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Freshwater production from Humidity under the appropriate technology paradigm: case study in La mesa de los Santos, Colombia.

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Abstract*–The purpose of this paper is to design, build, test and economically evaluate a system for capturing moisture from the atmosphere under the appropriate technology paradigm, taking as a case study the municipality of La Mesa de los Santos, Colombia. Initially, a bibliometric process was carried out to define mathematical models for the 3D CAD design of the technology, then the materials were selected under parameters of local availability, low economic cost and easy handling. Subsequently, the technology to be implemented was simulated in order to analyze its static behavior from analytical wind load data. Once the behavior of stresses, deformations and deflections of the proposed technology was evaluated, the implementation and experimentation were carried out, measuring temperature, humidity, flow and volume variables. The results show an average water production per day of 16,152 liters and the economic study highlights a value of 0.00114 euros per liter.

Keywords-- Appropriate technology, Humidity capture, Water production and Water supply

I. Introduction

Population growth, increasing technological development, and climate change have had a direct impact on water scarcity in various regions of the planet[1]. In addition, the imminent global warming has generated a phenomenon known as water stress, limiting this natural process of water Supply [2]. Generally, the water collection process is carried out naturally by means of channeling in rivers and depends on the rainfall in each country; however, high temperatures have caused extreme Droughts [3].

The Sustainable Development Goals, specifically, Goal 6, refers to clean water and sanitation, seeking to ensure access to safe drinking water, sanitation and hygiene as a basic need for human health care [4]. For this reason, there is a growing need worldwide to develop alternatives for water production [5], to generate a matrix of water resources that guarantee a year-round Supply [3].

Currently, there are commercial technological developments with the ability to produce water [6], which generally rely on desalination [7] and dew harvesting [8], however, they consume a lot of energy, raising the cost of implementation [9]. In this sense, water harvesting from air moisture present in fog becomes an urgent future need for Society [10].

In the approach of producing clean water from the capture of evaporated water in fog, it has been highly attractive and effective in coastal areas[11]. However, in high mountain areas with altitudes above 1500 m above sea level, technological developments have been made in recent decades in countries such as Chile [12], Perú [13], Mexico [14], Colombia [15], Ecuador [16] and Bolivia [17].

The process of producing water in the fog consists of placing a collection system consisting of a permeable surface that allows the fog to pass through it. Fog is understood as a type of cloud, which is present in areas where small water particles do not have enough weight to fall and settle on the ground [18]. In this context, the water particles are retained on the permeable catchment surface and fall by gravity into a storage container.

On their part, [19] evaluated the technical, economic, environmental and social feasibility of a fog trap in Ráquira, Colombia. They compared the proposed system with technological developments applied in Chile, Peru and Bolivia. On the other hand, [20] implemented an automatic fog meter in order to evaluate its ability to capture fog water in La Paz, Bolivia. The authors compared the results with works carried out in Chile and Peru, additionally determining the water quality for direct human consumption.

[21] made a theoretical proposal of a fog-catcher system to supply the needs of a village in Los Santos, Colombia. The authors propose a methodology for the selection of a fog trap that adapts to the geographical and meteorological conditions of a specific area, based on the experience of other authors in Chile. Recently, [22] presented an investigation on obtaining water from the air by means of porous metallic structures. The author proposes an alternative system for future research, where it is compared with normally implemented materials.

A few years later, [23] performed a comparison of fiber types for fog collection, evaluating 12 different materials. The authors highlight three specific materials with better water collection characteristics: (i) nylon, (ii) polyethylene and (iii) plastic. Additionally, they emphasize their high availability and low cost for implementation.

Based on the above, the main purpose of this research was to implement a system for the production of water from moisture capture in high mountain areas using a material with high availability in the experimental area, with low cost and easy to use by local personnel in case of repairs.

II. Methods and Materials

A. Methodology

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Fig. 1 presents the flow diagram of the methodology developed during the research process. Initially, a bibliometric process was carried out using the Scopus database and the VOSviewer software to identify the current advances in moisture harvesting systems, as well as to define the mathematical models required for the subsequent conceptual design using the SolidWorks ® software.

