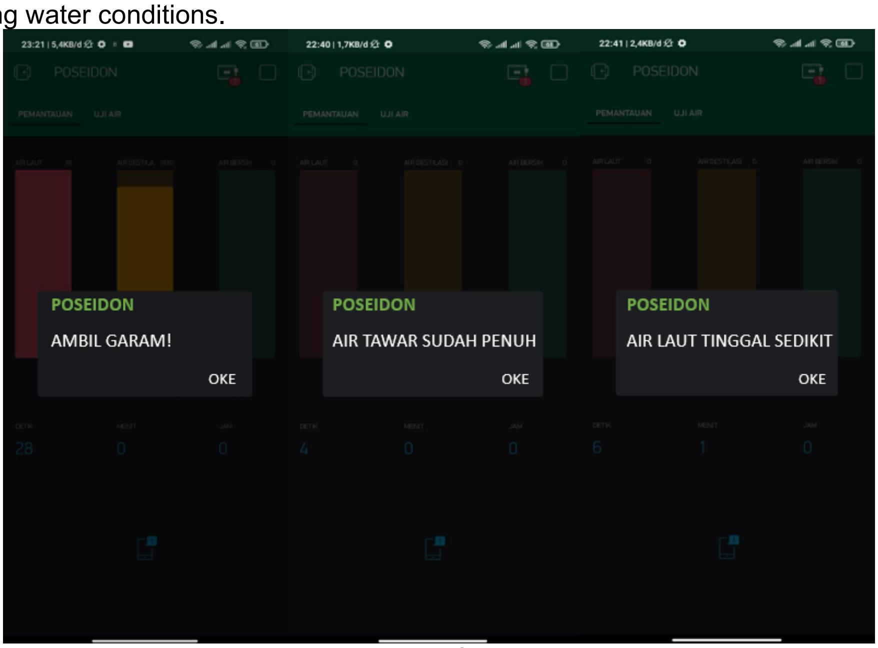

Figure 5. Blynk Notification Display

Project Design And Manufacturing

A. Tools and Materials

The tools used in this study are a set of distillator tools whose dimensions consist of an evaporator with a length of 50 cm and a width of 50 cm, a sloping side length of 92 cm, a back height of 40 cm and a front height of 10cm, ESP32, DC Motor 2, Motor Driver VNH2SP30, Ultrasonic Sensor, Pump Set 1 Piece, Heater Plate 1 Piece, Water Level Sensor, Step Down, Solar Panel, 12 Volt AC DC Inverter, Accu, Solar Charge Controller and AWG Cable.

B. Project Design

To realize an efficient and environmentally friendly seawater desalination system, the researcher designed an automatic distillation device based on IoT technology that utilizes solar energy as its primary power source. This design integrates various electronic and mechanical components that work in a coordinated manner to convert seawater into freshwater through the processes of heating and condensation. The overall system design is illustrated in Figure 6.

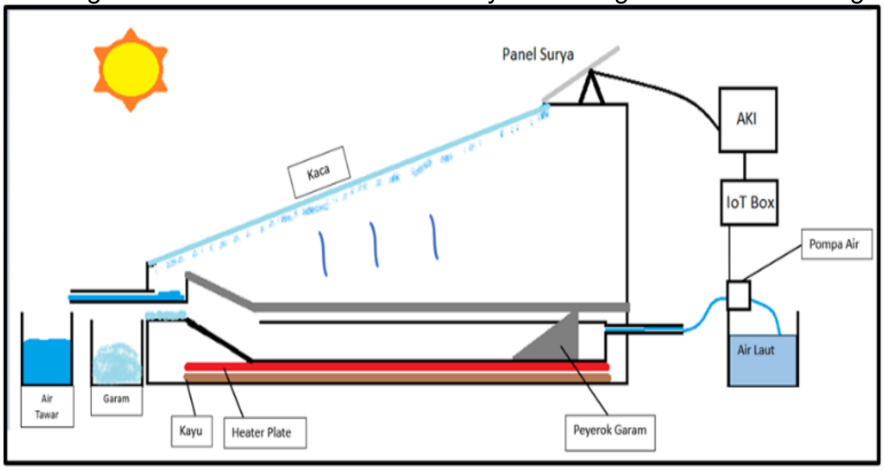

Figure 6. Project Design

Component	Function/Role
Solar Panel	Converts solar energy into electricity to power the entire system.
Battery (Accumulator)	Stores electrical energy from the solar panel for use when sunlight is unavailable.
IoT Box	Automatically controls system operations such as the water pump and heater.
Water Pump	Pumps seawater from the storage tank into the heating/desalination chamber.
Heater Plate	Heats seawater to produce water vapor through evaporation.
Slanted Glass	Serves as the condensation surface for vapor, turning it into fresh water droplets.
Fresh Water Channel	Directs the condensed water into a freshwater collection tank.

