Optimization Model of a Water Generation Prototype Based on Condensation

Carlos Iván Nolasco, Ingeniero Industrial, Maria Elena Perdomo, Master en Ingeniería Industrial, Jose Luis Ordoñez Avila, Master en administración de proyectos
Universidad Tecnológica Centroamericana UNITEC, Honduras, car_12dw@unitec.edu, maría_perdomo@unitec.edu, jlordonez@unitec.edu

***Abstract*— The aim of creating this prototype, although, at an experimental level, was to contribute in an alternative ways to generate water and mitigate the impact of the scarcity that exists. This research was the second phase with the generation prototype, where the first phase comprised its construction and first tests, where it was verified that it can generate water. This second phase comprised implementing mathematical optimization models to maximize the amount of water generated. It was necessary to know the most optimal conditions for a greater amount of water, conditions that were got with the applied models, overcoming and improving the generation results of the first phase. The forecast model designed for the investigation applied to each optimization model contributed to the selection of the best model alternative. With the final total forecast, it was possible to identify the uses or applications that it could have according to the amounts of water it would generate.**

Keywords— wáter generation, Lapalce optimization model, Hurwicz optimization model, Forecast

I. Introduction

Water scarcity is a problem that affects almost all human beings and it is necessary to innovate and create alternative ways to generate water. This project shows an alternative of using refrigeration systems to generate water. The first step is to collect data from the prototype. With the current physical and operational conditions, the optimization data is reliable as possible. This data is used to generate a mathematical model to describe the prototype behavior. The environmental conditions temperature, humidity, dew temperature are the main variable that affects the behavior of the prototype?

II. Theoretical Framework

A. Analysis of the current situation

Water scarcity is a global problem, and the magnitude of this problem is increasing every day. It could be said that scarcity is generated when a supply of fresh water does not have the capacity to supply the demand in an area. Water scarcity is directly attributed to climate change and all places are exposed to this phenomenon reaching them, even, those places that have high percentages of rain. Its effects are not only of a physical nature, such as the lack to carry out daily activities (Human Consumption) and the environmental impact that it carries with it, translated into the affectation of flora and fauna. This also has a high impact in the social and economic sphere, triggering conflicts over water and great losses in various sectors. [1]

B. Consumer applications

Access to drinking water is a right of human beings and there is a dependence on this resource since it satisfies the basic needs related to the health and living conditions of individuals. Improving access to drinking water networks could translate into great benefits for human health and with this, the right to dignity of each individual would be respected.[2] A large number of infectious and parasitic diseases in the world are due to poor sanitation of the water sources available to people, where minors are the ones who are most affected and most of the victims belong to countries on development process. [3]

C. Industrial Applications

Agriculture is the economic sector in which water scarcity is most relevant. At present, agriculture is responsible for 70% of freshwater withdrawals and more than 90% of its consumptive use. [4] and in food industry Water is one of the most important inputs in the food manufacturing process. There is a term called Water Footprint that is important to consider when talking about water in the food industry and this is defined as the amount of fresh water that is needed in the manufacture of common consumer products, either as an ingredient in the final product or as part of the process to make it. [5]

D. Water Scarcity y Latin-America

In Latin America and the Caribbean, fresh water is one of the greatest riches, having 26% of the planet's freshwater reserves. Despite having 4 of the 25 longest rivers in the world and some of the great lakes in countries like Brazil, Colombia, Venezuela and Argentina. The lack of this precious resource is a common denominator in Latin American countries, and this could be attributed to various reasons such as rapid demographic growth, lack of education for people to properly care for water, high corruption, bad efforts, and lack of scientific work to address the shortage. Rivers and lakes in Latin America are rapidly depleting. [6] In Latin America and the Caribbean, about 38 million people do not have access to drinking water sources and water-borne diseases appear among the three major causes of death, with the consequent impact on public health in the region. [3]

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E. *Water Scarcity in Honduras*

6.3 million people in Honduras, have access to water, but not all of it is safe for consumption. Also, about 30% of Hondurans, some 2.7 million people, use water from surface sources [7], the Scarcity has worsened because the country has less forest cover, and much underground aquifers have dried up [8].

