Influence Of Thermal Conductivity On Energy Consumption Of Building

Remache Leila & Djermane Nacerddine
Science and Technology Department, Oum el bouaghi University, ALGERIA

Abstract

In building materials such as concrete, the moisture is removed by way of drying that needs an intense energy. It is introduced a mathematical model to describe this phenomenon. It consists to solve a system of two coupled equations, the first for mass transfer, and the second for heat transfer.
Thermo physical properties of concrete play an important rule.
Because thermal conductivity is considered as basic parameter to understand the heat flow in a material, it is computed by three ways and introduced in model equations.
It is concluded that thermal conductivity, which is affected by moisture content, has a significant influence on energy consumption.

***Key words**: moisture, energy, building, thermal conductivity, continuous approach, volume control method.*

1. Introduction

One of the many difficulties confronting researchers in the field of buildings is uncovering methods which reduce the energy consumption, new and innovative techniques which decrease heat losses and enhance product quality.
An analysis of conduction heat through structure is of great importance in energy efficient building design.
The knowledge of thermal conductivity and other thermal transport properties of construction materials involved in the process of heat transfer profile and heat flow through the material [1].
Effective thermal conductivity is the net overall thermal conductivity of porous materials. Its prediction is not a straight forward process. This turns out to be difficult problem because the transfer property is a complex function of many other parameters, such as the thermal conductivities of each phase, their relative proportions, the size of the solid particles, the contact areas and distribution within the medium,[2].
Many models based on different assumptions and with various degrees of realism have been developed in order to predict the effective thermal conductivity of these heterogeneous systems [2].
The presence of moisture may affect thermal conductivity. It increases with increasing moisture content. Since water has conductivity about 25 times that of air, it is clear that when the air in the pores has been partially displayed by water or moisture, the concrete must have greater conductivity [4].
Seiger and Hurd [5] reported that when unit weight of concrete increased 1% due to the water absorbsion, the thermal conductivity of the concrete increases 5%. This proves that moisture has an effect on heat transfer then on energy consumption.
So in this study, it is necessary to analyze and characterize the behavior of different phenomena as mass and heat transfer.

2. Moisture transfer

Moisture is one of the most deteriorating factors of building. The masonry moisture content depends on hygroscopic equilibrium between building materials and environment, which is determined by the drying and wetting rate of masonry. Therefore, the moisture content is not determined by the water that is absorbed by the material, but also by the amount of water that is evaporated, as described by the drying process [6].

Moisture has become an important parameter to predict the thermal properties, because of its adverse affects on porous material.

2.1. Mathematical model

For predicting, variation of thermal conductivity with moisture content, it is adopted a model of mass transfer for computing moisture content for concrete.

A humid porous plane of concrete is dried by air (T_a=323K, v=20m/s, φ=40%) (fig.1).

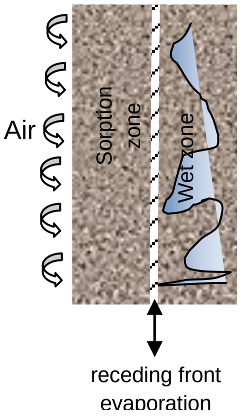

Figure 1 Mathematical model.

Moisture migration is modeled using a continuous approach. It is based on a description of the system as a fictitious continuum by using effective coefficients of heat and mass transfers [7], [8], [9].

The receding front model is employed for describing this process of migration [10].

In the wet zone ($\xi<x<e$)

$$\frac{\partial S_1}{\partial t} = \frac{\partial}{\partial x}\left(D_1 \frac{\partial S_1}{\partial x}\right)$$

(1)

In the sorption zone ($0<x<\xi$)

$$\frac{\partial S_2}{\partial t} = \frac{\partial}{\partial x}\left(D_{Sorp} \frac{\partial S_2}{\partial x}\right) + \frac{\partial}{\partial x}\left(\frac{D_v M_v}{RT} \frac{\partial P_v}{\partial x}\right)$$

(2)

Where D_1 is the liquid transfer coefficient, S_1 is the moisture saturation of free water, D_{Sorp} is the adsorbed water transfer coefficient, S_2 is the adsorbed water saturation, M_v denotes the molar mass of vapor and P_v is the partial vapor pressure.

For non hygroscopic material, $S_2=0$ and D_{Sorp} is negligible.

<u>Initial condition</u>

$S_1=0$

(3)

<u>Condition at interface</u>

$$\rho D_1 \frac{\partial S_1}{\partial t} = \rho D_{Sorp} \frac{\partial S_{Sorp}}{\partial x} + \frac{D_v M_v}{RT} \frac{\partial P_v}{\partial x}$$

(4)

The effective vapor diffusivity does not depend on the distribution of the pores, but the evaporation area. Therefore, this transport parameter is assumed as a function of saturation, porosity and the binary diffusion coefficient [11], [12].

$$D_1 = D_{eff}(S,T,P) = (1-S)\psi\delta_{va}(T,P)$$

(5)

The binary diffusion coefficient δ_{va} is considered as temperature and pressure dependent.

