Water obtention from salted water using greenhouse effect and IoT integration

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Abstract

This project aims to develop a sustainable solution for obtaining drinking water from saltwater using greenhouse systems to supply a community of approximately 300 people. It begins with an introduction and description of the reason for the development of the system, followed by the projection of the state of the art including similar solutions that can support the design of the system. Along with the distillation structure, the project will be integrated with an IoT solution that will communicate the data obtained from various sensors to manage and control the greenhouse effect solution remotely.

Keywords: solar still, IoT, Arduino, distillation.

Project Introduction

According to the United Nations, the average number of liters of water consumed per day in an occidental country comes up to 150 l/day. This number includes water for personal drinking and cleaning (washing…). The UN has determined that the minimum quantity of liters per day in a 3rd world condition environment would be 10% of what is needed in developed countries, therefore a basic consumption per person of 15 l/day. Out of this 15 l/day, 2 L are used for drinking and the rest for other necessities.

This project has been carried out with the help of MMUU and the engineering foundation of ICAI to study the different technologies related to obtaining water from salt water for a rural location of 300 people.

It has as a starting point, the use of the greenhouse effect and focused on low cost. Other technologies are capable of distilling water but the technology that uses the greenhouse effect is known as the solar distiller.

What is a solar still? The solar still is a structure that takes advantage of the sun's irradiation and the greenhouse effect to distill water.

The process is detailed in the following phases:

1. The first phase is where the salt water accumulates in a dedicated area.
2. As the solution heats up due to solar radiation and the greenhouse effect, the water begins to evaporate, the vapor rises to the surface while the salt accumulates at the bottom of the saltwater container.
3. Once the vapor hits the cover (usually made of a transparent material such as glass or methacrylate) it condenses and falls to the surface thanks to gravity and surface tension.
4. Finally, once the water droplets reach the end, they group to form larger water droplets and fall into the distilled water zone.

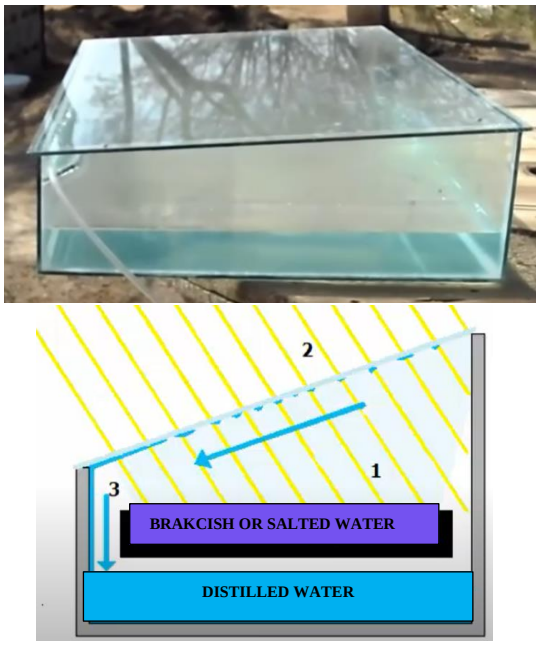


Figure 1 Experimental one-sided still

State of the art

Water Distillation Technologies

Multiple technologies can obtain distilled water from salted water. The main desalination techniques can be classified into three large groups according to the principle they apply:

a) Phase Change:

1. Evaporation

-Sudden multiple-stage evaporation (ESME or SPS)

-Multiple Evaporation Effect (EME or MED)

-Vapor compression (CV)

2-Freezing

It is based on the different melting points of fresh water and salt water.

The ice crystals obtained are separated in the brine, then washed to extract the salt, and melted into fresh water.

b) Selective Membranes

-Reverse Osmosis (RO)

-Electrodialysis (ED)

c) Chemical Bond

-Ion Exchange (IQ)

-Solvent extraction

Reverse Osmosis

This process applies pressure to overcome the osmotic pressure of the water to be treated. The reverse osmosis process is perhaps the simplest method to desalinate and in which better energy efficiency is obtained. The system takes its name for performing the passage of solutions in a way contrary to normal osmotic processes. That is, the less concentrated solutions move, by potential energy difference, towards the more concentrated ones, through a semipermeable membrane, with the need to apply an external force to achieve the separation of water and salt.

