Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 17, Issue, 03, pp.32001-32005, March, 2025
DOI: https://doi.org/10.24941/ijcr.48498.03.2025

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

EXPERIMENTAL STUDY AND MODELLING OF SORPTION ISOTHERMS OF CEMENT BLOCKS

Benjamin Kiema[1*], Daouda Sawadogo[1], Hamidou Sankara[1], Ousmane Coulibaly[1], Xavier Chesneau[2] and Belkacem Zeghmati[2]

[1]Laboratory of Environmental Physics and Chemistry (LPCE), Department of Physics, Joseph KI-ZERBO University, Ouagadougou, Burkina Faso; [2]Laboratory of Modelling Pluridisciplinary and simulation (LAMPS), University of Perpignan Via Domitia, Perpignan, France

ARTICLE INFO

Article History:
Received 20th December, 2024
Received in revised form
19th January, 2025
Accepted 26th February, 2025
Published online 27th March, 2025

Key words:
Sorption Isotherm, Gravimetric Method, Hysteresis, Cement Block.

***Corresponding author:**
Benjamin Kiema

ABSTRACT

The aim of this study is to carry out experimental analysis and modelling of the sorption isotherms of construction materials, in particular cement block. The equilibrium desorption and adsorption moisture content of the materials were determined at 40°C using the static gravimetric method. Equilibrium was achieved after 28 days for desorption and 21 days for adsorption. The results show that the isotherms obtained have a sigmoidal shape and are classified by the International Union of Pure and Applied Chemistry (IUPAC) as type II isotherms. For a fixed temperature, the moisture content of the material varies according to the relative humidity. This moisture content increases with relative humidity. The material has a greater capacity to absorb water as relative humidity increases. The effect of hysteresis is observed at this temperature. Three mathematical models were used to modelsorption isotherms and predict hygroscopic behaviour during absorption or drying. The GAB model, Henderson and Oswin model. The prediction of the isotherms showed that the Henderson model is the most appropriate for describing these isotherms.

Citation: Benjamin Kiema, Daouda Sawadogo, Hamidou Sankara, Ousmane Coulibaly, Xavier Chesneau and Belkacem Zeghmati. 2025. *"*Experimental study and modelling of sorption isotherms of cement blocks*". International Journal of Current Research, 17, (03), 32001-32005.*

1. 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 the one hand, and withstand different climatic conditions on the other. In Africa, and particularly in Burkina Faso, cement blocks have become one of the most widely used building materials, because they are easier to make and have greater mechanical strength than concrete. In terms of thermal behaviour, cement blocks are better conductors of heat than local materials (Etienne Malbila, 2017). This building material plays an essential role in the durability and performance of structures. Among the many parameters influencing its properties. 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 (Ahouannou, 2010). 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 (Lamharrar, 2007). 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, thereby facilitating the optimisation of materials for different applications. The aim of this work is therefore to explore the sorption properties of cement block using the static gravimetric method at a temperature of 40°C 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 the GAB model, Henderson and Oswin model. The results obtained will contribute to a better understanding of thermo-hydric interactions and will enable strategies to be developed to improve the durability and performance of materials in a variety of environments.

2. MATERIALS AND METHODS

2.1. 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 4) were formulated at the National Building and Public Works Laboratory (LNBTP) in Ouagadougou and at the Environmental Physics and Chemistry Laboratory (LPCE) of the Joseph KI-ZERBO University (UJKZ). The characteristics of these materials are taken from previous work (Kiema, 2024).

Figure 1. Samples of dimensions 4 cm×4 cm ×4 cm

2.2. Experimental protocol : The procédures for obtaining water sorption isotherms for products are described in detail by several authors (Gal, 1987; Wolf, 1985). 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 shows the different salts as a function of their relative humidity.

Table 1. Saturated salts used to determine sorption curves at 40°C

Saturated salt	Relative Humidity RH (%)
KOH	6.3
$MgCl_2$	31.6
K_2CO_3	42.3
NaCl	74.7
$BaCl_2$	89.1
K_2SO_4	96.4

The gravimetric method we used to determine the sorption isotherms of our materials consists of acquiring laboratory salts (Figure 2) and hermetically sealed bocal (Figure 3). These solutions are prepared in these bocals and kept isothermal in a temperature-controlled oven (Bizot, 2021; Greenspan,). The main problem with measurements made using this method is that the time taken to reach equilibrium is very long. The diffusion rate of water vapour is a limiting factor (Kechaou, 2000). However, this method has the advantage of continuously obtaining all relative humidity values between 5 and at least 90% (Lahsasni et al. 2000 ; Idlimam *et al.*, 2008). 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 3days). 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.