$$\delta_{va}(T,P) = 2.26.10^{-5}\left(\frac{T}{T_R}\right).\frac{P_R}{P_g}, m^2/s$$

(6)

Where T_R =273.15K and P_R =101325 Pa are reference temperature and pressure respectively.

$$D_{Sorp} = D_o\left(\frac{u_l - u_{eq}}{u_{ms} - u_{eq}}\right)\exp\left(\frac{-E_d}{RT}\right) [13]$$

(7)

$$u_l = 0.0105\varphi^{0.2} + 0.00125\exp(20\varphi) - 20$$

(8)

Sorption isotherm is applied in the model. Its value is obtained experimentally by allowing sufficiently long contact of material with air under isothermal conditions. The function of sorption isotherm is obtained by fitting curves from experimental data[14]:

$$\varphi(S) = \begin{cases} 1 if S \rangle S_{irr} \\ \frac{S}{S_{irr}}\left(2 - \frac{S}{S_{irr}}\right) if S \le S_{irr} \end{cases}$$

(9)

3. Heat transfer

The numerical modeling of heat transfer in porous media requires the accurate knowledge of several thermo physical properties as thermal conductivity.

3.1. Thermal conductivity

Thermal conductivity is the property that determines the working temperature levels of a material. It assumes a critical role in the performance of materials and it is important parameter in problems involving steady state heat transfer. It is one of the physical quantities whose measurement is very difficult and it requires high precision in the determination of the factors necessary for its calculation.

Many models are available to predict the thermal conductivity of two phases systems in terms of the thermal conductivities of the constituents [15].

The thermal conductivity is function of moisture content and temperature. It decreases linearly with temperature [16] and it is reported that is 70% great in moist state more than that in dry state [1].

Three values of thermal conductivity are taken for computing heat transfer:

a) Maxwell Euken model:

$$\lambda = \frac{1}{4}\left[\lambda_p(3V_p - 1) + \lambda_s(3V_s - 1)\right] + \left[\begin{matrix}\lambda_p(3V_p - 1) + \\ \lambda_s(3V_s - 1)\end{matrix}\right]^2 + 8\lambda_p \lambda_s^{1/2} \quad (10)$$

λ_s and λ_p thermal conductivities of solid and porous, V_s and V_p volume fractions.

b) $$\lambda = -0.41222S^2 + 0.77459S + 0.20601 \quad (11)$$

Thermal conductivity determined by "hot box method" [17], [18] and [19].

c) $\lambda = \lambda_0 + aT$ [20] (12)

Heat transfer equations are written:

In the wet zone: $$\rho c_{p1}\frac{\partial T_1}{\partial t} = \frac{\partial}{\partial x}\left(\lambda_1 \frac{\partial T_1}{\partial x}\right) \quad (13)$$

In the sorption one :

$$\rho c_{p2}\frac{\partial T_2}{\partial t} = \frac{\partial}{\partial x}\left(\lambda_2 \frac{\partial T_2}{\partial x}\right) \quad (14)$$

Where c_{p1}, c_{p2} are the specific heat capacities of water and vapor, λ_1, λ_2 are the thermal conductivities of water and vapor.

Initial condition: $T_1 = T_2 = T_p$ (15)

Condition at interface :

$$\lambda_1 \frac{\partial T_1}{\partial t} = \lambda_2 \frac{\partial T_2}{\partial x} + \Delta h_v \frac{D_v M_v}{RT}\frac{\partial P_v}{\partial x} \quad (16)$$

Boundary conditions :

$$\lambda_1 \frac{\partial T_1}{\partial x}\bigg)_{x=0} = 0 \quad (17)$$

$$\lambda_1 \frac{\partial T}{\partial x}\bigg)_{x=\frac{e}{2}} = h_T\left(T_{air} - T_{surf}\right) - \Delta h_v\left(\rho_{vsurf} - \rho_{v,\infty}\right)$$

(18)

In the model external mass and heat transfer coefficients are assumed to be constants as long as the external conditions are constant [21].

Convective heat transfer coefficient has been estimated from the mass transfer coefficient using the Chilton Colburn relation.

The non linear partial differential equations of the mathematical model calculate material moisture content and temperature as a function of position and time.

The procedure adopted for their solution consists basically of discrediting the spatial variable according to the control volume method [22].

4. Results

Figure 2 shows that mass transfer is controlled by three mechanisms which become sequentially significant with the progress of drying; convection, followed by diffusion in the solid phase, and conversion of bound into free diffused water in the last stages of drying until equilibrium is reached [23].

