THE SIMULINK MODEL OF A MULTILAYER WALL FOR THE STUDY OF THE THERMAL TRANSFER IN TRANSIENT REGIME

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Abstract **– The problem of modeling and simulation of the dynamic regimes of the electrical ovens and of the electro-thermal plants in general, proves to be extremely complex. Such a simulation must take into consideration many parameters which can evolve depending on the plant temperature. Such evolutions (with different degrees of nonlinearity), can appear close to the heat sources, but also in the areas using heat. When simulating an electrical oven for thermal treatments, we must take into consideration the phenomena such as auto-heating of the electrical resistors, of the walls of the oven, of the parts and of the air from inside the oven. The modeling of the dynamic regime of heating the electrical oven, allowed us to emphasize some conclusions extremely useful in the design activity. The simulation of the whole plant of the oven with resistors, allowed us to obtain the results presented in the paper. The simulations realized at higher powers of the heating resistors, have showed the necessity of ensuring an automated control of the oven. In [6] are presented aspects related to the modeling of the oven and observations regarding their dimensioning and use. The simulation model of the multilayer wall presents the advantage that can add very easy as many intermediary layers as it is necessary.**

Keywords: *circuit simulation, electric heating, electrothermal effects, industrial power systems, system modeling*

1. INTRODUCTION

The paper aims to determine a model for the multilayer plan-parallel wall, in order to simulate the thermal transfer in transient regime.
This thing is especially important because in the majority of cases we deal with a thermal transfer through such a wall, even if we talk about an industrial plant (for example an electrical oven), or if we take into consideration the wall of a building.
Taking into consideration the cases mentioned previously, we can consider that the thickness of the wall is much smaller compared with its length and width. So we will consider that the thermal flux through the wall is transmitted across. In general, such a thermal flux appears because the wall separates two areas with different temperatures.
At the wall surfaces, depending on the content of the adjacent zones, the heat can be transmitted by conduction phenomena, by radiation or combined. In this paper we take into account a convection-radiation thermal transfer on both sides of the wall. To provide big enough convection and radiation fluxes, we have considered the wall of an oven for thermal treatments.
This wall comprise a refractory interior layer, one or more layers made of thermo-insulated materials and an exterior metallic carcass. The concrete modeled case takes into consideration an oven with resistors, meant for thermal treatments up to the temperature of 1200°C, and with the dimensions of the interior cavity of 1×0.8×0.7m. The walls comprise a dolomite refractory layer, with a thickness of 250mm, a diatomite thermal insulated layer, with a thickness of 85mm and a metallic carcass with a thickness of 6mm.

2. MATHEMATICAL MODELING

For the whole oven without anything inside, the thermal phenomena can be seen in Figure 1.

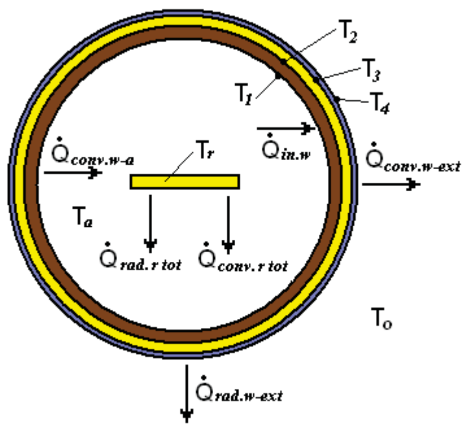

Figure 1: The energetic balance

Here we can observe the heating resistive elements which generate total thermal fluxes.

$\dot{Q}_{rad.r.tot}$ - total thermal flux of radiation from the heating element to the wall;

$\dot{Q}_{conv.r.tot}$ - total thermal flux of convection from the heating element to the air from inside the oven;

The temperatures of the different elements which are involved into the modeling are:

T_r - the temperature of the heating elements (remark that the temperatures for the resistive elements placed in different areas of the oven can differ);

T_a - the temperature of the air from inside the oven;

T_1, T_2, T_3, T_4 - the temperatures from the separation zones of the layers of the multilayer wall;

T_0 - the temperature of the air and of the elements from outside the oven;

Depending on the temperatures at each moment of the inner surface of the wall (T_1) and of the air from inside the oven (T_a), between the wall and the oven appears a convection thermal flux wall-inner air noted $\dot{Q}_{conv.w-a}$, which can inverse sense.