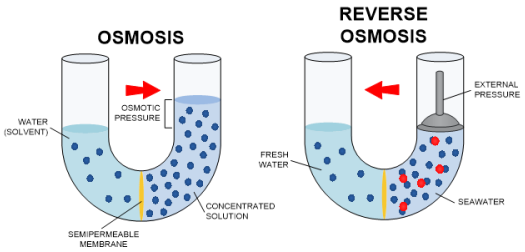


Figure 2 Osmosis and Reverse Osmosis [1]

Professional approach

To obtain information for the development of a system as viable as possible, INCLAM Group was contacted. INCLAM is a company dedicated to the realization of sanitation, purification, water purification, and infrastructure development projects in communities around the world. They have carried out several projects in Latin America, Africa, Asia, and Europe.

Among the wide variety of projects, the project carried out in Peru is of great relevance for this work. This project, financed by the Peruvian government, consisted of a water supply system for 65 rural communities using Reverse Osmosis systems.

Figure 3 Reverse Osmosis in Perú. INCLAM

Technology Comparison

As mentioned, there are several technologies that can produce water from a brackish or salted solution The following table attaches the most important desalination processes, as well as their main characteristics. It can be observed that the reverse osmosis method is the cheapest, but in it, lower water quality is obtained than in the other desalination methods. At the moment, the Reverse Osmosis method is used more, because its energy consumption is lower.

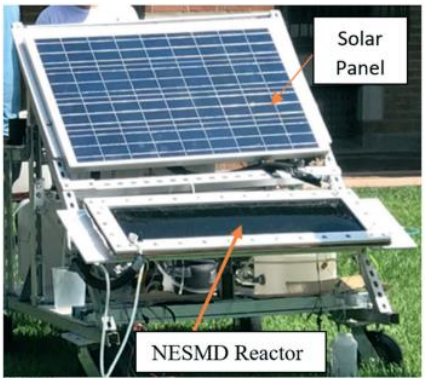
Table 1 Technological comparison

Characteristics	MSF	MED	CV	RO	RE
Type of Energy	Thermal	Thermal	Electric	Electric	Electric
Energy consumption (Kj/Kg)	High(<200)	Medium/High(150-200)	Medium(100-150)	Low (<80)	Low (<80)
Initial cost	High	Medium/High	High	Medium	Medium/Low
Production (m3/day)	High (>50000)	Medium (<25000)	Low(<5000)	High(>50000)	Medium (<25000)
Scalability	Difficult	Difficult	Difficult	Easy	
Reliability	High	Medium	Low	High	High
Output salted water quality (ppm)	High(<50))	High(<50)	High(<50)	Medium (300-500)	Medium (300-500)
Surface required for development	big	medium	small	small	small

Similar Projects

Rice University

Other relevant solutions include the one developed by Rice University. The project consists of a standalone solution sustained by solar power. The desalination system includes a NESMD (nanophotonic enhanced solar membrane distillation) reactor to obtain a low-cost and high-efficiency solution for the desalination of seawater and hypersaline brine. The nanophotonic material acts as a photothermal coating collector to preserve the heat and generates high heat in the area where the membrane is localized.



This NESMD solution is still under development since the membrane is manufactured in the laboratory as it is not available on the market. Unlike other distillation systems, this one has a solar panel that provides the extra energy needed to reach the boiling point of the water. Finally, it should be noted that this system is capable of producing a flow rate of 0.75 l/(m2*h) which makes it less productive than other standard solutions on the market.

Fcubed

F Cubed provides an off-grid system that is simple to install, modular and scalable; It also eliminates contamination from all water sources and requires limited expertise to install, maintain or operate. It is environmentally friendly using solar energy only and rainwater harvesting and can actively engage local communities in installing and maintaining the off-grid water solution.

Figure 4 FCubed 5 Carocell Panel set up

Each standalone panel will produce approximately 15 liters per day. Therefore, a 5-panel water farm will produce around 75 liters of distilled water each day; and will

harvest rainwater (ranging from 5-10 liters per day). In total, a 5-panel water farm will provide a combined output (on average) of 100-125 liters of potable water per day and provide a year-round solution

MIT University

There are other types of solutions that despite not including processes such as the greenhouse effect are also interesting due to their use as is the case of the system developed by MIT using reverse electrodialysis and energy contribution with solar panels. It is a project capable of supplying a community of 2000 people in India with a total cost of around 23000 dollars. This project produces a flow of 1.6 cubic meters every hour and a recovery of 96% going from a salt concentration of 3360 parts per million to 250 parts per million.

