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DESIGN, CONSTRUCTION AND TESTING OF AN EVAPORATION SYSTEM CONSISTING OF POROUS JARS AND SAND FOR COOLING WATER

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ABSTRACT

In this work, we present an experimental study based on the combined transfer of heat and mass in a porous medium made of baked clay, in which measurements of the physical parameters (temperature, relative humidity, wind speed, quantity of water) were taken for 30 days. This article explores the design, construction and testing of an innovative water cooling system based on evaporation, using porous jars and a layer of sand. The results obtained show that climatic and physical factors have a major impact on cooling. The aim is to analyse the effectiveness of this system, both in terms of reducing the water temperature and preserving it in hot climatic conditions. The lowest water temperature value (minimum) of 16.32°C was observed during the last three days of December, when the relative air humidity had fallen to 45% with an ambient temperature of 27.55°C; during this period the wind speed was 20 km/h. The maximum temperature of the water in the jar, 25.51°C, was observed on 16 January with a relative air humidity of 81%, an ambient temperature of 27.55°C and a low wind speed of 10km/h. We therefore understand that the climatic and physical factors mentioned above have an influence on the phenomenon of water cooling from the fired clay jar.

KEYWORDS: Design, production, experimentation, materials, fired clay.

1. INTRODUCTION

Long before the first fluid compression refrigeration machines appeared in the 19th century, many civilisations (Greek, Egyptian, etc.) used the evaporation effect of water through porous vases and jars. The need for simple, environmentally-friendly and affordable water-cooling systems is increasingly pressing in regions where access to electricity and conventional refrigeration systems is limited. Porous jars, known as 'ghara' in some countries, have been used for centuries to preserve and cool water [1] or to cool and preserve food. The techniques used from ancient times to the present day are highly varied and depend on the civilisation, climatic conditions and needs of each people. To guarantee thermal comfort indoors, it is essential to have heating, ventilation and air conditioning (HVAC) systems, which are responsible for energy consumption [2]. However, it is possible to take certain precautions to achieve human thermal comfort outdoors. Evaporative coolers are widely used in a variety of locations such as offices, warehouses, hospitals, laboratories and homes [3]. In natural convection in a porous cavity with variable permeability [4], a numerical and analytical study was carried out on the combined mass and heat transfer in a globally homogeneous and anisotropic porous medium. The governing equation was the Darcy-Brinkman equation whose coupled system of equations was solved by the classical finite volume method. [5] examined theoretically and numerically the natural or mixed thermosolutal convection in a porous medium saturated with a binary fluid, in the presence of the Soret effect and the chemical reaction, with and without an internal heat source. The permeable flat plate, heated and emerging vertically in a porous medium saturated with a Newtonian binary fluid, is considered the field of study. In the same vein, natural convection in a multilayer porous medium, which is similar to our system (jar in jar separated by a layer of sand), each layer of which is

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homogeneous and isotropic and saturated with a single fluid [6], was solved numerically using the finite volume method to solve the adimensional equations governing this system. Numerical and analytical studies in natural convection were carried out by [7] to evaluate the effect of the Darcy-Dupuit convection drag in a rectangular horizontal porous cavity saturated by a fluid, subjected to a vertical thermal gradient. Numerical methods (ADI and SOR) based on the finite difference method were used to obtain numerical solutions of the governing equations. For the preservation of food products by natural convection in macro-porous media [8], an experimental and numerical study was carried out in an ordered stack of products in refrigerators subjected to convection at low air velocity. The comparison of results from experimental measurements and numerical simulations carried out with fluid mechanics software gave satisfactory predictions. In the study of moisture transfer through a porous clay material from the north of Burkina Faso, [9] experimentally determined the structural and thermo-hydric properties of a fired clay sample taken from the north of Burkina Faso. The experimental tests made it possible to obtain consolidation and saturation coefficients, as well as the permeability of the wet sample and that of the fired sample not saturated with water. In the desert refrigerator system or Zeer in cooling without electricity [10] have developed a thermodynamic model that has made it possible to write down the physical phenomena at play through important physical characteristics such as thermal conductivity, enthalpy of vaporisation, heat capacity, etc. In the spirit of rehabilitating and reinvigorating this technology, which is both economic and environmental, we first used an experimental model under tropical climatic conditions to observe the variation in the temperature of the water in the jar as a function of changes in the physical parameters influencing cooling.