C. The Way Project Will Run

POSEIDON relies on solar power (greenhouse effect) to turn seawater into fresh water and produce salt. The way POSEIDON works is that we put water in a bucket, later the water in the bucket will be pumped into the distillation process if the water level sensor in the device detects water less than 1 cm. After the water is pumped in, the water will carry out the distillation process manually with the help of solar power and also assisted by a heater that comes from a hotplate under the pan where the water is. Later, the hot water will produce steam, and when the hot steam from the water touches the glass or a cooler surface in this condition, namely the glass, the gaseous steam will undergo a condensation process and turn into dew or water droplets on the glass. After the condensation process occurs and there is a lot of dew on the surface of the glass, the water will run down and be collected in a reservoir, which is then flowed into a jerry can.

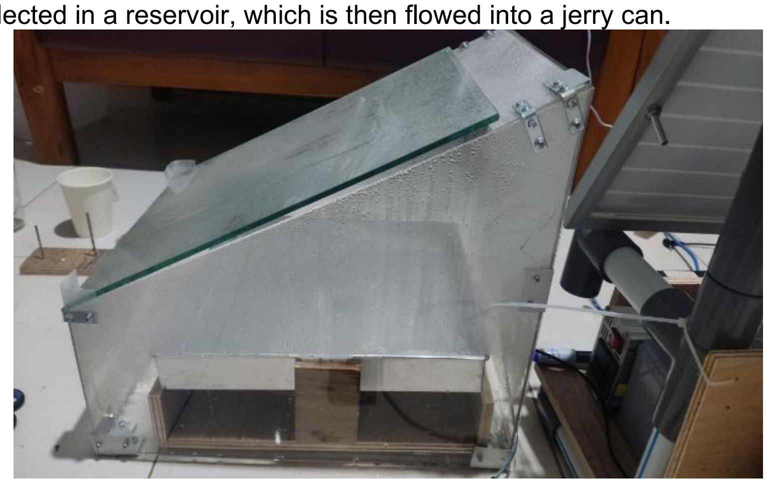
Figure 7. System and Device Prototypes

Then, the water that has been distilled earlier will leave the rest of the distillation residue, namely the grains of salt, after the water has shrunk to below less than equal to 1 cm, the program will run a motor equipped with a tool such as a scraper will sweep the salt out of the box and enter the box where the salt is collected, after completion of the pump from the bucket to the tool will pump back up to the height limit that has been set. When the water level is greater than 3 cm, the pump will turn off and stop filling water. At night this tool still works because of the utilization of sunlight as energy that can be converted into electrical energy using solar panels. The solar panel will convert sunlight into a DC power source stored in the battery so that it can be used at night. The electricity generated earlier is the main source of the IoT system, as a system for managing the device independently.

3. RESULTS AND DISCUSSIONS

Table 1. application test result data

Testing	Sensor				Relay	Blynk
	pH	Ultrasonic	TDS	Water Level		
1	On	On	On	On	On	Connect
2	On	On	On	On	On	Connect
3	On	On	On	On	On	Connect
4	On	On	On	On	On	Connect
5	On	On	On	On	On	Connect

Table 2. pH and PPM Measurement Data

testing	pH Distillate Result	PPM Distillate Result
1	7,01	798
2	7,24	754,79
3	7,51	588,38
4	7,08	651,62
5	7,19	639,23

Table 1 shows the results and discussion of the research, listing five tests conducted using the sensors. All sensors, namely pH, ultrasonic, TDS, and water level sensors, are active and connected to the Blynk application. In Table 2, the pH values of the distilled water ranged from 7.01 to 7.51, indicating near-neutral conditions, while the PPM values ranged from 798 to 588.38 with a decreasing trend in some tests. A simple one-way ANOVA statistical test was applied to determine whether the variations in pH and PPM values across the five tests were statistically significant. The results showed p-values > 0.05 for both parameters, indicating that the variations were not statistically significant and demonstrating the consistency and repeatability of the POSEIDON system's performance. Furthermore, the coefficient of variation (CV) for pH was approximately 2.4%, and for PPM about 10.4%, suggesting high consistency in pH data and moderate variability in PPM data—which is still acceptable in distillation processes influenced by external environmental factors.

The following graph shows the results of an experiment conducted on 0.7 liters of seawater, focusing on two parameters: freshwater yield (L) and the amount of salt (gr) separated during the distillation process.