Subsequently, the patterns of meteorological behavior were identified, to perform a calculation of analytical parameters in order to perform a static analysis, through a CFD simulation process, using the SolidWorks ® software. Once the structure was validated in terms of stresses, deformations and displacement, the prototype was implemented in the property located in La Mesa de los Santos, Colombia.

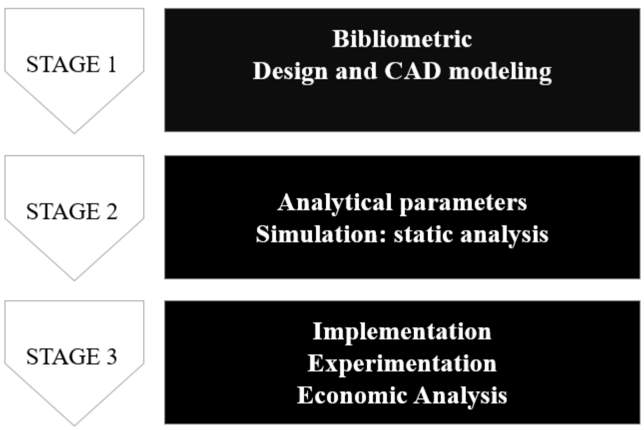

Fig. 1 Activity flow diagram

Los The materials were implemented applying the concept of appropriate technology (AT). AT is understood as an alternative to sustainable solutions and developments in terms of materials, components, cost, maintenance and operation, adapted to the social conditions of the application environment.

Once the implementation process is carried out, the experimentation is developed for 15 days, measuring the value of the variables of temperature, humidity, flow and production volume. Finally, an economic analysis is made according to the water production.

B. Location

Fig. 2 shows the satellite map of the farm called "Sol Naciente", where the fog harvesting system for water production will be implemented. The red box refers to the area of the farm and the light blue arrows to the wind direction. The property is located near the municipality of Los Santos, specifically, at coordinates 6°56'15.573' N, 73°5'42.628 W, at an altitude of 1564 m above sea level. Additionally, the average wind speed is 4 m/s, the average temperature is 19 °C at night and 25°C during the day, and the average humidity is 96%.

Fig. 2 Satellite view of the implementation site
Note: Own adaptation. Image taken from Google Maps

C. CAD modeling

The 3D CAD modeling was performed using SolidWorks ® software; specifying physical measurements of the system (support structure and intake structure) to perform a static analysis and obtain drawings for implementation. Initially, a series of preliminary calculations are made for the CAD design.

Analytically, the wind force is estimated based on climatological data from the implementation site. The wind speed (v) is 4 m/s; however, the density is estimated using equation (1) [9].

$$r = 24 * \frac{P}{273+T} = 24 * \frac{12.182\ (PSI)}{273+25} = 0.04087\ g/l \qquad (1)$$

Where, P is the barometric pressure in PSI (determined from the height above sea level) and T is the average ambient temperature (day) in °C.

Once the velocity is estimated, it is necessary to pass the units of kg/m^3 and apply equation (2) to estimate the wind force.

$$Pv = \frac{1}{2} * r * v^2 = 0.32696\ N/m^2 \qquad (2)$$

The estimated wind pressure value is used in the software to perform the simulations. Additionally, the following considerations are presented:

- 18 m2 catchment area
- Mechanical properties of materials taken from the software libraries.
- Air force was not considered
- Ground level was not considered
- Gravity was not considered
- Assembly alignment not considered
- The cross section of the collection chute is neglected.

Fig. 3 presents the shape and sectioning of the fog catcher (3 sections).