2. MATERIALS AND METHOD

2.1 MATERIALS

2.1.1 DESCRIPTION OF THE STUDY AREA

The climate in Conakry, the capital of Guinea, is tropical, with a dry season from December to April, and a rainy season due to the African monsoon which extends from approximately mid-May to mid-November. The rains are particularly frequent and heavy in July and August, when it rains almost every day and more than a metre of rain falls every month. This is the wettest part of Guinea. During the dry season (December, January, February), the harmattan, the dry, dusty wind from the Sahara, blows across the capital [11].

The average temperature in the coldest month (August) is 25.8°C, while the average temperature in the hottest month (April) is 28.4°C, with an annual average of 27.15°C. Rainfall is very abundant, totalling 3,730 millimetres per year. There is also an average of 2,220 hours of sunshine a year. The average relative humidity is 67% and the average wind speed is 11 km/h [12]. With such a climate, the heat is great and the relative humidity high, and the evaporation effect can only be amplified by applying techniques such as combining two nested jars with highly porous materials in between. By placing one jar inside a larger one with a porous material in between, the efficiency of the evaporation phenomenon is improved by cooling.
From a thermodynamic point of view, the aim is to optimise the cold gain resulting from the vaporisation of the water by exchanging sensible heat with the surrounding environment.
To carry out this work, we used two categories of equipment

2.1.2 EQUIPMENT FOR MAKING THE DEVICE

The equipment used to build and test the device is divided into two categories: materials used to build the device and measuring equipment.

The main materials used are: Clay, sand, water, boiler, etc.
a- Measuring equipment

- ✓ **thermocouple multimeter KRYSTAL MY-64**

A temperature-measuring device consisting of two different metal wires connected at either end. One junction is placed where the temperature is to be measured, and the other is kept at a constant lower temperature**.**

- ✓ **Ruler graduated in centimetres to measure and gauge the water level in the jar**
- ✓ **Thermo-hygrometer**

Portable temperature and humidity measuring device (thermohygrometer), type rotronic DV-2. Humidity is measured by a capacitive sensor, temperature by a silicon diode.

2.2 THE METHOD

The method used in this study concerns the design, construction and testing of fired clay jars.

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a- Implementation

This consisted in making two porous jars with capacities of 10 litres and 12 litres. To do this, we took the clay from a quarry in the Upper Guinea region, which is often used by potters from this region. We then crushed and mixed it with 5 litres of water. Then, using potters' moulds, we made two porous jars of 10 and 12 litres, which were dried in the sun for a week. This slow drying reduces the risk of cracking. Finally, we fired them in a pottery kiln at 900 to 1000°C.

The various jar parameters are shown in Table 1:

N°	Parameters	Values
1	Thickness (inner and outer jar)	0,5 cm
2	Diameter of inner jar opening	25 cm
3	External jar opning diameter	35 cm
4	Diameter et middle of inner jar	30 cm
5	Internal jar volume	10 L
6	External jar volume	12 L

