**Influence of Temperature on the Sorption Isotherms of Building Materials**

# ABSTRACT

Building materials are porous and interact with moisture in the ambient air through sorption phenomena. However, under real world using conditions, the temperature of these materials varies constantly. The problem is that this temperature variation influences the materials' ability to adsorb or desorb moisture, which can distort the assessment of their hygrothermal performance. It is therefore necessary to analyze and model the effect of temperature on these isotherms in order to better predict the behavior of materials under real conditions. The aim of this study is to carry out experimental analysis and modelling of the sorption isotherms of construction materials, in particular cement bricks. The equilibrium desorption and adsorption water contents of the materials were determined at 35°C, 40°C and 50°C using the static gravimetric method. Equilibrium was obtained between 28 and 30 days for desorption and between 21 and 27 days for adsorption at all three temperatures. The results show that the isotherms obtained have a sigmoidal shape and are classified according to International Union of Pure and Applied Chemistry (IUPAC) in the category of type II isotherms. The effect of temperature on sorption isotherms was evaluated. The moisture content of the materials decreases with increasing temperature. The effect of hysteresis is observed for all three temperatures. The experimental points were approximated by the GAB (Guggenheim - Anderson - Boer), Henderson and Oswin models to describe all the isotherms for all the ranges of relative humidity and temperature used. A comparison of these three models shows that the Henderson model is the most appropriate for describing the sorption isotherms of our materials.

*Keywords: sorption isotherm, gravimetric method, temperature, moisture content, hysteresis, cement block*

# INTRODUCTION

# One of the greatest challenges facing the construction sector worldwide today is the development of appropriate building materials that can reduce energy consumption on one hand,and withstand different climatic conditions on other. In Africa, and particularly in Burkina Faso, cement brick have become one of the most widely used building materials, because they are easier to make and have greater mechanical strength than clay brick. In terms of thermal behaviour, cement blocks are better conductors of heat than local materials [1]. This building material has an essential role in the durability and performance of structures. Among the many parameters influencing its properties, the interaction with ambient humidity is decisive, as it directly affects the mechanical, thermal and hydric characteristics of the material. Understanding these interactions is important to ensure optimum performance under different climatic conditions. Sorption isotherms, which describe the relationship between the relative humidity(RH) of the surrounding air and the water content of materials at constant temperature, are fundamental tools for analysing these interactions [2]. These isotherms can be used to characterise moisture adsorption and desorption processes in porous materials, highlighting phenomena such as hysteresis. An in depth study of sorption isotherms provides a detailed understanding of moisture transfer mechanisms and physico-chemical transformations within materials [3]. But the complexity of building materials, with their multi-scale porous structure, requires a combination of experimental and modelling approaches to characterise these isotherms. On the one hand, experimental measurements make it possible to obtain reliable data specific to each material. On the other hand, modelling makes it possible to predict hygroscopic behaviour under unexperimented conditions, there by facilitating the optimisation of materials for different applications. The aim of this work is therefore to analyse the effect of temperature on the sorption properties of cement block using the static gravimetric method, by means of an experimental approach and advanced modelling. More specifically, it involves first formulating the materials (cement blocks)

then measuring the adsorption/desorption isotherms of the materials and finally modelling these isotherms using mathematical models such as GAB, Henderson and Oswin model. The results obtained will contribute to a better understanding of thermo-hydric interactions and enable strategies to be developed to improve the durability and performance of materials in a variety of environments.

# MATERIALS AND METHODS

# Materials and Sample Preparation

# The samples used in this study were cubic in shape, measuring 4 cm x 4 cm x 4 cm. These samples (Figure 1) were formulated at the National Building and Public Works Laboratory (LNBTP) in Ouagadougou and at the Environmental Physics and Chemistry Laboratory (LPCE) of Joseph KI-ZERBO University (UJKZ). The characteristics of these materials are taken from previous work [4]

**Fig. 1**. Samples of dimensions 4 cm×4 cm ×4 cm

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* 1. **Experimental protocol**

The procedures for obtaining water sorption isotherms for products are described in detail by several authors [5, 6]. These procedures include either dynamic methods in which the sample is placed in a gas stream at constant temperature and humidity, without air agitation, or static procedures in which the sample to be adsorbed or desorbed is placed in chambers containing saturated salt solutions maintained at constant temperature and relative humidity until thermodynamic equilibrium is reached. Table 1 show the different salts as a function of their relative humidity.