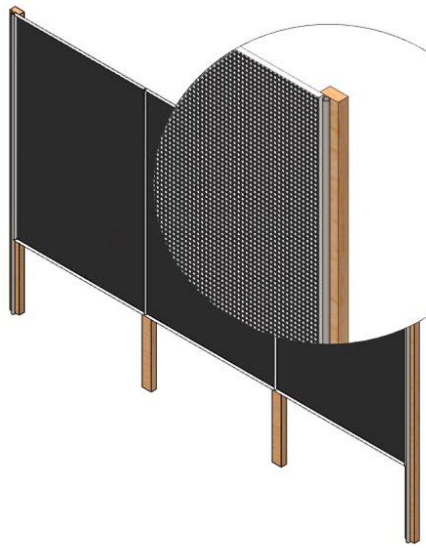

Fig. 3 3D CAD modeling of the mist collector prototype to be implemented

Finally, the mass flow to be used is estimated once the catchment area and wind speed are defined, assuming a fog density of0.05 g/m^3 [20] using equation (3).

$$m = pvA = 0.0036\,\frac{kg}{s} \tag{3}$$

D. Materials

The construction process of the fog collection system was based on the drawings obtained from the CAD modeling. The system consists of three main subsystems: support structure, collection structure and collection system. Table I lists the main materials used in the manufacturing process and technological implementation.

TABLE I
PRINCIPAL MATERIALS

Quantity	Unit	Elements/Material	Observation
1	m	Black water/PVC piping	Addition of anticorrosive paint
24	m^2	Mesh Raschel/ polyethylene	80% shading coefficient
3	m	Pipe/PVC	Operating pressure 21-200 PSI
1	Ud.	Tee/PVC	
5	Uds.	Elbow-Unión/PVC	
6	Uds.	Posts/Wood	
1	Ud.	Tank/Polypropylene	Capacity 20 Liters
1	Ud.	Flowmeter	

The selection of the main material was based on two criteria: (i) search for information and (ii) availability of the material. The search process was Bibliometric in nature using the Scopus database and the VOSviewer program for information processing. The terms used in the search were "Water production" and "Humidity". We identified antecedents in geographic environments similar to the experimental site with satisfactory results for the use of polyethylene Raschel mesh with 80% shading coefficient, as well as abundant local availability.

In general, it is a permeable material for outdoor use, favorable to let the humid wind flow against the current, being flexible and adaptable to the geometries required for the assembly.

III. Results and Analysis

A. Simulations

The simulation process in the SolidWorks ® software was centered on the static analysis of stresses, displacement and unit deformation of the intake structure and the support structure, as shown in Fig. 4 A, Fig. 4 B and Fig. 4 C, respectively.

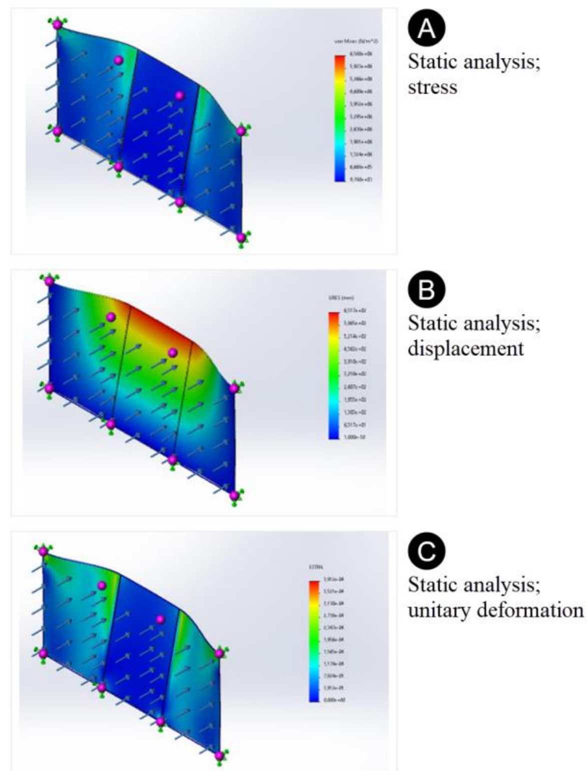

Fig. 4 Static analysis using SolidWorks

The minimum simulated load was the pressure value determined in Equation (2) and the contact ratio was based on a global interaction between components; mesh, structure and rigid joints. The result of the stress analysis (see Fig. 4 A) gives a minimum value of 0 N/m^2 at node 10592 and a maximum value of 6.580e+0.6 N/m^2 at node 3557, specifically towards the areas bordering the junction points of the three 6 m^2 catchment sections that make up the system unit.