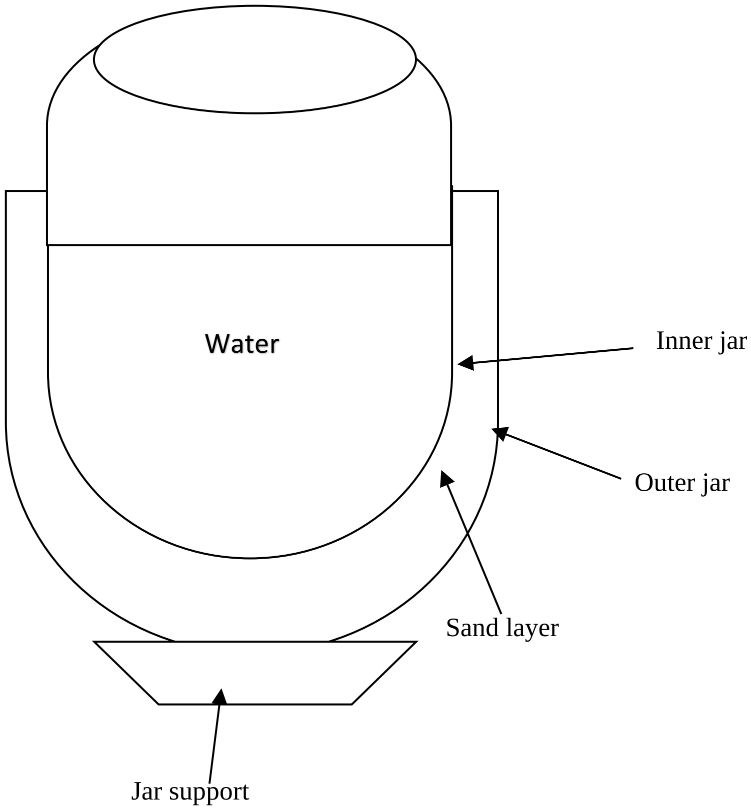

Figure1: Diagram of the experimental stand

b- Testing the device

As part of the experimentation of our device, in the courtyard of Gamal Abdel Nasser University in Conakry under a tree, we installed our device and then filled the space between the two jars with sand. After all that, we filled the inner jar with 10 litres of water taken from the tap. It should be pointed out that the tap water, clay and sand used were not analysed in the laboratory. The sand placed between the two jars was watered every two days during the experimental period.

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We then measured the parameters influencing cooling (temperature, relative humidity, volume of water) from 21/12/2023 to 19/01/2024. For the volume of water, since evaporation leads to a reduction in the quantity of water. Using a graduated ruler, we measured the volume of water from the first day by plunging the ruler from the bottom of the jar to the free surface of the water and recording this value. Each day, we repeated this experiment to determine the difference in volume.

We formalised the information (data) obtained from the measurements in a computer. Then we processed the data.

We then analysed the data Finally, we drew a conclusion on the experiment involving the cooling of water by evaporation through a porous surface in a humid tropical environment.

3. RESULTS AND ANALYSIS

3.1 Results

In this experiment we used an internal jar with a small capacity of 10 litres. These quantities of water, under the effect of evaporation, decreased over time during the experimental period. The more time passed, the more the climatic conditions changed, and this variation in climatic parameters influenced the phenomenon studied, enabling us to assess one period in relation to another, and also to know which part of the country is best suited to the system. The following tables are based on repeated measurements over 30 days.

Table1: Results of measurements from 21 to 28/12/2023

Measurement date	Water initial quantity	Air humidity measu-rement	**t** in the vicinity of the outdoor canary (°C)	Initial **t** of water in the canary (°C)	**t** between the two canaries at the measuring wire (°C)	Volume of water in the canary at the measuring wire (L)	**t** of water in the canaries at the measuring wire (°C)	**t** ambiant temperature (°C)
21/12/2023	10 L	**64%**	**27,55**	26,53	**26,53**	**10**	**26,53**	**28,57**
22/12/2023		**64%**	**22,44**		**21,93**	**9,60**	**21,42**	**26,53**
23/12/2023		**61%**	**21,42**		**21,42**	**9,35**	**20,4**	**25,51**
24/12/2023		**59%**	**22,44**		**21,42**	**9.15**	**20,4**	**29,59**
25/12/2023		**62%**	**21,42**		**21,42**	**9.00**	**20,4**	**25,51**
26/12/2023		**45%**	**17,34**		**17,34**	**8.15**	**16,32**	**27,55**
27/12/2023		**58%**	**22,44**		**20,4**	**7,90**	**19,38**	**25,51**
28/12/2023		**55%**	**23,46**		**20,4**	**7,78**	**19,38**	**26,53**