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| --- | --- | --- | --- | --- |
| Temperatures (°C) | T= 35°C | T= 40°C | T=50°C | |
| Salts | RH (%) | RH (%) | | RH (%) |
| KOH | 6.7 | 6.3 | | 5 .7 |
| MgCl2 | 32.1 | 31.6 | | 30.5 |
| K2CO3 | 32 | 42.3 | | 45.6 |
| NaCl | 74.9 | 74.7 | | 74.4 |
| BaCl2 | 89 | 89.1 | | 88.23 |
| K2SO4 | 96.7 | 96.4 | | 95.8 |

**Table 1.** Saturated salts used to determine sorption curves

In this study, we used the gravimetric method to determine the sorption isotherms of our materials. This method involves acquiring laboratory salts (Figure 2) and hermetically sealed bocal (Figure 3). The solutions are prepared in these bocal and kept isothermal in a temperature controlled oven [7, 8]. The main problem with measurements made using this method is that the time taken to reach equilibrium is very long. The speed of water vapour diffusion is a limiting factor [9]. But this method has the advantage of continuously obtaining all relative humidity values between 5 and at least 90% [10, 11]. The sample is suspended in the bocal, above the salts, and therefore remains in an environment that is stabilised in terms of temperature and humidity. The whole assembly (bocal + sample) is placed in a controllable oven (Figure 4). Mass loss during desorption and mass gain during adsorption were monitored using a digital balance with a precision of ± 0.01 g (within 3 days). Hygroscopic equilibrium is achieved when there is no exchange of air between the material and the ambient air. Equilibrium is monitored by the variation in mass of the sample. Equilibrium is considered to have been reached when the difference between two consecutive mass measurements is less than or equal to 0.001 g. Dry masses are determined by placing the sample in the oven at 105°C for 24 hours. The material is pre-dried to allow adsorption to take place. Pre-drying is carried out in an oven at a temperature of 50°C until the material is fully dehydrated.

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| **Fig.2**. Laboratory salts  **Fig.4**. Disposition of the bocal in the oven  **Fig.3.** Bocal used in the experiment |

# Experimental method

The equilibrium water content of the samples is measured, for three constant temperatures of 35°C, 40°C and 50°C, in successive stages of increasing relative humidity (absorption isotherm) and then

decreasing relative humidity (desorption isotherm). The equilibrium water content for each value of relative humidity in the absorption and desorption cycle is calculated from the following expression:



(1)

: equilibrium water content,

 : mass of sample at hygroscopic equilibrium,

: dry mass of the sample.

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| **Fig. 5**. Adsorption-desorption isotherms for cement block at T=35°C |

**3. RESULTS AND DISCUSSION**

**3.1 Results of adsorption-desorption isotherms**

Figures 5, 6 and 7 shows the results of adsorption-desorption isotherms for cement block. These curves have the same shape but with different sorption capacities. This sigmoidal shape is frequently encountered in construction materials [12]. These isotherms confirm the fact that the adsorption isotherm is not generally overlay on the desorption isotherm: the sorption phenomenon exhibits a hysteresis.

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| **Fig. 6**. Adsorption-desorption isotherms for cement block for T=40°C |

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| **Fig.7**.Adsorption-desorption isotherms for cement block for T=50°C |

**Figure 5** show the results of the adsorption and desorption isotherms for the materials at 35°C. As shown in Figure 5, the adsorption-desorption curves for the cinder blocks have the same shape, but with different sorption capacities. The isotherms obtained have an almost sigmoidal shape and are classified according to the classification of the International Union of Pure and Applied Chemistry (IUPAC) in the group of type II isotherms. This sigmoidal shape is frequently found in hygroscopic building materials [13]. We can see that the desorption curve is above the adsorption curve, indicating a higher water content for the same relative humidity. The material therefore absorbs less water for the same relative humidity. At a relative humidity of less than 0.2, the water content remains low in both processes, but slightly higher for desorption. This indicates that the material still retains water at low relative humidity during desorption. At relative humidities above 0.8, the water content increases rapidly, especially during desorption. This increase suggests that the material can retain a lot of water when it has already been saturated. **Figure 6** shows the results of the adsorption/desorption isotherms at a temperature of 40°C. For a relative humidity of less than 0.2, the difference between the adsorption and desorption curves is minimal, indicating similar water retention for these two isotherms. For a relative humidity greater than 0.8, the difference is more marked, indicating a greater water retention capacity during desorption. **Figure 7** show the results of the adsorption and desorption isotherms for cement block at a temperature of 50°C.For a relative humidity of less than 0.2, the difference between