F. *Psychrometry, Humidity, Dew Point*

The author [9] mentions that psychrometry is the science that involves the thermodynamic properties of humid air, and the effect of atmospheric humidity on materials and human comfort. with various areas of application such as laboratories, plant air conditioning, food industry, refrigeration, among others.

Humidity is related to the water vapor that is contained in the atmosphere. Steam is generated through the process of evaporation of water from the seas, rivers, lakes and all living things that contain water. The amount of water in the air will depend directly on its temperature. High temperatures can absorb a greater amount of water vapor [10]. The dew point is the temperature in which water vapor condenses in a gas sample [11].

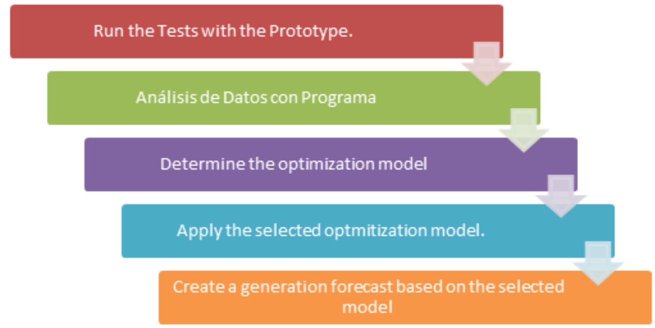
$$Td = T + 35\, log(\emptyset)$$

G. *Optimization Models*

A model is obtaining as much of a real problem as possible; to which certain mathematical considerations will be applied that allow to get optimal results. It can be said that a mathematical model is an equation, inequality or system of equations or inequalities, which represents certain aspects of the physical system represented in the model. Models of this type are widely used in the physical sciences, engineering, business, and economics. [12]

III. METHODOLOGY

It was determined that the research carried out was with a quantitative approach since the results are based directly on the analysis of statistical data got from the tests carried out with the prototype of water generation based on condensation. It is of an experimental type since unlike other types of research in which the researcher is only an observer, in this one he can act consciously on the object of study and know the effects produced by his actions. The method of comparing the results with data from previous investigations is useful in this one since there is data from the initial tests in the prototype construction process with which the new results after the optimization can be compared.



The sample size for this investigation was obtained with the formula for optimal sample size with infinite population with the following parameters: Confidence Level= 95%; Accepted Error= 5%; Z Value= 1.96; Probability of success= 0.91; Probability of failure= 1-p = 1-0.91 = 0.09.

$$n = \frac{z^2 \cdot P(1-P)}{e^2}$$

$$n = \frac{1.96^2 \cdot 0.91(1-0.91)}{0.05^2}$$

$$n = 125$$

IV. RESULTS

With the data on the amount generated and the dew point temperature of the 125 tests, an analysis was carried out to know the correlation that exists between the dew point temperature and the milliliters generated for the entire project, with which it was identified that there is a negative correlation between both variables, which means that when the values in one variable increase, in the other they decrease, as shown in Fig. 1.

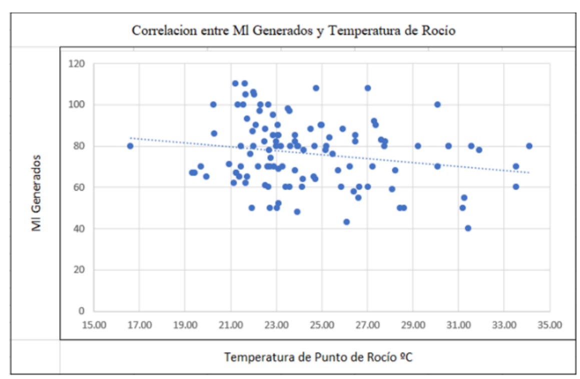


Fig. 1- Milliliters Generated/Dew Point Correlation Diagram

It was necessary to define the classes or groups into which the data would be divided and which at the same time would serve as dew point temperature limits. Using basic statistics, it was determined that the suggested classes were 8, each with an amplitude of 2.21 calculated with the rule of Sturges.