Table 2: Measurement results from 29/12/2023 to 06/01/2024

Measurement date	Water initial quantity	Air humidity measu-rement	**t** in the vicinity of the outdoor canary (°C)	Initial **t** of water in the canary (°C)	**t** between the two canaries at the measuring wire (°C)	Volume of water in the canary at the measuring wire (L)	**t** of water in the canaries at the measuring wire (°C)	**t** ambiant temperature (°C)
29/12/2023	10 L	**63%**	**26,53**	25,51	**25,51**	**7,65**	**24,48**	**27,55**
30/12/2023		**65%**	**22,44**		**18,36**	**7,45**	**17,34**	**23,46**
31/12/2023		**61%**	**24,48**		**19,89**	**7,40**	**18,87**	**25,51**
01/01/2024		**75%**	**24,48**		**21,42**	**7,35**	**20,4**	**25,51**
02/01/2024		**68%**	**24,48**		**22,44**	**7,30**	**21,93**	**26,53**
03/01/2024		**84%**	**25,51**		**24,48**	**7,25**	**22,44**	**27,55**
04/01/2024		**83%**	**25,51**		**23,46**	**7,20**	**23,46**	**26,53**
05/01/2024		**80%**	**25**		**22,44**	**7,10**	**22,44**	**26,53**

Table 3: Measurement results from 07 to 14/01/2024

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Measurement date	Water initial quantity	Air humidity measu-rement	**t** in the vicinity of the outdoor canary (°C)	Initial **t** of water in the canary (°C)	**t** between the two canaries at the measuring wire (°C)	Volume of water in the canary at the measuring wire (L)	**t** of water in the canaries at the measuring wire (°C)	**t** ambiant temperature (°C)
07/01/2024	10 L	**71%**	**26,53**	26,53	**26,53**	**7,00**	**26,53**	**27,55**
08/01/2024		**74%**	**25**		**23,46**	**6,90**	**23,46**	**27,55**
09/01/2024		**82%**	**25,51**		**25**	**6,85**	**23,46**	**27,55**
10/01/2024		**81%**	**25**		**23,97**	**6,80**	**23,46**	**27,55**
11/01/2024		**79%**	**23,46**		**22,44**	**6,70**	**22,44**	**26,53**
12/01/2024		**76%**	**23,46**		**21,93**	**6,40**	**20,4**	**25,51**
13/01/2024		**83%**	**23,46**		**21,42**	**6,35**	**20,4**	**25,51**
14/10/2024		**80%**	**25**		**24,48**	**6,34**	**23,46**	**25,4**

Table 4: Results of measurements from 15 to 19/01/2024

Measurement date	Water initial quantity	Air humidity measu-rement	**t** in the vicinity of the outdoor canary (°C)	Initial **t** of water in the canary (°C)	**t** between the two canaries at the measuring wire (°C)	Volume of water in the canary at the measuring wire (L)	**t** of water in the canaries at the measuring wire (°C)	**t** ambiant temperature (°C)
15/01/2024	10 L	**75%**	**25,51**	26,54	**24,46**	**6,33**	**23,46**	**27,55**
16/01/2024		**75%**	**24,48**		**22,95**	**6,30**	**22,44**	**27,55**
17/01/2024		**50%**	**22,44**		**19,38**	**5,00**	**18,36**	**27,55**
18/01/2024		**54%**	**24,48**		**20,91**	**4,80**	**20,4**	**27,55**
19/01/2024		**80%**	**25,51**		**24,48**	**4,70**	**22,44**	**26,53**

3.2 Discussion
The discussion of our results focuses on their analysis and interpretation, and we have therefore represented them in curves as a function of each operating condition.

The temperature curves for the water in the jar, the ambient air and the relative humidities obtained from measurements taken between 21 December 2023 and 19 January 2024 are illustrated in the following graphs.