the adsorption and desorption curves are negligible, indicating similar moisture retention for both processes. For a relative humidity greater than 0.8, the difference is greater, indicating a high moisture retention capacity of the material during desorption.

**3.2 Influence of temperature on the adsorption-desorption isotherms of materials**

We are studying the influence of temperature on the adsorption-desorption isotherms of cement block. The figures below (Figure 8 and Figure 9) represent the points (HR, Xeq) obtained by the saturated salt method for three temperatures (35°C, 40°C, 50°C). **Figure 8** show the influence of temperature on the adsorption isotherms of cement block for three temperatures (35°C,40°C,50°C).Generally speaking, it can be seen that temperature influences the water adsorption capacity of the material. At low temperatures, the material absorbs more water than at higher temperatures. As the temperature increases, the rate of adsorption decreases. These experimental curves also show that, for different temperature ranges, the equilibrium moisture content of the cement block sample increases as the relative humidity of the environment in which it is placed increases. This result is in line with the behaviour of certain construction materials[14, 15].The study of adsorption isotherms is necessary because it provides important information for the selection and use of materials in a variety of environments, ensuring the durability and optimum performance of building structures.

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| **Fig.9**. Influence of temperature on the desorption isotherms of cement block for three temperatures (35°C,40°C,50°C)  **Fig. 8**. Influence of temperature on the adsorption isotherms of cement block for three temperatures (35°C,40°C,50°C) |

# Figure 9 show the influence of temerature on the desorption isotherms of cement block for three temperatures. Generally speaking, the curves are non-linear. This non-linearity is justified by the fact that the material contains fine particles during its formulation (0/4 sand). For a range of relative humidity between 0 and 0.25, the three curves show a jump which could be due to a strong interaction of the solid matrix of the material with the gaseous molecules of the environment, which favour a slight increase in the water content of around 0.015 kg/kg. At a relative humidity of over 0.03, the material begins to lose weight. Between 0.4 and 0.7 of the relative

# humidity value, the curves become practically linear

# and reflect the weak interaction of the solid matrix of the material with its environment. After 70% or 0.7 of relative humidity, the isotherms increase rapidly because the free water contained in the material has evaporated almost completely, allowing the material to dry continuously.

**3.3. Influence of temperature on the hysteresis curves of materials**

We analyse the influence of temperature on the hysteresis curves of cement block for three different temperatures (Figure 10).

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| **Fig.10**. Influence of temperature on the hysteresis curves of cement block for three temperatures (35°C,40°C,50°C) |

(4)

**Figure 10** show the influence of temperature on the hysteresis curves of materials. It can be seen that temperature has an effect on the hysteresis curves. At 50°C, hysteresis is greater, with a peak of around 1.6%, indicating a marked difference between adsorption and desorption. At 35°C and 40°C, the hysteresis is less pronounced but with a similar trend and a relative humidity of RH=0.8. Hysteresis affects the durability of building materials, with high hysteresis indicating prolonged water retention, which can influence the mechanical and thermal properties of materials.

**3.4 Modelling sorption isotherms for materials**

Numerous models have been proposed for modelling sorption isotherms. Some are based on theoretical approaches to sorption, while others are empirical or semi empirical. To fit and model the isotherms of materials, we have applied the GAB (Guggenheim - Anderson - Boer), Henderson and Oswin models to our experimental results. Numerous works[16, 17]on modelling the sorption isotherms of construction materials have already been carried out. In this work, the authors note that these three models are well suited to hygroscopic materials such as ours.