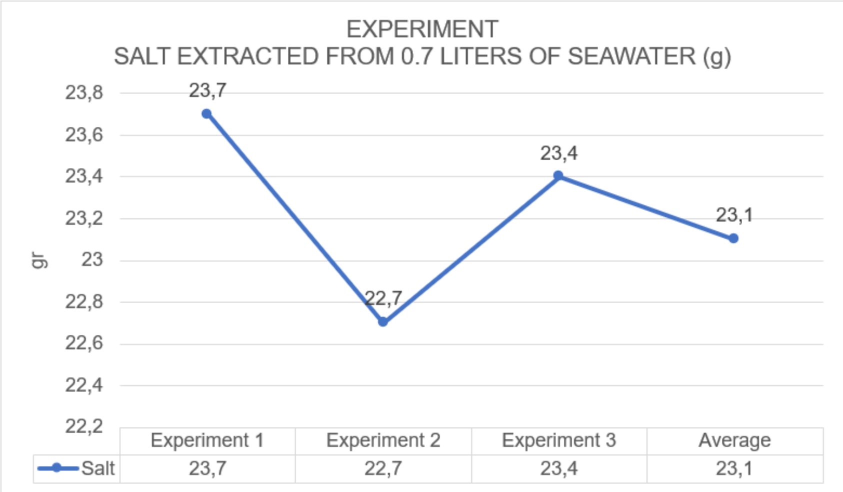

Figure 8. Data Graphic of Salt Results Obtained

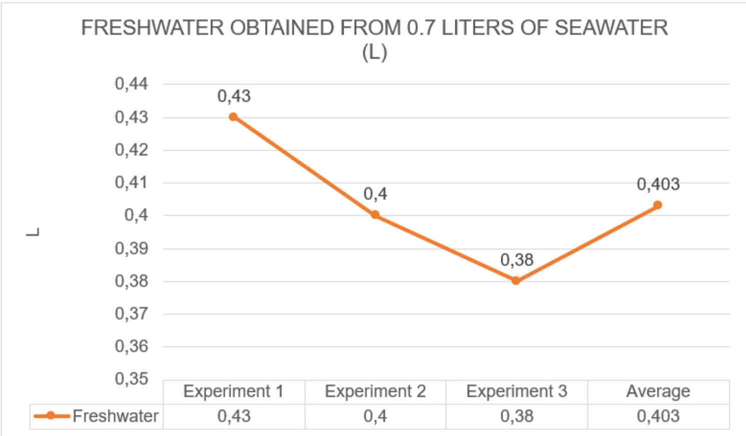

Figure 9. Graphic of Freshwater Results Data Obtained

Graph 1 in Figure 8 shows the amount of salt produced during the distillation process. In experiment 1, the amount of salt was recorded as 23.7 g, and then decreased in experiment 2 to 22.7 g. In experiment 3, there was a slight increase back to 23.4 g, with an average yield of salt obtained of about 23.1 g. The fluctuations seen in the amount of salt indicate that despite variations in yield, the distillation process is quite consistent in separating salt from seawater.

Graph 2 in Figure 9 shows the volume of fresh water produced from the experiments. In experiment 1, the volume of freshwater obtained was 0.43 L. This volume decreased slightly in experiment 2 to 0.40 L, before dropping further in experiment 3, reaching 0.38 L. The average volume of freshwater produced at the end of the experiment was recorded at 0.403 L. This shows a decrease in the volume of freshwater as the experiment progressed, which may be related to the efficiency of the distillation process or changes in operating conditions.

Compared to conventional technologies such as Reverse Osmosis (RO) or Multi-Effect Distillation (MED), POSEIDON offers significant advantages in energy consumption, portability, and night-time operability due to its hybrid solar-powered configuration. However, the system is limited in its relatively low output volume and higher PPM values compared to RO, which typically produces water with PPM below 500. Therefore, future versions of this system should consider integrating additional filtration stages (such as activated carbon or ion-exchange filters).

Overall, the POSEIDON system demonstrates stable performance in desalination and salt extraction processes, with consistent pH results and moderate PPM reduction, making it a promising solution for remote areas facing water scarcity, such as small islands.

4. CONCLUSIONS

Test results prove that the POSEIDON system successfully maintains the quality of distilled water with stable pH (7.01–7.51) and PPM reduction (798–588.38), supported by low coefficients of variation (pH 2.4%; PPM 10.4%). This system excels in energy efficiency, portability, and nighttime operation compared to RO/MED, though it has limitations in production volume and higher PPM values. Notification testing demonstrated the system's reliability in providing real-time alerts when parameters are met, such as critical seawater/freshwater levels or when salt residue is ready for harvest. To improve water quality, further development could consider integrating additional filtration stages such as activated carbon or ion exchange filters. With stable performance and smart monitoring capabilities, POSEIDON is a viable sustainable solution for remote areas facing water scarcity.

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