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Design and Construction of a Water Generator System from Air Humidity in the City of Guayaquil

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Introduction

This work focused on the design and construction of a water generator system from air humidity that can be implemented in areas where access to this basic life service is difficult.

The World Health Organization (WHO) estimates that 80 % of all diseases in the developing world are due to the lack of clean water and necessary filtration (World Health Organization, 2011). In Ecuador, while it is true that 70 % of the population has access to safe water, 30 % still do not and therefore are exposed to consuming contaminated water (Unicef, 2018).

In addition to this, pollution in general, climate change, and inefficient management by different entities have exponentially aggravated the ecosystems that allow for water generation, regulation, and storage, decreasing their production capacity over time (Uribe, 2015). This affects everyone, especially the most vulnerable populations located in the outskirts of the city of Guayaquil - people with limited resources who do not have a potable water supply network.

This device captures water vapor from the air and then extracts the water through a drying process. The liquid is obtained in a pure state, but not yet suitable for use, so it must be treated to make it potable.

The functionality of the device will depend on environmental conditions such as humidity and temperature, as well as access to an electrical power source.

To carry out this project, before building the prototype and making the necessary improvements for its correct functionality, it was necessary to simulate the water generation process using simulation software (MATLAB-Simulink) (Matworks, 2023).

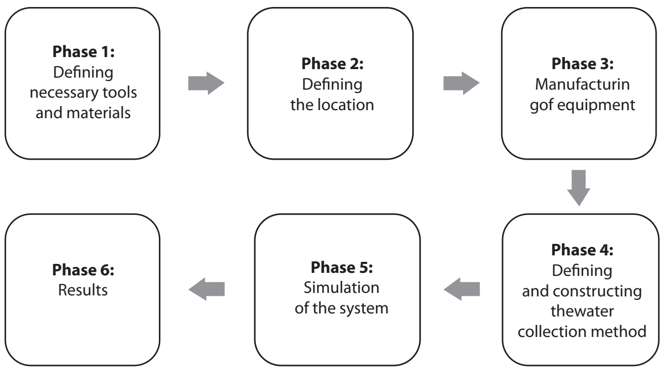
This initiative arose from the need to supply communities where a constant source of water is nonexistent or scarce. It is also important to address these types of issues that affect our environment by designing a device that generates water that meets quality requirements and is environmentally friendly at the same time.

The following sections of the article describe the materials and methods used for the design and construction of the air moisture-based water generator system in the city of Guayaquil. This is outlined in six phases. Subsequently, the simulation of the system using MATLAB-Simulink and PC SIMU is analyzed in the results section. Finally, the relevant conclusions of the study are presented.

Materials and Methods

The following is the methodology used for the simulation (Figure 1), design, and construction of the water generator system. To do this, it was necessary to resort to the thermodynamic cycle with mechanical refrigeration technology and electronic control, which was carried out according to the following methodology:

Figure 1
Phases of simulation, design, and construction of the water generator system



Phase 1: Defining necessary tools and materials

Defining necessary tools, materials, and resources for the development of the water generator equipment. The materials necessary for the construction of the water generator device are explained below:

- **Evaporator:** it is a device with an operation divided into two parts, its main function is to absorb the heat from a space to be cooled and its secondary function is to remove the moisture from the refrigerated area (Bravo, 2022).
- **Condenser:** The condenser is the mechanism responsible for heat exchange, where the superheated vapor enters to be condensed into a liquid state thanks to the cooling of the system.
- **Capillary tube:** It is a throttling device that reduces the pressure of the refrigerant, its process begins from the condenser that leads the high-pressure fluid to the evaporator system by decreasing the pressure (Goncalves, 2021).
- **Compressor:** It is a machine that aims to displace compressible fluids such as compressed gases or vapors, driven by the compression generated by the kinetic energy exchange of the device (Ortiz et al., 2023).
- **Fan:** A device that pushes and pulls air, its specific function is to cool the motor or evaporator by circulating cooling throughout the system (Pucuji, 2022).
- **Metallic structure:** 1.2 mm galvanized, 1 ½ inch casters, 3-inch metal latch, 6011 welding electrodes, glossy white paint and cutting and folding.

Phase 2: Defining the location considering humidity and altitude factors

Define the location considering the factors of humidity and altitude at which the device is located with respect to the ground in relation to the water collection. In this case, the location for the respective tests of the device will be in the city of Guayaquil (Figure 2), which is at an altitude of 4 meters above sea level and has an average humidity of 70 %.