A. OPTIMIZATION MODEL ACCORDING TO LAPLACE CRITERIA

This decision-making criterion suggests that all the states of nature of the problem are equally probable. The first model designed for optimization is the following:

$$Re = x_1(P_1) + x_2(P_2) + x_3(P_3)$$

Where, Re presents the Expected results that would be the generated milliliters, and the X1(Failure), X2(Without changes) and X3(Success) variables represents the states of nature of the problem, each with a 0.3333 probability. And the results of the application of these first model are the following:

Table 1 Laplace Model Results

Upper Class Limit	Classes	Water Milliliters Average	frequency	Max. per class (Success)	Min. per class (Failure)	Expected Milliliters
18.83	(16,62-18,83)	56.00	2	80.00	32.00	55.99
21.04	(18,83-21,04)	75.14	7	100.00	65.00	80.04
23.25	(21,04-23,25)	79.69	48	112.00	40.00	77.22
25.46	(23,25-25,46)	80.26	27	120.00	48.00	82.74
27.67	(25,46-27,67)	73.41	19	108.00	43.00	74.80
29.88	(27,67-29,88)	67.67	9	110.00	30.00	69.22
32.09	(29,88-32,09)	67.10	10	100.00	38.00	68.36
34.30	(32,09-34,3)	70.00	3	80.00	60.00	69.99

Laplace's criterion suggests that the best alternative that can be selected from among all of them is the one with the highest value within the column of expected results. For this case, the best alternative would be number 4 with the highest amount of water generated, 82.74 milliliters.

This alternative also shows the optimal dew point temperature conditions (represented by the limits per class) that must exist for this amount of water to be given. Since the dew temperature totally depends on the ambient temperature and relative humidity, it was necessary to know what temperature and humidity conditions must exist in a certain place and at a certain time for the dew temperature to remain in the optimal range, As shown:

Table 2 Laplace Optimal alternative and conditions

Optimal Alternative	Dew Point Temperature Range °C	Expected Amount (ml)	Average Ambient Temperature (°C)	Average Humidity (%)
4	23.25 a 25.46	82.74	28.80	74.33

B. OPTIMIZATION MODEL ACCORDING TO HURWICZ CRITERIO

For the application of this model, the same dew point temperature and amount of water generated data with the previous model. This model works with a coefficient of optimism called Alpha, which must be calculated and assigned to each alternative. Similarly, the criterion suggests that the best alternative is the one with the highest value within the column of expected results.

$$PE(a_k) = \alpha Max\ Value(a_k) + (1-\alpha) Min\ Value(a_k)$$

Where, $PE = ER = Expected\ Results$ y $(a_k) = Alternative\ n$

Table 3 Hurwicz Model Results

Upper Class Limit	Classes	Water Milliliters Average	Frequency	Max per class (Success)	Min per clase (Failure)	α Coefficient	Expected Milliliters
18.83	(16,62-18,83)	56.00	2	80.00	32.00	0.5	56.00
21.04	(18,83-21,04)	75.14	7	100.00	65.00	0.285714286	75.00
23.25	(21,04-23,25)	79.69	48	112.00	40.00	0.541666667	79.00
25.46	(23,25-25,46)	80.26	27	120.00	48.00	0.423076923	78.46
27.67	(25,46-27,67)	73.41	19	108.00	43.00	0.473684211	73.79
29.88	(27,67-29,88)	67.67	9	110.00	30.00	0.555555556	74.44
32.09	(29,88-32,09)	67.10	10	100.00	38.00	0.6	75.20
34.30	(32,09-34,3)	70.00	3	80.00	60.00	0.333333333	66.67

The results of the application of this model suggest that the most optimal alternative is number 3, with the amount of 79 milliliters generated. likewise, the model shows the dew point temperature range that must exist to generate such an amount of water. Also, for this model it is necessary to know the conditions of environmental temperature and relative humidity that must exist for such dew point temperature.

Table 4 Hurwicz Optimal Alternative and Conditions

Alternative	α Value	Dew Point Temperature Range °C	Expected Amount (ml)	Average Ambient Temperature (°C)	Average Humidity (%)
3	0.541666667	(21,04-23,25)	79.00	26.85	74.13

For each optimal alternative according to the criteria, it was identified how many tests were performed during the day and evening. Almost all the tests were performed during the afternoon. With the environmental temperature and relative humidity data of each iteration, a correlation diagram was made. This diagram is shown in figure 2 with negative correlation which shows that, during the evening, when the temperature values drop, the humidity increases, which leads to a greater generation of Water. As shown in next illustration where X axis represents Humidity and Y axis Ambient temperature.