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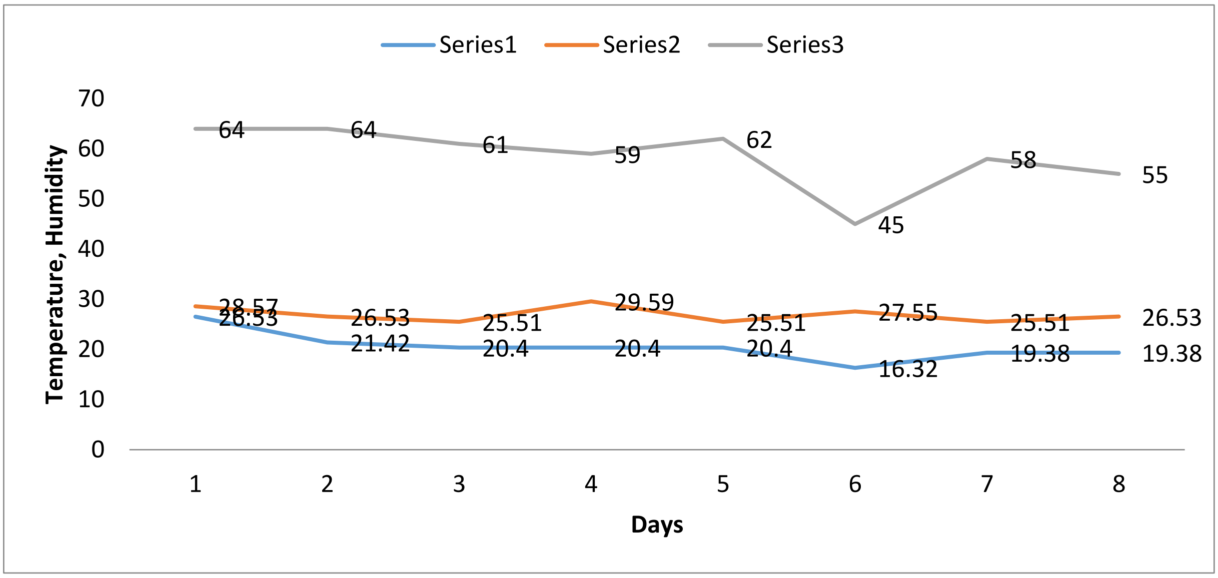
3.2.1: Variation of the temperature (in °C) of the water in the jar, the ambient air and the relative humidity as a function of time



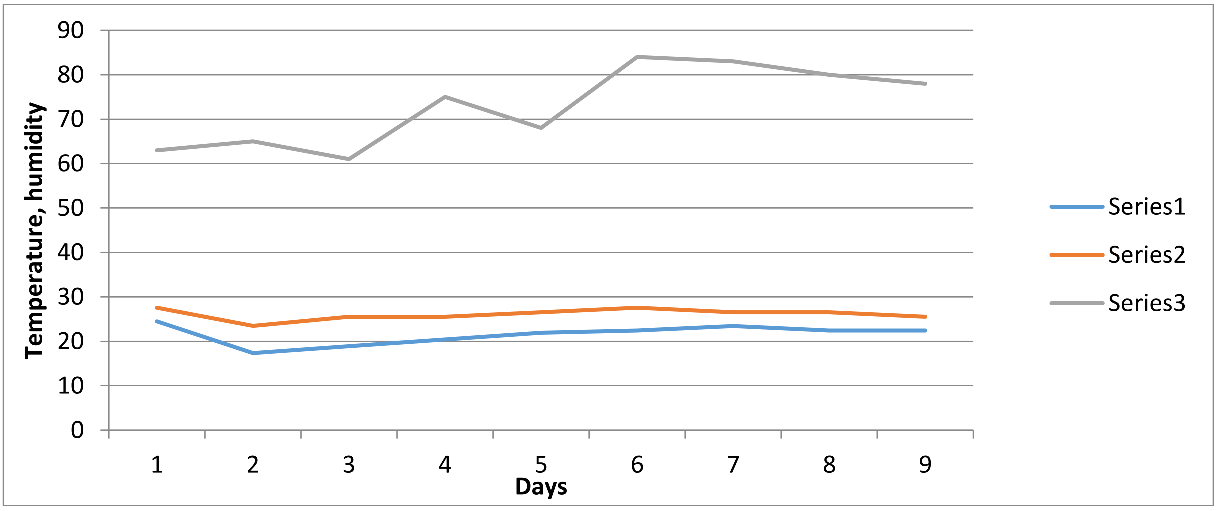
NB: Series 1 is the water curve in the jar, series 2 is the ambient air curve and series 3 is the relative humidity curve.

Figure 2: Variation of water, air and relative humidity temperatures over time in sand jars

This graph shows that the temperature of the water in the jar falls over time, but with an irregular trend, due to the fact that the air humidity and wind speed are very unstable.