(2)

(3)

 : water content dry basis of the material

: relative humidity

: temperature in °C

, , : model constants

To determine the various constants (k, n, C, X m) of these models, we used the multiple non-linear regression method and Matlab software. The experimental data were fitted to the models using the least squares method. The correlation coefficient R2 (equation 5) is the primary fitting criterion in our study. In addition to R2, two other criteria are adopted to assess the goodness of fit of each model: the standard error of estimation S (equation 6) and the sum of squares of the residuals RSS (equation 7). These statistical parameters are defined as follows:



(5)

(6)

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(7)

: ith experimental equilibrium moisture content (kg/kg),

: ith predicted equilibrium moisture content (kg/kg),

: predicted average moisture content,

N: Number of experimental points,

P: Number of variables in each model.

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| --- | --- | --- | --- | --- | --- | --- | --- |
| Model | model parameters | | | | R2 | RSS (×10-4) | S (×10-3) |
|  | K | C | X12 | n |  |  |  |
| GAB | 0.206 | -3.287 | -0.0136 | - | 0.9256 | 3.067 | 8.757 |
| Oswin | 0.0184 | - | - | 0.4202 | 0.9815 | 0.7625 | 3.905 |
| Henderson | 1.5 | - | - | 1.047 | 0.9899 | 0.146 | 2.551 |

**Table 2.** Model constants derived from material sorption isotherms: T= 35°C

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| **Table 3.** Model constants derived from material sorption isotherms: T= 40°C | | | | | | | |
| Model | model parameters | | | | R2 | RSS (×10-‘4) | S (×10-3) |
|  | K | C | X12 | n |  |  |  |
| GAB | 0.87 | 0.2624 | 0.02006 | - | 0.9577 | 1.477 | 7.016 |
| Oswin | 0.01448 | - | - | 0.4849 | 0.9803 | 0.6893 | 4 .151 |
| Henderson | 0.7189 | - | - | 0.8133 | 0.9884 | 0.14 | 3.338 |

**Table 4**. Model constants derived from material sorption isotherms: T= 50°C

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| --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | | | | |
| Model | Model parameters | | | | R2 | RSS (×10-4) | S (×10-3) |
|  | K | C | X12 | n |  |  |  |
| GAB | 0.3912 | 0.3424 | 0.1966 | - | 0.7845 | 6.112 | 12.36 |
| Oswin | 0.0206 | - | - | 0.3409 | 0.879 | 3 .431 | 8.284 |
| Henderson | 5.199 | - | - | 1.533 | 0.969 | 3.202 | 6.319 |

The three models (GAB, Henderson, Oswin) were compared with the experimental points. The model with the highest (R2) values and the lowest RSS and S values is the most appropriate for describing the sorption isotherms obtained experimentally. The fit of the experimental points obtained for adsorption and desorption at temperatures of 35°C, 40°C and 50°C by the Henderson model is statically satisfactory. To model sorption isotherms, several correlations exist in the scientific literature[18]. In order to take better account of the influence of temperature on hygroscopic equilibrium, and to be able to carry out interpolations, we use the Henderson model to model the sorption isotherms of our materials. The choice of this model is justified by the fact that it has the advantage of describing all the sorption isotherms for a wider range of temperatures and relative humidity of the environment surrounding the material, and of better following the evolution of the structure of the material during desorption.

**Conclusion and Recommendation:**

In this work, we presented the static gravimetric method used to determine the sorption isotherms

of cementitious materials. In addition, the materials formulation process was described. We also studied the influence of the environment in which these materials are placed on their hydric properties. The results show that the sorption isotherms of the materials have a sigmoidal shape, corresponding to the group of type II isotherms according to the classification of International Union of Pure And Applied Chemistry (IUPAC). The moisture content of the materials decreases with increasing temperature. The experimental points were approximated by GAB, Henderson and Oswin models to describe all the isotherms for all the ranges of relative humidity and temperature used. Comparison of these three models shows that the Henderson model is the most appropriate for describing the sorption isotherms of our materials.

At the end of this study, we recommend:

* In regions where temperature variations are significant, materials should be stored in controlled environments before being used in construction structures, especially those requiring better thermal insulation,
* In hot regions, provide mechanisms to compensate for moisture loss, in order to maintain the mechanical and thermal properties of the materials,
* In humid regions, protect materials to avoid excessive water absorption, which

could affect their long-term structural stability.

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