Figure 2
Map of Guayaquil city

Phase 3: Manufacturing of equipment considering AWG method

Manufacturing a functional device capable of creating water through the AWG (Atmospheric Water Harvesting) method (Wang, 2018), see Figure 3.

Figure 3
Manufacturing of equipment

Phase 4: Defining and constructing the water collection method

Choose one of the methodological models to be used with respect to the AWG method (artificial rainwater collection, fog water collection, and dew water collection) (Nahum et al., 2022), in this case, the dew water collection method was considered.

Phase 5: Simulation of the system to verify the functionality of the equipment

The implementation of a simulation model that represents the water generation process and allows for the verification of the equipment's functionality. This will be carried out using the variables and data obtained and then applied to a simulation using MATLAB- Simulink software.

Next, the model is presented according to the dynamics of the system's behavior, defined by first-order equations that describe the operation of the equipment (Tripathi et al., 2019).

Equations

$$W = \dot{m}\,(h2 - h1) \quad (1)$$

$$Q\,L = \dot{m}\,(h1 - h4) \quad (2)$$

$$Q\,H = \dot{m}\,(h3 - h2) \quad (3)$$

$$Q = \dot{m}\,v \quad (4)$$

$$h3 = h4 \quad (5)$$

Where w is power that must be applied from the compressor or fan. $Q\ L$ is Rate of heat extracted from the environment by the evaporator. $Q\ H$ is the rate of heat dissipated by the condenser, that is, the heat loss of the substance for its cooling. Q is Volumetric flow rate that will be obtained from the condenser when cooled. h3 = h4 represents the equality of enthalpies through a connection from the evaporator to the condenser.

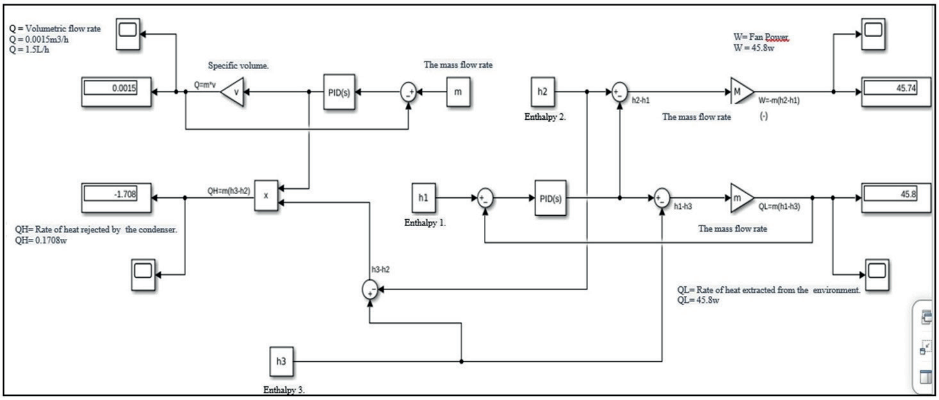
Table 1
Libraries where the model elements can be found

Element	Example
PID controller	Continuous
constant	Commonly used blocks
Scope	Sinks
Display	Sinks
Sum	Commonly used blocks
Gain	Commonly used blocks
Product	Math Operations

When implementing the model, an experimental procedure of a refrigerator is used as a basis, which has a cooling system consisting of a compressor or fan, an evaporator, and a condenser, which are the most important components of the prototype (Cattani et al., 2021). A system is generated with respect to heat transfer and fluid mechanics equations.

In the MATLAB-Simulink platform, a closed-loop simulation is created based on heat transfer and fluid mechanics equations. Four "constant" blocks are chosen for the enthalpies of the equipment and one for the mass flow rate that interacts with the desired flow rate. A gain block is added to the process, which represents the decomposition constant, named "k". It is connected to a summing block with a positive and a negative input. The chain of " |++" is replaced by "|+-" to indicate that the first one is a positive input and the second one is an inverting input (Torres, 2018); see Figure 4.

Figure 4
The model is implemented in MATLAB



To avoid possible disturbances, a closed-loop system was established, meaning that PID controllers and an error from a "Summation" block are included in devices such as the condenser and fan, because the operation of a refrigerator has moments where it rests, reaches a state where it needs to stop, and then resume the process. For the flow rate, a "Product" block is added that generates the equation procedure for obtaining volumetric flow (Abraham, 2019).