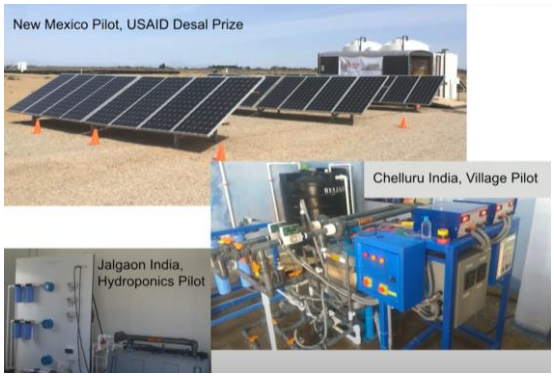


Figure 5 MIT System on the field

Energy Production

To provide energy for the water boilers, the most effective way would be using solar panels. There are four different solar panel technologies on the market for thermal solar purposes.

Table 2 PV Technologies

Thermal solar solutions	Image	Description	Efficiency	Losses	Applications	Market Presence
Flat panel		Low temperature	+++	+++	Water heating in mild and warm conditions	94%
Vacuum tubes		Medium and high temperature	++++	++	Industrial processes	4%
Polypropylene collector		Low temperature Flexible (plastic)	+	+++	Water heater for swimming pools	2%
Concentration		High temperature	++++	++	Still experimental	~0%

The most relevant technological solution, if it is needed for this project, will be the flat panel. It provides a good compromise between efficiency and losses, but the most relevant parameter is that it is the most accessible which will be the real constraint in our development. The power delivered depends on the efficiency of the panel, its area, and solar irradiation.

Prototype

The solution proposed is composed of four parts: the main frame/pool, the glass cover, joints, adhesive, and finally the legs. A visual representation is shown below

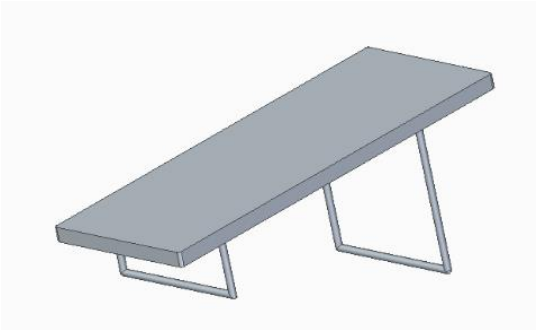


Figure 6 Solid Edge Still design

A humidity and temperature sensor has been used (Brand: Inkbird Model: IBS TH2 PLUS) to determine the conditions inside the structure. The sensor is connected by wire to a probe and the data is sent via Bluetooth 5.0. The user can see on the phone *Engbird App* the measurements collected. Since the protocol used is Bluetooth the app will only synchronize when the phone is near the sensor. The following figure shows an example of the temperatures captured on two days in August.

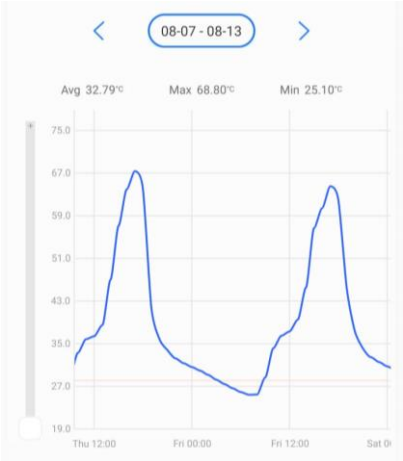


Figure 7 Prototype's inside temperature

Moreover, a good procedure to determine the cost of the modules is to find how many modules are needed and multiply by the cost of a single module. The cost of the materials of the prototype is described below. The prototype took 11 laboring hours amongst them are 2 hours to design and gather the materials, 5h for construction, and 4h for upgrades and fixes.