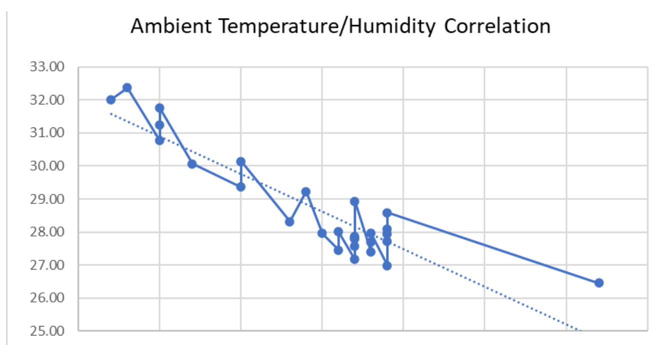


Fig. 2- Ambient Temperature/Humidity Correlation Diagram

Table 5 Optimal Tests according to Schedules

Optimal Tests	Day Schedule	Afternoon/Evening Schedule
27	10	17
100%	37.04%	62.96%

Although at this point in the project, the best alternative seemed to be the Laplace model over the Hurwicz model. It would be the forecasting model that would determine which of the 2 models is the most suitable for the prototype.

C. FORECAST MODELS

For this project, it was sought to design a generation forecast for a range of 14 days from September 25 to October 8, 2020, based on the data of maximum (0 to 12 hours) and minimum (13 to 24 hours) environmental temperature and humidity in the city of San Pedro Sula, Honduras, obtained from meteorological forecast resources.

For the general design of the forecasting model, the "If" function of Microsoft excel was used. function that allowed the optimal relationship of the criteria defined for the forecast. The same forecast model worked for both optimization models using the expected results data (Milliliters) of each one, respectively.

$$= +IF(K62 < \$H\$33; \$N\$33; IF(K62 < \$H\$34; \$N\$34; IF(K62 < \$H\$35; \$N\$35; IF(K62 < \$H\$36; \$N\$36; IF(K62 < \$H\$37; \$N\$37; IF(K62 < \$H\$38; \$N\$38; IF(K62 < \$H\$39; \$N\$39; IF(\$K\$62 < H40; \$N\$40; 0))))))))$$

Where,

$K_n = Dew\ point\ temperature\ of\ the\ forecast\ date.$

$H_n = Upper\ Limit\ for\ each\ Class.$

$N_n =$ $Milliliters\ expected\ for\ each\ class\ in\ the\ optimization\ models$

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D. FORECAST FOR LAPLACE OPTIMIZATION MODEL

Table 6 corresponds to the forecast for 12 hours with maximum temperatures. Table 7 corresponds to the remaining 12 hours with minimum temperatures. By adding the forecast for 12 hours with maximum and minimum temperature per date, the daily amount of generation is got, with which, later, the total generation forecast for the 14 days would be got. as shown in the third table 8.

For the first forecast, the expected results data from the Laplace model were used. The forecasting model related the dew point temperature data of the dates to be forecast with the class limits and milliliters expected in the Laplace model results table and thus generate the forecast.

Table 6 Laplace forecast with maximum ambient temperature

Forecast with Maximum Ambient Temperature					
Date	Temperature ° C	Humidity %	Dew Point ºC	Milliliters Forecast	Forecast 12 hrs P/Day
25/09/2020	33.00	64.00	23.00	77.22	1235.54
26/09/2020	34.00	62.00	26.73	74.80	1196.74
27/09/2020	35.00	56.00	26.19	74.80	1196.74
28/09/2020	34.00	60.00	26.24	74.80	1196.74
29/09/2020	33.00	66.00	26.68	74.80	1196.74
30/09/2020	30.00	85.00	27.53	74.80	1196.74
01/10/2020	31.00	80.00	27.61	74.80	1196.74
02/10/2020	31.00	86.00	28.71	69.22	1107.44
03/10/2020	31.00	86.00	28.71	69.22	1107.44
04/10/2020	31.00	68.00	25.14	82.74	1323.92
05/10/2020	31.00	80.00	27.61	74.80	1196.74
06/10/2020	31.00	90.00	29.40	69.22	1107.44
07/10/2020	31.00	87.00	28.88	69.22	1107.44
08/10/2020	31.00	65.00	24.45	82.74	1323.92
				Total	**16690.36**