As a final implementation, a "Scope" block will be selected to analyze the behavior of the devices over the working time and a final "Display" block that generates a specific numerical result.

In the MATLAB command window, the variables of the model are declared with their values. This can be visualized in Figure 5.

Figure 5
Declaration of model variables

```
>> h1=46.01

h1 =

   46.0100

>> h2=101.01

h2 =

  101.0100

>> h3=60.01

h3 =

   60.0100

>> v=0.036

v =

    0.0360

>> m=0.0015

m =

    0.0015

>> M=-0.0015

M =

   -0.0015
```

For the variables designated as enthalpies, mass flow rate, and specific volume, predefined data tables for the equipment specifications and technical thermodynamics tables are used to delimit them, as illustrated in Table 2.

Implementation of axial fan

Based on the geometric design, the axial fan was integrated to move the air which is at an average temperature of 25,6 °C. There are many factors that can be altered in the condensation process, such as temperature and air velocity.

Table 2
Equipment specifications

Capillary Length in mm	R 134a charge in grams	Enthalpy at evaporator inlet	Enthalpy at evaporator outlet	Mass flow rate of R134a	Thermal power in BTU/h
2100	80	46.01	101.48	4.01	222.66
2100	120	46.38	100.30	4.12	222.37
2100	160	49.55	102.25	6.53	343.94
2500	80	46.38	101.59	3.99	220.28
2500	120	47.00	100.30	4.10	218.52
2500	160	49.80	102.05	6.25	326.56
3300	80	46.71	101.82	3.81	209.98
3300	120	46.35	100.40	3.88	209.73
3300	160	50.13	101.80	5.50	284.21

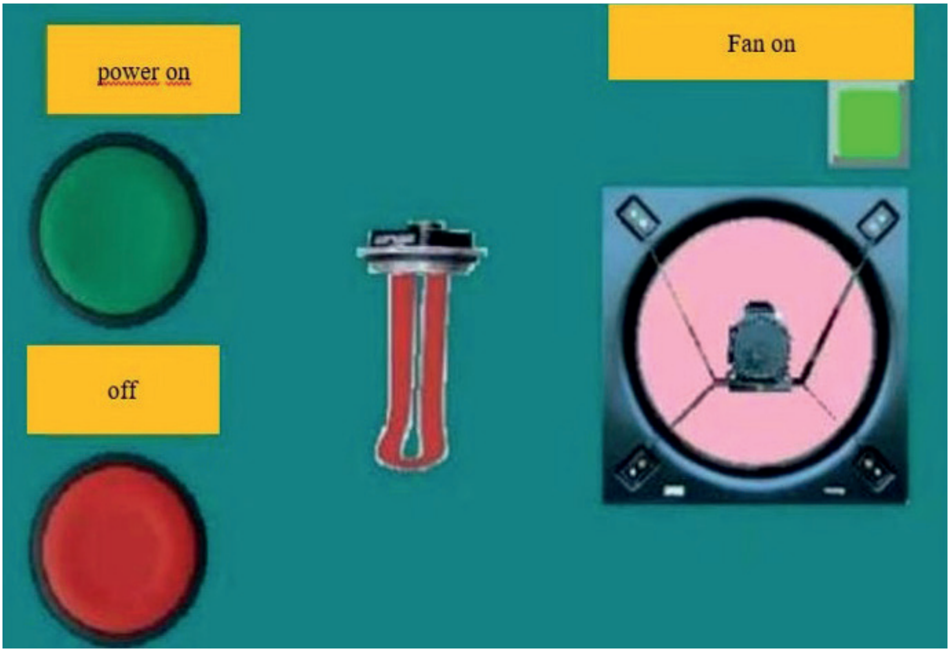
Simulation process

The CAD technology software CADe SIMU was used, which allows controlling any required process through a diagram or circuit, in this case in the water generation process.

The PC SIMU software was also used to control the water generation process in a more didactic and visual way. For representation purposes, a motor and a heating resistor were used, which, through a push button and a timer for connection/disconnection, allow the control of the temperature stabilization process in the device (Figure 6).