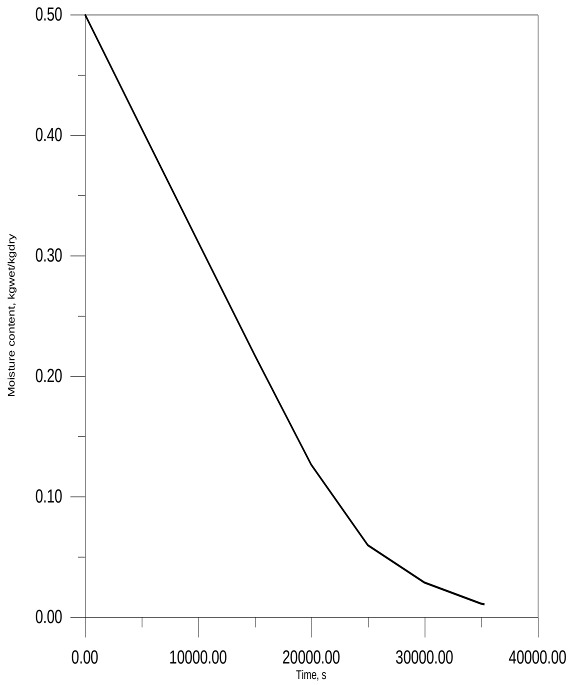

Figure 2 Moisture content function of time.

The drying is divided into an initial period and a second one [24]. During the initial period, it exists an evaporative plane at which all the free water evaporates. Since the liquid flow is insignificant beneath the plane due to the pit aspiration, this plane recedes into the material as drying proceeds. It divides the material into two parts, a wet zone beneath the plane and a sorption zone above it. In this last zone, moisture is assumed to exist as bound water and water vapor. In the wet zone, the moisture content remains at the initial value. After the evaporative plane reaches the centre layer of the board, drying is controlled by bound water diffusion and water vapor flow. It is called the second drying period [25].

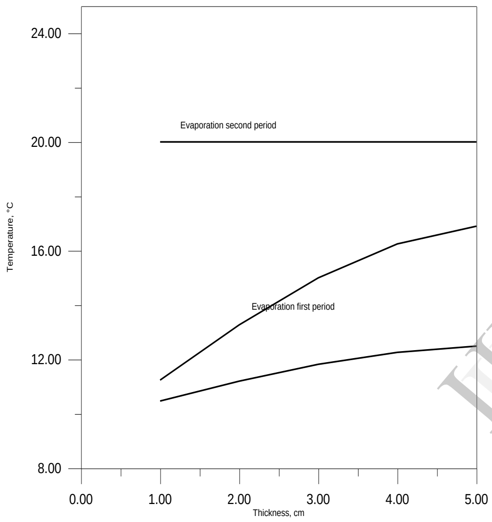

Figure 3 Temperature inside the material.

Thermal conductivity is computed by utilizing the moisture content evaluated by mass transfer equations and it is included in heat transfer equations.

Figure 3 shows that heat transfer in concrete covers heat conduction and phase exchange and they are interactive [26]. Convection is neglected because concrete is hygroscopic material.

Temperature increases than it reaches its equilibrium value.

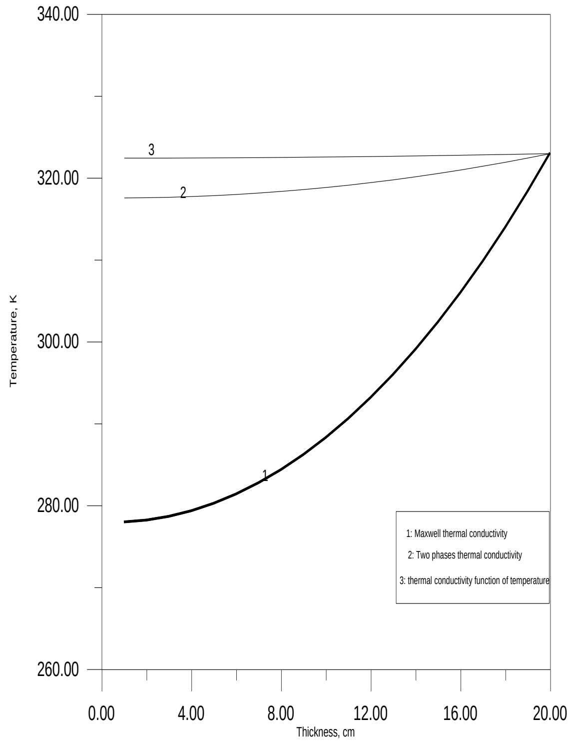

Figure 4 average temperatures for different values of thermal conductivity.

For different values of thermal conductivity, temperature varies (figure 4). Because the energy transfer in concrete to be dried results from the heat flow rate due to thermal conduction and the enthalpy flow rates of the liquid and vapor initiated by moisture transfer.

5. Conclusion

This study covers only some aspects of the processes occurring within the material during drying of porous solids.
From the results and simulations presented, some conclusions can be made:

- It is presented a solution technique for one dimensional drying simulation based on a comprehensive mathematical model, which describes all relevant transport phenomena, heat and mass transfer, by means of effective parameters (effective thermal conductivity, effective mass diffusion coefficient, effective permeability), by using the volume averaging method and the control volume element method;
- The advantage of employed model is that it offers a very good representation of the physical phenomena occurring in porous media during drying. However, the

problem encountered in its using is the difficulty is determining its complicated transport coefficients which depend strongly on the material properties and structure. These parameters are either function of moisture content or temperature or both them;

- The thermal conductivity of concrete is significantly affected by moisture content. It increases with its increase.

The objective of this study is analyzed the criteria of building design such as energy efficiency, minimization of environmental impact and protection of the health and safety of the inhabitants.

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