The total cost of the prototype is shown below:

Table 3 Prototype costs

Product	Units	Cost per unit	Total cost
Hose	2	2.89	5.78
Wooden board	1	20.79	20.79
Wooden sealer	1	9.99	9.99
Adhesive sealant	1	6.99	6.99
Valve	1	2.95	2.95
'L' PVC	3	4.39	13.17
Glue gun	1	7.29	7.29
40 wooden dowels	1	1.79	1.79
Repair tape vulcanizable	1	3.19	3.19
25 screws 3.5x12	1	2.69	2.69
TOTAL			74.63 Eur

IoT architecture

Based on the water produced by the Fcubed panels, 15 L/day per panel, and minimum consumption of 2 L/person per day, about 40 panels would be needed to supply the community. These panels are grouped five by five, so it would be necessary to build an architecture for 8 groups of water production.

This system is designed to be able to control the systems remotely, facilitating their operation and maintenance. The systems avoid the need for a person to physically move to control the operation of the distillers and receive alerts about possible failures that may occur and send orders in an automated manner.

The design of the architecture requires that the technology used has a low cost, high range in distance, and a high level of security.

Stages of IoT Architecture

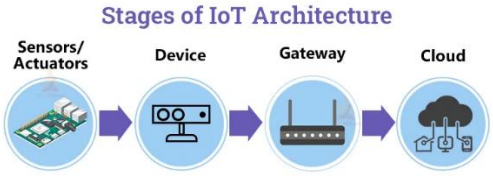


Figure 8 Stages of IoT Architecture [2]

Sensors/Actuators

Sensors translate differences in pressure, temperature, and humidity … (continuous world) into a discrete value that can be interpreted by a computer. Actuators, on the other hand, are motors, gates, and lights that are turned on/off or perform a specific action when the processor sends them a signal.

The sensors needed for this project include:

Temperature sensor: to control the proper functioning of the still

Humidity sensor: to control the water saturation inside the still

Light sensor: to detect whether the still is open or

closed (for brine purge purposes)

Weight sensor: to control the water being produced

The actuators needed for this project include:

The switch for the pumping unit allows the control of the water flow inside the still. There should be a compromise between sensors/actuators extra cost on the project and the benefit they will provide to the system. Therefore, the less the better.

Device

The device will include a processor, an antenna, and the energy unit.

Gateway

The gateway includes the communication modules required to send and receive the information.

Cloud

Finally, the cloud collects the information from all the nodes/groups determines what to do, and sends the information to the actuators to perform some kind of action.

The standard communication network used on the internet is divided into 5 layers:

1) The physical layer (source coding, channel coding, modulator/demodulator)
2) The data link layer (Medium Access Control, Logical Link Control)
3) The network layer (IP)
4) The transport layer (Transport Control Protocol, User Datagram Protocol)
5) The application layer (HTTP, SSH, DNS, MQTT, CoAP…)

Common technologies for the physical and Datalink layers include LPWAN (Low Power Wide Area Network) such as Sigfox, and other kinds of technologies WiFi, 4G/3G/2G cellular, Bluetooth, ZigBee …

For network communication, the standard is defined by Ipv6 (128 bits) and Ipv4 (32bits)

For the transport layer, there are two types of protocols depending on the reliability of the communication needed. For higher reliability connections it is preferred TCP as it has end-to-end reliability with no duplicates and flow control compared with UDP, on the other hand, UDP requires fewer bits for the same message content for it to be sent.

Finally, in the Application layer, there are two main paradigms: client-server communications (CoAp, DMLS) and publish-subscribe communications (MQTT, OpenAdr)

Different communication segments depend on transmission mode (wired or wireless), depending on the use of resources (shared medium or dedicated medium), depending on coverage, cost, consumption, data rate, coverage…

The figure below shows the different communication networks and technologies depending on their distance reach.

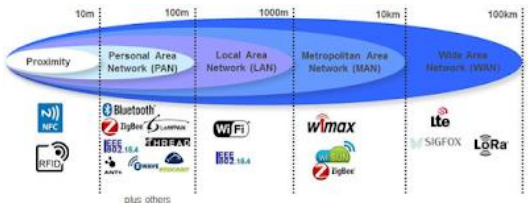


Figure 9 Types of networks [3]

Hardware

In terms of hardware, there are two main technologies on the market: Arduino and Raspberry Pi. While Arduino boards are on average cheaper Raspberry Pi's provide more functionalities, however, the cost of the project is the main contingency and since both technologies would perform the job correctly it would be more suited to the

project to select Arduino as the main hardware.