Figure 2. Laboratory salts

Figure 3. Bocal used in the experiment

Figure 4. Disposition of the bocal in the oven

2.3. Experimental method : The equilibrium moisture content of the samples is measured, at a constant temperature of 40°C, in successive stages of increasing relative humidity (absorption isotherm) and then decreasing relative humidity (desorption isotherm). The equilibrium moisture content for each value of relative humidity in the absorption and desorption cycle is calculated from the following expression :

$$X_{eq} = \frac{m_h - m_s}{m_s} \quad (1)$$

X_{eq} : moisture content at equilibrium

m_h : weight of the sample at hygroscopic equilibrium,

m_s : dry weight of sample.

3. RESULTS AND DISCUSSION

3.1 Results of adsorption- desorption isotherms : Figures 5 and 6 shows the results ofadsorption-desorption isotherms for cement block bricks. These curves have the same shape but with different sorption capacities. The isotherms have a sigmoidal shape and are classified according to the International Union of Pure and Applied Chemistry (IUPAC) as type II isotherms. Isotherms confirm the fact that the adsorption isotherm does notgenerally overlap with the desorption isotherm: the sorption phenomenon exhibits hysteresis. Figure 5 show the results of the adsorption-desorption isotherms for cement blocks 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. The time lag between adsorption and desorption indicates the presence of hysteresis (Figure 6) for this temperature (T=40°C). Figure 6 show the hysteresis of cinder blocks at a temperature of 40°C. It can be seen that : for a relative humidity of less than 0.2, the hysteresis increases progressively, indicating that the first changes in relative humidity have a significant effect on the water content of the material. For humidity between 0.2 and 0.6, the curve shows a relatively stable trend, with a slight increase in hysteresis. This stability suggests that, at this range, changes in relative humidity do not have a significant effect on the water content, due to saturation of the material.

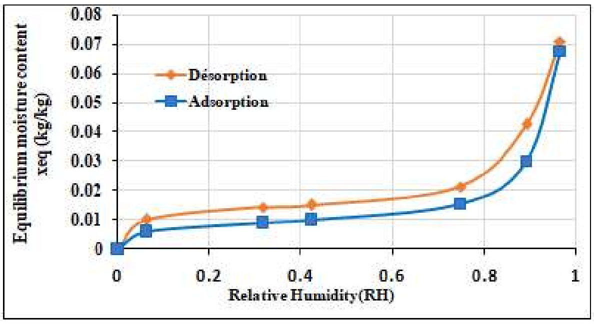

Figure 5. Adsorption-desorption isotherms for cement blocks for T=40°C

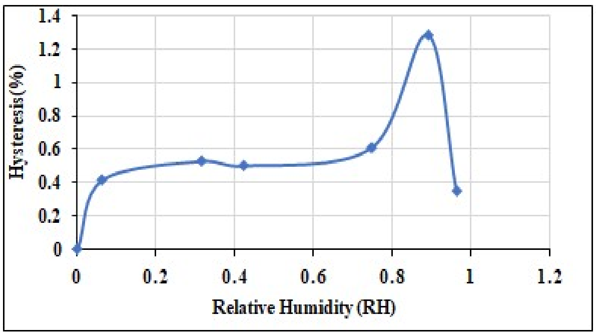

Figure 6. Hysteresis of cement blocks for T=40°C

3.2. Smoothing polynomial from experimental points : Polynomial smoothing of the experimental points is used to describe the sorption isotherms of cinder blocks at a temperature of 40°C. The interpolation polynomial and the correlation coefficient R^2, whose degree was optimised, were obtained using Matlab software. This polynomial is used in the work of(13) for the numerical modelling of heat and mass transfers. This polynomial is shown in **Figure 7**.