Table 7 Laplace forecast with minimum ambient temperature

Forecast with Minimum Ambient Temperature					
Date	Temperature ° C	Humidity %	Dew Point ºC	Milliliters Forecast	Forecast 12 hrs P/Day
25/09/2020	23.00	64.00	16.22	55.99	895.91
26/09/2020	23.00	62.00	15.73	55.99	895.91
27/09/2020	24.00	56.00	15.19	55.99	895.91
28/09/2020	24.00	60.00	16.24	55.99	895.91
29/09/2020	24.00	66.00	17.68	55.99	895.91
30/09/2020	22.00	85.00	19.53	80.04	1280.63
01/10/2020	22.00	80.00	18.61	55.99	895.91
02/10/2020	23.00	86.00	20.71	80.04	1280.63
03/10/2020	23.00	86.00	20.71	80.04	1280.63
04/10/2020	22.00	68.00	16.14	55.99	895.91
05/10/2020	22.00	80.00	18.61	55.99	895.91
06/10/2020	22.00	90.00	20.40	80.04	1280.63
07/10/2020	23.00	87.00	20.88	80.04	1280.63
08/10/2020	23.00	65.00	16.45	55.99	895.91
				Total	**14466.36**

Table 8 shows the last results of the forecast that was made for the Laplace criterion model, where the amount of mL expected for each of the days can be visualized, giving a total for the predicted amount of 31,156.72 mL or 31.15 liters in 14 days.

Table 8 Laplace fourteen days forecast

Total Water Generation	
Date	Daily Amount (Milliliters)
25/09/2020	2131.45
26/09/2020	2092.65
27/09/2020	2092.65
28/09/2020	2092.65
29/09/2020	2092.65
30/09/2020	2477.38
01/10/2020	2092.65
02/10/2020	2388.08
03/10/2020	2388.08
04/10/2020	2219.83
05/10/2020	2092.65
06/10/2020	2388.08
07/10/2020	2388.08
08/10/2020	2219.83
Total Generated in 14 days	**31156.72**

E. FORECAST FOR HURWICZ OPTIMIZATION MODEL

As with the forecasts got with the data from the Laplace model, in tables 9 and 10, corresponding to the maximum and minimum temperatures, respectively. The results contradict the statement that during the night with minimum temperatures, the amount of water generated is greater. This contradiction is because no variations in humidity were used for the forecasts and the temperatures used are not data with much variation, unlike the data got in tests where the sensor detected the smallest changes in temperature, which directly affects the dew temperature and, therefore, the amount of water generated.

Table 9 Hurwicz forecast with maximum ambient temperature

Forecast with Maximum Ambient Temperature					
Date	Temperature º C	Humidity %	Dew Point ºC	Milliliters Forecast	Forecast 12 hrs P/Day
25/09/2020	33.00	64.00	23.00	79.00	1264.00
26/09/2020	34.00	62.00	26.73	73.79	1180.63
27/09/2020	35.00	56.00	26.19	73.79	1180.63
28/09/2020	34.00	60.00	26.24	73.79	1180.63
29/09/2020	33.00	66.00	26.68	73.79	1180.63
30/09/2020	30.00	85.00	27.53	73.79	1180.63
01/10/2020	31.00	80.00	27.61	73.79	1180.63
02/10/2020	31.00	86.00	28.71	74.44	1191.11
03/10/2020	31.00	86.00	28.71	74.44	1191.11
04/10/2020	31.00	68.00	25.14	78.46	1255.38
05/10/2020	31.00	80.00	27.61	73.79	1180.63
06/10/2020	31.00	90.00	29.40	74.44	1191.11
07/10/2020	31.00	87.00	28.88	74.44	1191.11
08/10/2020	31.00	65.00	24.45	78.46	1255.38
				Total	**16803.63**