In conclusion, for the thermal fluxes which get into the wall we can write:

$$\dot{Q}_{in.w} = \dot{Q}_{rad.r\,tot} - \dot{Q}_{conv.w-a} \qquad (1)$$

This flux is stored partially inside the wall as heat. The rest is transferred outside the oven as convection ($\dot{Q}_{conv.w-ext}$) or radiated thermal flux ($\dot{Q}_{conv.w-ext}$).

In Figure 2 is presented the circuit of the thermal flux through the wall:

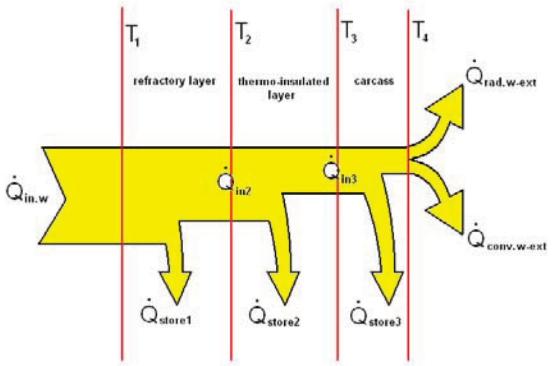

Figure 2: The thermal fluxes through the wall

The two thermal fluxes through the exterior surface of the wall ($S_{w.ext}$) can be written as:

$$\dot{Q}_{rad.w-ext} = \varepsilon \cdot c_n \cdot S_{w.ext} \cdot (T_4^4 - T_0^4) \qquad (2)$$

Where:

ε - the darkness degree of the exterior wall;

c_n - the Stefan-Boltzmann constant;

$$\dot{Q}_{conv.w-ext} = \alpha_{ext} \cdot S_{w.ext} \cdot (T_4 - T_0) \qquad (3)$$

In which:

α_{ext} - the convection coefficient between the air and the exterior wall;

If we consider the multilayer structure of the wall, and if we make this analysis at the level of each component layer, we can determine the mathematical equations which will underline the modeling.

2.1. The mathematical model for the inner layer

The temperature of the layer through which goes in the thermal flux is T_1 and the temperature of the layer through which goes out the thermal flux is T_2. For all the layers we consider a linear distribution of the temperature, so the average temperature in the first layer will be $(T_1 + T_2)/2$.

In these conditions the heat stored in the refractory layer at a certain moment of time will be:

$$Q_{store.1} = m_1 \cdot c_1 \cdot [(T_1 + T_2)/2 - T_0] \qquad (4)$$

In the relation above, m_1 and c_1 represent the mass and the heat specific to the material from the refractory layer, and T_0 represent the temperature of the cold wall, i.e. the ambient temperature [1].

The thermal flux transferred through the refractory layer is described by:

$$\dot{Q}_{in.2} = (T_1 + T_2)/R_T = \frac{\lambda_R \cdot S_R}{g_R} \cdot (T_1 - T_2) \qquad (5)$$

In which:

R_T - the thermal resistance;

λ_R - the thermal conductivity;

S_R - the surface of the refractory layer (calculated at its center, taking into account the parallelepiped shape of the oven);

g_R - the thickness of the refractory layer;

According to Figure 2:

$$\dot{Q}_{in.w} = \dot{Q}_{in.2} + \dot{Q}_{store1} = \dot{Q}_{in.2} + \frac{d}{dt}(Q_{store.1}) \qquad (6)$$

When modeling it must be taken into account that the value T_2, as well as the values of the three thermal fluxes which are involved in equation (6), are not known. They will be determined dynamically within other functional blocks. T_1 will be calculated within the block and it will be sent as output data [2].