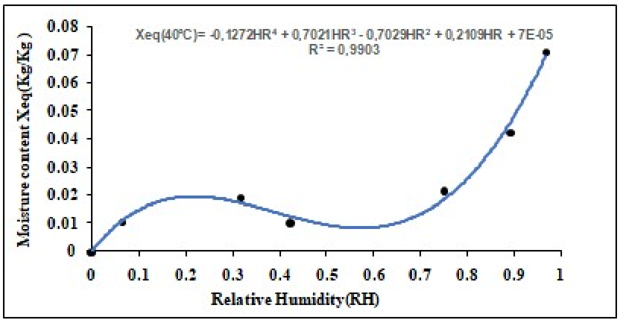

Figure 7. Polynomial fonction for T=40°C

3.3 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 model (Guggenheim - Anderson - Boer), Henderson and Oswin model to our experimental results. The Works (Karoglou, 2005 ; Andrade, 2011) on the modelling of sorption isotherms for construction materials has already been carried out. In this work, the authors note that these three models are well suited to hygroscopic materials such as ours.

Henderson model:

$$Weq = \left(\left(-\frac{1}{A.T}\right)\ln(1-HR)\right)^{1/B} \quad (2)$$

GAB model :

$$Weq = \frac{X_m.C_G.K.HR}{(1-K.HR)(1+(C_G-1).K.HR)} \quad (3)$$

Oswin model :

$$Weq = A\left(\frac{HR}{1-HR}\right)^B \quad (4)$$

Xeq : moisture content, dry basis of the material
RH : Relative Humidity
T : Temperature in °C
X_m, C, G, K, A, B : 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 R^2 (equation 5) is the primary fitting criteria in our study. In addition to R^2, 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 (equation7).These statistical parameters are defined as follows:

$$S = \frac{1}{(N-P)^2}\sqrt{\sum_{i=1}^{N}\left(W_{eq_{exp,i}} - W_{eq_{cal,i}}\right)^2} \quad (5)$$

$$RSS = \sum_{i=1}^{N} \left(W_{eq_{\exp,i}} - W_{eq_{cal,i}} \right)^2 \quad (6)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N} \left(W_{eq_{\exp,i}} - W_{eq_{cal,i}} \right)^2}{\sum_{i=1}^{N} \left(W_{eq_{\exp,i}} - \overline{W_{eq_{cal,i}}} \right)^2} \quad (7)$$

$W_{eq_{\exp,i}}$: ith experimental equilibrium water content (kg/kg),

$W_{eq_{cal,i}}$: ith predicted equilibrium water content (kg/kg),

$\overline{W_{eq_{cal,i}}}$: average predicted watercontent,

N: Number of experimental points,

P: Number of variables in each model.

The three models (GAB, Henderson, Oswin) were compared with the experimental points (Figure 8). The model with the highest (R^2) 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 in adsorption and desorption at a temperature of 40°C by the Henderson model is statically satisfactory.

Tableau 2. Model constants derived from material sorption isotherms: T= 40°C

Model	Model parameters				R^2	RSS ($\times 10^{-4}$)	S ($\times 10^{-3}$)
	K	C	X_{12}	n			
GAB	0.87	0.262	0.020	-	0.957	1,477	7.016
Oswin	0.014	-	-	0.484	0.980	0.689	4.151
Henderson	0.718	-	-	0.813	0.967	1.14	5.338

To model sorption isotherms, numerous correlations exist in the scientific literature (Kechaou, 2005). 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

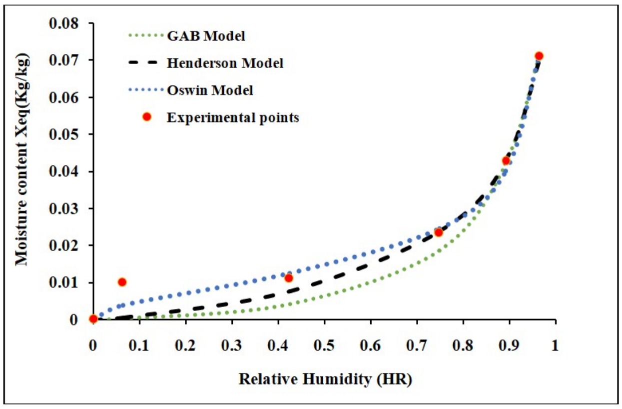

Figure 8. Experimental desorption isotherm curves and those predicted by the three models at T=40°C

model to model the sorption isotherms of 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 its desorption.

4.CONCLUSION

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 quasi-sigmoidal shape, corresponding to the group of type II isotherms according to the classification of the International Union of Pure And Applied Chemistry (IUPAC). The effect of temperature on the sorption isotherms was analysed. The water content of materials varies as a function of relative humidity for a fixed temperature. The experimental points were approximated by the GAB (Guggenheim - Anderson - Boer), Henderson and Oswin models to describe all the isotherms for all ranges of relative humidity and fixed temperature. 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 conserved 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 prevent excessive water absorption, which could affect their long-term structural stability.