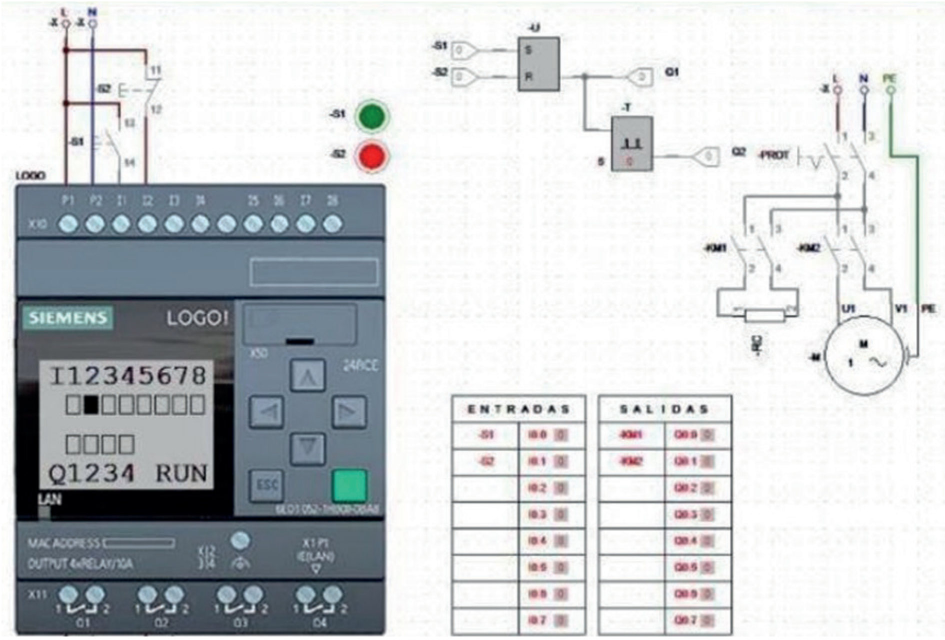
In the PC SIMU software, two buttons were placed, one for start and the other for stop, which allow to start or end the process. Two indicator lights were also placed to announce the correct operation of the fan and the heating resistance.

Figure 6
The fan turned on in PC SIMU



A PLC was used to command the process (Figure 7) in such a way that it can be implemented in practice. This PLC helps to control what is desired to execute through programming.

Figure 7
PLC was used to command the process



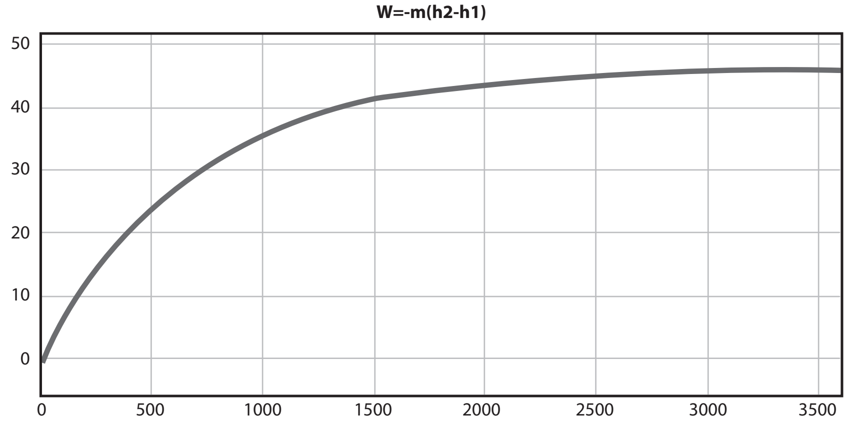
Results

Once the relevant tests were carried out in the prototype design and the analysis and interpretation of the system behavior were conducted, the objectives were fulfilled and the respective parameters for the water extraction process were found. The obtained results are detailed below.

In terms of the power required by the compressor for an hour of operation, the process reaches a state where it must stop, enters a steady state, and the cycle repeats. During the operating time, it uses 45.74 watts of power. Refer to Figure 8 for observation.

Figure 8

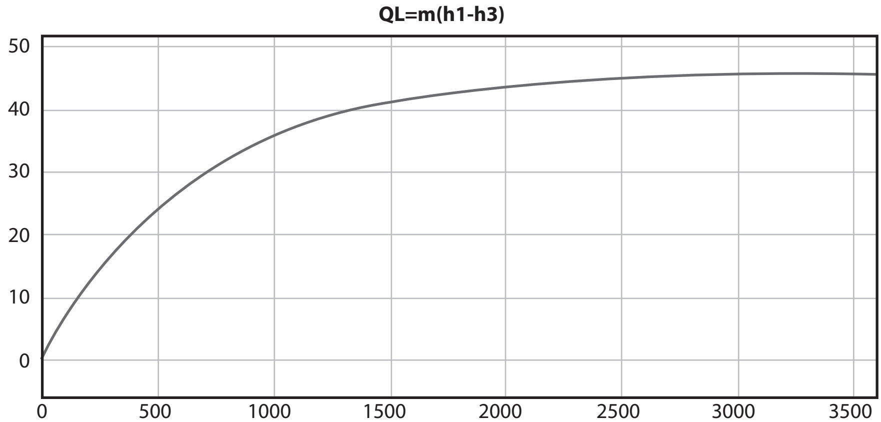
Behavior of the power supplied to the fan