In turn, the resultant of the displacement analysis (see Fig. 4 B) gives a minimum value of 0 N/m^2 at node 10592 and a maximum value of 6.517e+0.6 N/m^2 at node 10992, specifically in the upper central zone, directly affecting the central section of 6 m^2 of catchment that make up the system unit.

On the other hand, the resultant of the equivalent unit deformation analysis (see Fig. 4 C) gives a minimum value of 0 N/m^2 at node 5115 and a maximum value of 3.912e+0.4 N/m^2 at node 4539, specifically in the upper central zone, directly affecting the two lateral sections of 6 m^2 each, which make up the system unit.

In summary, the simulation process allowed to verify the behavior of the system from a minimum load resulting from meteorological data of the area, showing an adequate behavior to carry out the construction and implementation process.

B. Implementation

Fig. 5 presents the final implementation of the water production system from moisture harvesting, based on the meteorological data survey of the area, the preliminary analytical calculations and the load study presented in the previous section. The system built and subsequently implemented, consists of three main sections: collection structure, support structure and water collection system.

Fig. 5 System Implementation

The structure was tested preliminarily to the experimental process for one week, in order to corroborate the information obtained from the simulation process. The result was a structure resistant to the climatic conditions of the region. Finally, the flow, temperature and humidity measurement systems were implemented to carry out the measurement process.

C. Experimentation

Fig. 6 shows the water production system from humidity (red box), implemented and subjected to the climatic conditions of the region for the preliminary and final testing process. The mesh is responsible for accommodating water droplets resulting from direct contact with the orographic fog coming from the mountains in the direction of the assembly.

Fig. 6 Experimental process under regional environmental conditions

The experimental process was carried out during 15 continuous days in July 2022. Table II shows the daily average values of the flow rate and the volume of water captured by the implemented system. The final average production volume (P_D) of the experimental process was 16,152 liters/day.

TABLE II
TEST DATA

Date	Flow measurement (m^3)	Volume of water captured (Liters)
10/07/2022	0,00198	1,98
11/07/2022	0,02031	18,33
12/07/2022	0,03392	13,61
13/07/2022	0,05441	20,49
14/07/2022	0,06887	14,46
15/07/2022	0,08092	12,05
16/07/2022	0,09786	16,94
17/07/2022	0,10683	8,97
18/07/2022	0,13004	23,21
19/07/2022	0,14825	18,21
20/07/2022	0,16372	15,47
21/07/2022	0,18286	19,14
22/07/2022	0,19759	14,73
23/07/2022	0,21809	20,5
24/07/2022	0,24229	24,2

Fig. 7 graphically relates the data presented above in Table II. The maximum daily production point was the last day of testing (07/24/2022) with an average daily production of 24.2 liters, while the least favorable day was the first day (07/10/2023), with an average daily production of 1.98 liters.

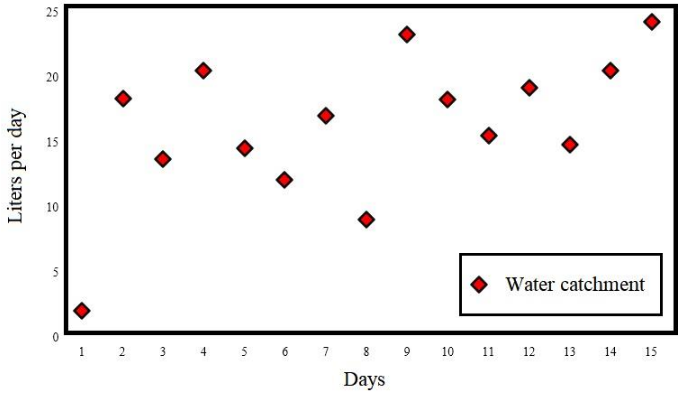

Fig. 7 Average water production volume of the experimental process

In addition, the behavior of temperature and humidity was monitored during the experimental period, as shown in an inversely proportional relationship between temperature and humidity was observed in the sector where the system was implemented, i.e., the higher the humidity, the lower the temperature value. The temperature values were in the range of 18 to 27 °C, while the humidity ranged from 60 to 100%.