REFERENCES

Etienne Malbila, David Y.K. Toguyeni, D. Joseph Bathiebo, « Hygrothermal behavior of two buildings constructed in cement bricks and cut laterite blocks, »*World Energy and Environment Technology Ltd,* vol. 5, pp. 1-6, 2017.

Ahouannou, C. Y. Jannot, Sanya E. et Degan G.,« Détermination expérimentale et modélisation des isothermes de désorption de produits agricoles tropicaux, » *Afrique Science,* vol. 06, n° %13, p. 1– 17, 2010.

Lamharrar, A. C.E.S. Kane, A. Idlimam, S. Akkad, M. Kouhila, A. Mimet et M. Ahachad, « Détermination expérimentale des isothermes de sorption et de la chaleur isostérique des feuilles d'absinthe et de menthe pouliot, » chez *13èmes Journées Internationales de Thermique,* Albi, France, 28 au 30 Août, 2007.

Kiema, B. O. Coulibaly, E. Ouedraogo, « Study of the Influence of Storage Media on the Thermo-Mechanical Behavior of Concrete and Cement Blocks, » *Physical Science International Journal. Https://doi.org/10.9734/psij/2024/v28i1820,* vol. 28, n° %11, pp. 45-55, 2024.

Gal, S. « The Need for, and Practical Applications of Sorption Data In Physical Properties of Foods, »*Elsevier Applied Physical Science,* pp. 13 - 25, 1987.

Wolf, W. W.E.L. Speiss and G. Jung, « Standardization of Isotherm Measurements, »*Properties of Water in Foods, Martinus Nijhoff Publishers,*pp. pp. 661 - 679, Dordrecht, The Netherlands, 1985.

Bizot H. et J.L. Multon, « Méthode de Référence pour la Mesure de l'Activité de l'Eau dans les Produits Alimentaires, »*Annales de Technologie Agricole,* vol. 27, n° %102, pp. 441 - 448, 2021.

Greenspan, L. « Humidity Fixed Points of Binary Saturated Aqueous Solutions, »*Journal of Research of the National Bureau of Standards,* vol. 81A, n° %101, pp. 89-96, A, Physics and Chemistry.

Kechaou, N. Etude Théorique et Expérimentale du Processus de Séchage de Produits Agro-Alimentaires', Thèse de Doctorat d'État, Faculté des Sciences de Tunis, Tunisie, PP.192, 2000.

Lahsasni, S. M. Kouhila, M. Mahrouz and M. Fliyou, «Moisture Adsorption-Desorption Isotherms of Prickly Pear Cladode (Opuntia Ficus Indica) at Different Temperatures,» *Energy Conversion and Management,* vol. 44, n° %106, pp. 923 - 936, 2009..

Idlimam, A. A. Lamharrar, N. Abdenouri, Kane C.S. Ethmane, S. Akkad, A. Jamali and M., « Thermodynamic Properties and Moisture Sorption Isotherms of Argania spinosa and Zygophyllum gaetulum', »*Journal of Agronomy,* vol.7,n°10, pp. 1 P 1- 14, 2008.

Hansen, K.K. « Sorption Isotherms-A Catalogue,» chez *Technical Report*, Technical University of Denmark, Lyngby, 1999..

Karoglou, M. A. Moropoulou, Z.B. Maroulis, M.K. Krokida, « Water sorption isotherms of some building materials., » p. 289–303, 2005.

Andrade, P.M. Lemus, C. Perez, « Models of sorption isotherms for Food: uses and limitations, Vitae,» vol. 18 , n° %13, p. 325–334 , 2011.

Kechaou, N. M. Bagane, M. Maalej, C, C. capseu, « Approche empiriquende la cinetique de séchage des dattes, » chez *in CDER et ENIM(Eds), Actes des 7 èmes journées Internationales de Thermique JITH 95, Marrakech, Maroc pp.581-593*, 2005.

****

Kiema, B., Coulibaly, O., Chesneau, X. and Zeghmati, B., « Numerical Modelling of Coupled Heat and Mass Transfer in Porous Materials : Application to Cinder Block Bricks, »*Open Journal of Applied Sciences. https://doi.org/10.4236/ojapps.2024.149156,*vol. 14, pp. 2360-2373, 2024.