The lowest point (minimum) of these curves, 16.32°C, was observed during the last three days of December, when the relative humidity had dropped to 45% with an ambient temperature of 27.55°C; during this period, the wind speed was a little high at 20km/h. These results show that the system works well at low humidity and that the evaporation mechanism is reduced at high humidity.

The figure below is obtained under the following experimental conditions, the mass of water in the jar is 10 kg and hygrometries 63%, 65%, 61%, 75%, 68, 84%, 83%, 80% and 78%, the air temperatures are 27.55; 23.46; 25.51; 25.51; 26.53; 27.55; 26.53; 26.53; 25.51°C.



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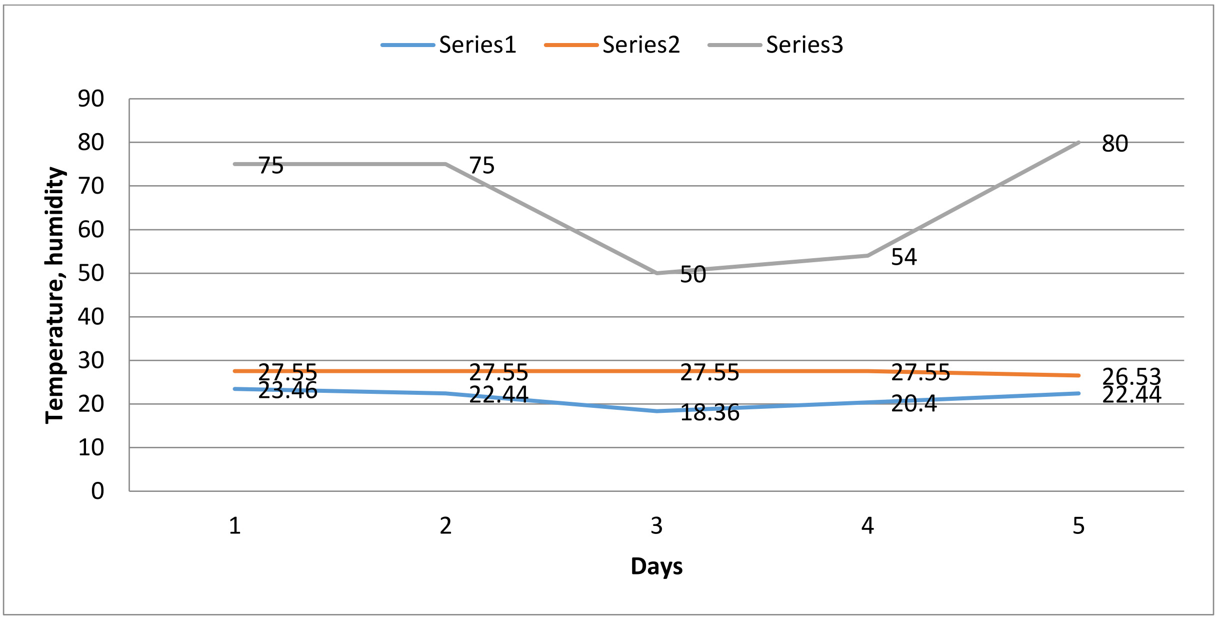
NB: Series 1 is the water curve, series 2 is the air curve and series 3 is the relative humidity curve.
Figure 3: Variation in the temperatures of the water in the jar, the ambient air and the relative humidity over time in jars with sand

Analysis of this curve shows that the further away we get from December, the drier the air becomes and the hygrometry approaches saturation. As a result, the variation in water temperature becomes very small compared with the ambient temperature. This is why we can see in the figure that the water curve decreases, then increases slightly and finally stabilises near the air temperature.

From the last table we obtained curves illustrating the course of the water temperature, air temperature and relative humidity through the jars.