Table 10 Hurwicz forecast with minimum ambient temperature

Forecast with Minimum Ambient Temperature					
Date	Temperature º C	Humidity %	Dew Point ºC	Milliliters Forecast	Forecast 12 hrs P/Day
25/09/2020	23.00	64.00	16.22	56.00	896.00
26/09/2020	23.00	62.00	15.73	56.00	896.00
27/09/2020	24.00	56.00	15.19	56.00	896.00
28/09/2020	24.00	60.00	16.24	56.00	896.00
29/09/2020	24.00	66.00	17.68	56.00	896.00
30/09/2020	22.00	85.00	19.53	75.00	1200.00
01/10/2020	22.00	80.00	18.61	56.00	896.00
02/10/2020	23.00	86.00	20.71	75.00	1200.00
03/10/2020	23.00	86.00	20.71	75.00	1200.00
04/10/2020	22.00	68.00	16.14	56.00	896.00
05/10/2020	22.00	80.00	18.61	56.00	896.00
06/10/2020	22.00	90.00	20.40	75.00	1200.00
07/10/2020	23.00	87.00	20.88	75.00	1200.00
08/10/2020	23.00	65.00	16.45	56.00	896.00
				Total	**14064.00**

Table 11 shows the forecast got for each day, and the total forecast for the 14 days. With a total expected amount of 30,867.63 mL equivalent to 30.87 liters of water.

Table 11 Hurwicz fourteen day's forecast

Total Water Generation	
Date	Daily Amount (Milliliters)
25/09/2020	2160.00
26/09/2020	2076.63
27/09/2020	2076.63
28/09/2020	2076.63
29/09/2020	2076.63
30/09/2020	2380.63
01/10/2020	2076.63
02/10/2020	2391.11
03/10/2020	2391.11
04/10/2020	2151.38
05/10/2020	2076.63
06/10/2020	2391.11
07/10/2020	2391.11
08/10/2020	2151.38
Total Generated in 14 days	**30867.63**

It was possible to determine that the most suitable optimization model for this project. Fig. 3 shows a comparison between Laplace (blue) and Hurwicz (orange) models. The difference of 260.72 mL compared to the Hurwicz model. The difference may seem small, but optimization seeks to provide the best alternative even if the benefit is minimal. This reinforces the first decision attempt, when comparing only the expected ml of the alternatives suggested by each model, the value of the alternative by Laplace's criterion was greater than the value by the Optimism coefficient.

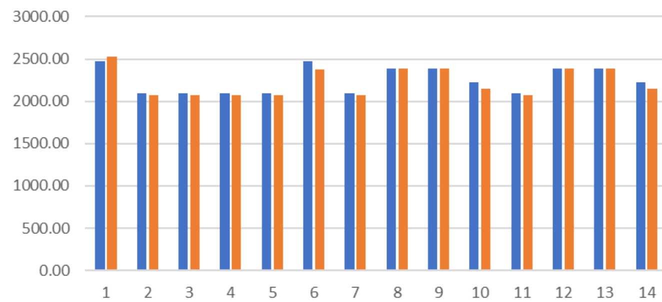

Fig. 3- Laplace and Hurwicz model comparison

V. CONCLUSIONS & DISCUSSIONS

The primary aim of this research was to design an optimization model for a water generation prototype based on condensation and create a generation forecast for a certain time with the data got in the optimization models. Considering the results got, and the analysis carried out, the following is concluded:

It was determined that the most suitable optimization model for the project is the Laplace Criterion model, considering the suggested temperature, time and humidity conditions to ensure a better functioning of the prototype, what means, a higher water generation.

Both models showed that a greater generation of water is got during the afternoon / night, when the ambient temperature drops and humidity increases, a behavior that was verified with implementing correlation diagrams between ambient temperature and relative humidity.

The lack of variation in the future temperature and humidity data generates a certain imprecision in the forecast values because these are estimates, unlike the temperature data used in the tests got with sensors and sufficient variation to guarantee the precision. A better forecast could be performed using a control based on images filtered by gray scale [13].

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