If Fig. 8. is related to the results presented in Fig. 7, a trend of 100% humidity and temperatures at the lower limit of the average (18°C) is evident for the days of higher water production.

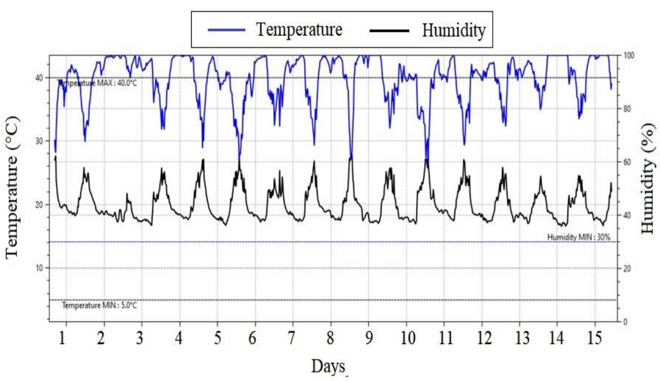

Fig. 8 Behavior of temperature vs. humidity over time of the experimental process.

With the information obtained, the global efficiency of the system is calculated, which is the algebraic sum of the deposition efficiency (η_{dep}) , the aerodynamic efficiency (η_{AC}) and the drainage efficiency (η_{dr}) . The deposition efficiency is determined by applying equation (4).

$$\eta_{dep} = \frac{stk}{stk+\frac{\pi}{2}} \quad (4)$$

The Stokes number (skt) is determined by applying equation (5).

$$Stk = \frac{\rho_t \; v \; {d_d}^2}{18 \; \mu \; D_w} = \frac{\left(997 \frac{kg}{m^3}\right) * \left(4 \; \frac{m}{s}\right) * (0{,}0004 \; m)^2}{(9) * (0{,}0000174 \; pa * s) * (0{,}002 \; m)} = 2.25542 \quad (5)$$

Where, v = wind speed (m/s), μ = wind viscosity (pa*s), = water droplet density (kg/ , = droplet diameter (m) and = mesh diameter (m).

Finally, the deposition efficiency is equal to: $\eta_{dep} = \frac{2.5542}{2.5542 + \frac{\pi}{2}} = 0{,}6192 = 61.92\%$

On the other hand, the aerodynamic efficiency is determined by applying equation (6). Where the shading coefficient (s) is 80%, the pressure drop coefficient of the air flow through the screen ( ) is 27.6048 and the drag coefficient of an impermeable surface ( ) is 1.185, corresponding respectively to the commercial shading coefficient.

$$\eta_{AC} = \frac{S}{1 + \sqrt{\frac{C_o}{C_D}}} = \frac{0{,}8}{1 + \sqrt{\frac{27{,}6048}{1{,}185}}} = 0{,}1373 = 13{,}73 \; \% \qquad (6)$$

The drainage efficiency is determined by applying equation (7).

$$(\eta_{dr}) = \frac{12{,}96 * \eta_{dep}}{0{,}673} = \frac{12{,}96 * 0{,}6192}{0{,}673} = 11{,}923 = 11{,}92 \; \% \quad (7)$$

It should be taken into account that the daily production corresponds to 16,152 liters, which means that an average of 0.673 liters are collected per hour. Thus, as the volumetric flow corresponds to one hour is 12.96 liters.