NB: Series 1 is the water curve, series 2 is the air curve and series 3 is the relative humidity curve.
Figure 4: Variation of water, air and relative humidity temperatures over time in sand jars

From these curves we can see a considerable drop in relative humidity (from 75% to 50%), resulting in a drop in water temperature of 18.36°C. This sudden variation in hygrometry was caused by a climatic disturbance due to light rainfall for a while. It then resumed its growth as the water temperature rose over time. We noticed that the further we got from December, the more evaporative cooling was compromised in Conakry because of its climate. This is why we carried out a few days of experiments in April to observe the phenomenon. The results of this experiment are shown in the following graph

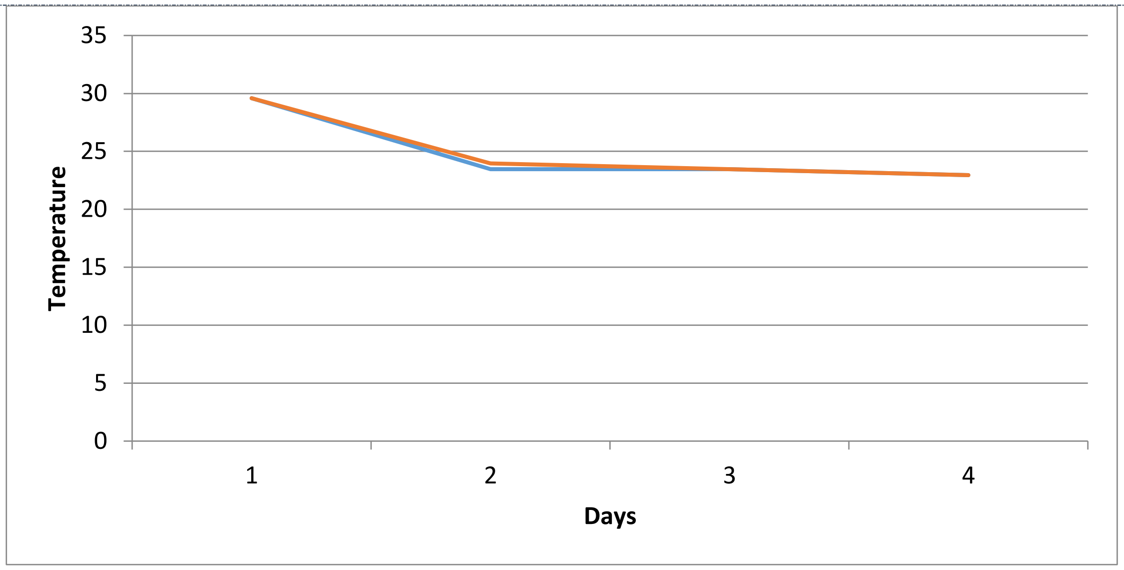


Figure 5: Temperature variation over time in these three systems

The graph shows that the water temperature fell slightly in April compared with December and January, with the highest temperature recorded in April being 29.59°C compared with 26.53°C in December and January, and the lowest in April being 22.95°C compared with 16.32°C in December and January.

In short, the evaporation system using porous jars and sand has proved to be an ecological and practical solution for cooling water in hot climates. Unlike conventional cooling systems, it requires no electricity or complex mechanical components, making it a low-cost, sustainable solution. However, the efficiency of this system is highly dependent on environmental conditions, including humidity and ambient temperature.

4. CONCLUSION

In this experiment, we designed two porous jars made of baked clay, then assembled the stand with sand sanded in between the two jars. This is a refrigeration system based on the evaporation of water through a porous wall. The results we obtained showed that the phenomenon of cooling water in baked clay is strongly influenced by the physical factors on which the evaporation of a liquid through a porous wall mainly depends, namely: the temperature of the ambient air, the relative humidity of the ambient air, the exchange surface and the wind speed.

These results show that although the climate is tropical in the study area, the phenomenon is quite observable and can be much more significant at certain times of the year than at others.

The study also showed that adding a layer of sand around the porous jars significantly improves the process of cooling water by evaporation. This system could be optimised and used on a large scale in areas with limited resources, where access to advanced cooling technologies is restricted. Future research could focus on optimising the materials used to manufacture the jars and understanding the optimum environmental parameters for maximising the efficiency of this process.

Since they consume no electrical energy, these refrigerators can be used in a wide range of applications, including water cooling, food preservation and, why not, air conditioning.

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