As the different modules would be separated further than 100 m the connectivity would be 2G/3G Cellular and one of the best hardware options for it is the Arduino MKR gsm 1400

Table 4 Arduino MKR GSM 1400 Datasheet [4]

MICROCONTROLLER	SAMD21 Cortex®-M0+ 32bit low power ARM MCU (datasheet)
RADIO MODULE	u-blox SARA-U201 (datasheet)
SECURE ELEMENT	ATECC508 (datasheet)
BOARD POWER SUPPLY (USB/VIN)	5V
SUPPORTED BATTERY	Li-Po Single Cell, 3.7V, 2500mAh Minimum
CIRCUIT OPERATING VOLTAGE	3.3V
DIGITAL I/O PINS	8
PWM PINS	13 (0 .. 8, 10, 12, 18 / A3, 19 / A4)
ANTENNA GAIN	2dB (bundled antenna at the Arduino Store)
CARRIER FREQUENCY	GSM 850 MHz, E-GSM 1900 MHz, DCS 1800 MHz, PCS 1900 MHz
WORKING REGION	Global
SIM CARD	MicroSIM (not included with the board)
LENGTH	67.64 mm
WIDTH	25 mm
WEIGHT	32 gr.

Other alternative connectivity solutions

Using 4G

The best protocols aiming for low energy, low cost per device, large scalability, deep coverage, and low bandwidth required are Long Term Evolution-M and NarrowBand-IoT (NB-IoT).

In the case of LTE-M, it would be a more suited configuration for eDRx, when the device is powered or regularly charged when big chunks of information are required to be sent or in the case of moving objects

On the other hand, NB-IoT is more suited when the device is super low cost required, high penetration is needed, or the device must run on super low energy.

Therefore, the NB-IoT protocol would work best to send the data from each module to a central station as the modules are not externally powered and the cost is one of the main constraints of the project

Using Zigbee

This solution would be more suitable when the still modules are centralized within a 100m range area (PAN). Zigbee is a wireless communication protocol that transmits information with ultra-low battery consumption. In this case, a hardware solution could be formed by: one Arduino nano or Arduino Uno, two XBee modules (one for the emitting side and one for the receiving side) [5]

Database (DB)

The data obtained from the sensors would be collected on a database, there are two main types of database configurations: relational databases and non-relational databases.

Relational databases (SQL DB) such as MySql data are stored in tables with a static table structure, vertical scalability, and could have downtimes. It has great performance for data analysis, provides easier organization for complex data structures, and is more robust.

On the other hand, non-relational databases (NoSQL DB) such as MongoDB have high availability, with horizontal scalability. The fact that there are no relationships means that there won't be joints in the data selection which will increase the read speed of data.

Figure 10 MongoDB vs MySQL performance [6]

Considering the pros and cons of both technologies the most suited database for this project would be a relational database for its ease of data management and organization and higher writing speed. The data obtained by the sensors will be periodically written on the database while the reading action will only be performed occasionally.

Conclusions

As mentioned earlier the purpose of this project is to develop a sustainable off-grid solution to obtain water from salted water using the greenhouse effect and the additional technological configuration it would need to be managed remotely using IoT solutions.

The solar still solution would be formed by modular panels that depending on the weather conditions and materials used will produce more or less freshwater liters at the end of the day. To determine the number of panels needed to supply clean water for a community of 300 inhabitants it has been taken as standard the liters produced by the company Fcubed modules which produce 15 liters per solar still per day. Assuming a consumption of 2 liters per day per person, 40 modules will be needed. Fcubed centralizes the modules in groups of five so 8 groups/nodes will be required.

From the technological standpoint, each node would be integrated with an IoT solution with different sensors and actuators, the communication will differ depending on the distance between nodes. In the case that the nodes are distanced further than 10 km, the cellular network is required so it has been chosen as the communication standard for the project. To allow cellular communication an Arduino MKR gsm 1400 would be the best fit. The application layer will be defined by a publish-subscribe communication where all the nodes will send the data using the same topic. Finally, the database selected will be MySql for its faster writing speed, and data organization easier to understand when compared to other non-relational databases such as MongoDB.

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