Finally, the overall efficiency is determined by applying equation (8) and is 29.19%.

$$\eta_{col} = \frac{\eta_{dep} \; \eta_{AC} \; \eta_{dr}}{3} \qquad (8)$$

C. *Error propagation*

The errors that exist in the measurement of a magnitude to an instrument cause it to have an uncertainty. In this context, Table III lists the error propagation of the measuring instruments used in the experimental process.

TABLE III
ERROR PROPAGATION

Instrument	Parameter	Range	Accuracy	Uncertainty
Temperature (T) and Humidity (Hr) Sensor	Temperature and Humidity	0°C a + 50°C 30 a 100 %	T +/- 2 °C Hr +/- 5 %	T +/- 0.5°C Hr +/- 0.6%
Flow Meter	Flow Rate	0 2.5 m^3/hora	+/- 2.5 %	+/- 1.5 %

D. *Economic analysis*

The economic study of a water production system depends on parameters such as useful life (n), the total cost of the device (C_{CC}), the maintenance cost (C_m) and the total cost of the product (C_T). For the present economic analysis, the following assumptions are taken into account:

- Useful life (n) is 10 years.
- Maintenance cost equal to 20% of the total cost of the device.
- Production period (P_P) 365 day per year
- Period of operation (P_F) 24 hours per day

The total cost of the device, estimating the cost values for materials, equal to 223.5 euros. The variable cost (Cv) The variable cost (Cv) of the system is determined in equation 9 and takes into account the assumed values for the useful life (n) and the maintenance cost.

$$C_V = 20\% * 223.5\,€ * 10\,años = 447\,€ \tag{9}$$

The total cost of the product (C_T), is estimated with (C_{CC}) and (Cv) by applying equation 10.

$$C_T = C_{CC} + C_V = 223.5 + 447 = 670.5\,€ \tag{10}$$

The number of liters that would be produced (P_T) are directly related to P_D , P_F and n (see Equation 11).

$$P_T = \left(16.152\,\frac{L}{día}\right) * \left(365\,\frac{día}{año}\right) * 10\,años = 58{,}954.8\,L \tag{11}$$

Finally, the cost of water per liter (Cw) is equal to (C_T) over (P_T) as shown in equation 12.

$$C_w = \frac{C_T}{P_T} = \frac{670.5}{58{,}954.8} = 0.0114\,Euros\,(€) \tag{12}$$

When comparing the cost per liter of freshwater production of the proposed system with the world average, according to an analysis of 92 countries in 2022 [24] where a freshwater cost of 0.13 euros is established, a significant difference is observed.

IV. CONCLUSIONS

The production of water from the capture of moisture in isolated areas will play an important role in the world's water supply. However, a preliminary analysis of the specific environmental, geographic, social and economic characteristics of each region and specific population is necessary. In this sense, the appropriate technology paradigm offers a sustainable solution over time at low cost. In this context, it is possible to implement a honey trap system and the main conclusions are listed below:

- The average water production of the proposed technology is 16,152 liters per day, reaching the minimum levels mentioned by the United Nations (15-29 liters/day) for the minimum water supply of a person, however, it requires an additional treatment to make the fluid drinkable.
- Water production is directly affected by weather variables of low temperature and high humidity to realize a process of condensation of the water vapor present in the mist. If this relationship is not maintained, water production will drop.
- The static analysis performed in CFD with analytical data estimated on the basis of meteorological variables, allowed to implement a system resistant to wind speed and the resulting stresses on the surface of the prototype.
- The economic analysis reveals that the water production value is lower than the value of drinking water according to the world average. In addition, the system was implemented in a region that experiences constant water shortages throughout the year, representing a solution to guarantee water supply during periods of scarcity.
- The design of the system presents favorable characteristics such as modularity and low maintenance, favoring the expansion in square meters of catchment area, incurring directly in an increase in production.

In general, it was possible to implement an alternative technology for the production of water from humidity in high mountain areas with water shortage problems. At the same time, the concept of appropriate technology is used as a basis to promote functional technological developments with low economic needs for their maintenance over time.

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