In the case of the evaporator process, it can be observed that its progress is very similar, this is because the amount of forced air it receives to overheat and drive it towards the condenser is the same. Therefore, the process occurs in the same way until the compressor reaches the resting state, with the same measures of 45.8 watts that the evaporator manages to extract in its working hour, as shown in Figure 9.

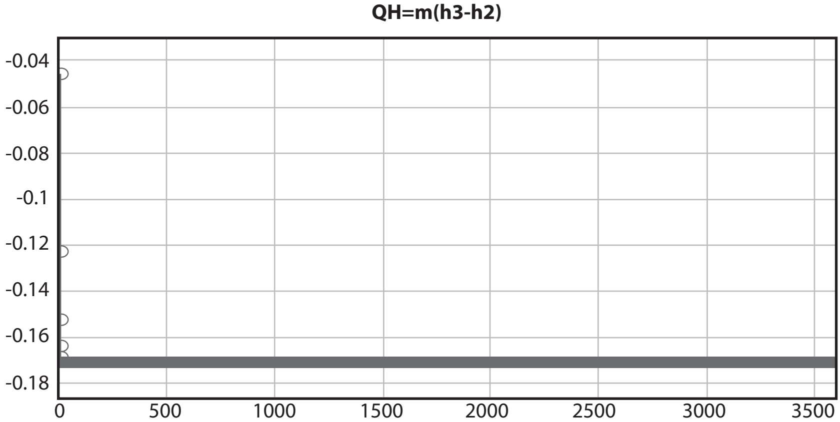
Figure 9

Evaporator process involves forced air extraction



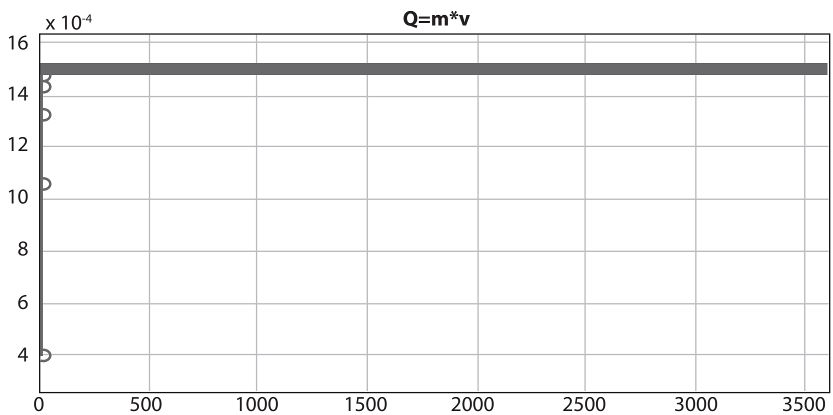
In the condenser, the temperature exchange occurs to cool down the overheated fluid during the estimated one-hour working time, where there will be a mass flow depreciation or loss of –0.1708 watt, while the rest will condense into liquid as illustrated in Figure 10.

Figure 10
Temperature exchange and mass flow loss in the condenser



As the system will extract the condensed liquid to be stored, the volumetric flow rate that can be stored during the condenser's operating time is calculated, which in its procedure is equal to the loss, except that it is the extraction amount, obtaining 0.0015 m^3/h and this equals to 1.5 L/h. These values represent the amount of water obtained in an hour, as shown in Figure 11.

Figure 11
Extraction of flow rate and storage of condensed liquid



Conclusions

The dynamic behavior of the atmospheric generator was evaluated through a simulation model on the MATLAB-Simulink platform, using heat transfer equations and fluid mechanics with basic control actions to which two closed-loop controllers were added. Through feedback, disturbances were rejected, and errors were eliminated in less time, so that the system is not affected in the heat exchanger process, ensuring correct system behavior.

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