2.2. The mathematical model for the thermo-insulated layer

Taking into account that it can be many thermo-insulated layers, we will use the notations:

T_{out} = Output temperature = T_3

T_{in} = Input temperature = T_2

$\dot{Q}_{IN}$ = Input flux = $\dot{Q}_{in.2}$

$\dot{Q}_{OUT}$ = Output flux = $\dot{Q}_{in.3}$

λ_{TIZ} = the thermal conductivity

S_{TIZ} = the surface of the layer

g_{TIZ} = the thickness of the layer

The equations which describe the thermo-insulated layer are:

$$Q_{storeTIZ} = m_{TIZ} \cdot c_{TIZ} \cdot [(T_{OUT} + T_{IN})/2 - T_0] \quad (7)$$

$$\dot{Q}_{OUT} = \frac{\lambda_{TIZ} \cdot S_{TIZ}}{g_{TIZ}} \cdot (T_{IN} - T_{OUT}) \quad (8)$$

$$\dot{Q}_{IN} = \dot{Q}_{OUT} + \frac{d}{dt}(Q_{storeTIZ}) \quad (9)$$

2.3. The mathematical model for the exterior carcass

$$Q_{store.3} = m_c \cdot c_c \cdot [(T_4 + T_3)/2 - T_0] \quad (10)$$

$$\dot{Q}_{OUT.C} = \dot{Q}_{rad.w-ext} + \dot{Q}_{conv.w-ext} \quad (11)$$

$$\dot{Q}_{IN.C} = \dot{Q}_{OUT.C} + \frac{d}{dt}(Q_{store.3}) \quad (12)$$

Where:

m_c - the mass of the metallic carcass;

c_c - the specific heat of the carcass;

3. THE SIMULINK MODEL

To create the model we have started from the idea that the only layer to which is easy to calculate the output flux is the exterior carcass. So, respecting the equations (10)-(12) for the carcass, we have realized the Simulink model presented in Figure 3. This block has as output values, the temperatures T_3 and T_4, and as input values: the thermal flux leaded by the oven in the environment ($\dot{Q}_{IN.C}$), the ambient temperature (T_0) and the parameters which are involved in the mathematical model.

For the refractory layer and for the thermo-insulated layers, the mathematical relations are similar and, consequently, the Simulink models will be alike [3], [5]. They are presented in Figure 4.

We can observe that each layer has as output variables the thermal flux transferred by the next layer and the temperature at the input of the layer. In this way, by connecting successively the models that simulate the layers of the wall, we can make the calculus of the temperatures $T_1 \div T_4$ and the thermal fluxes through the exterior. The connection diagram is presented in Figure 5.

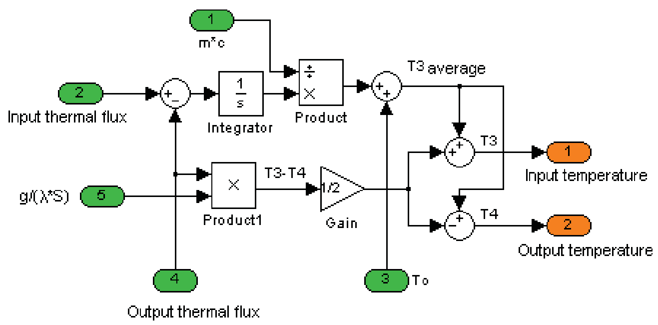

Figure 3: The carcass

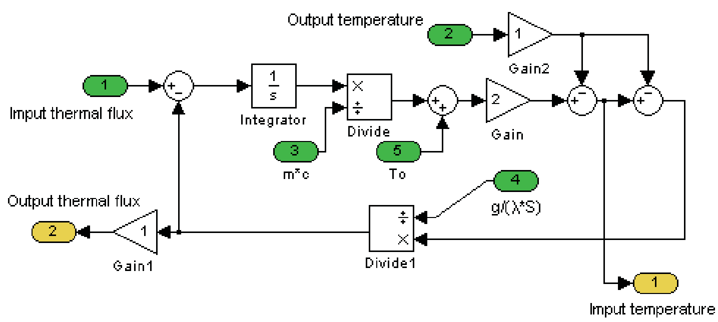

Figure 4: The refractory layer and the thermo-insulated layers

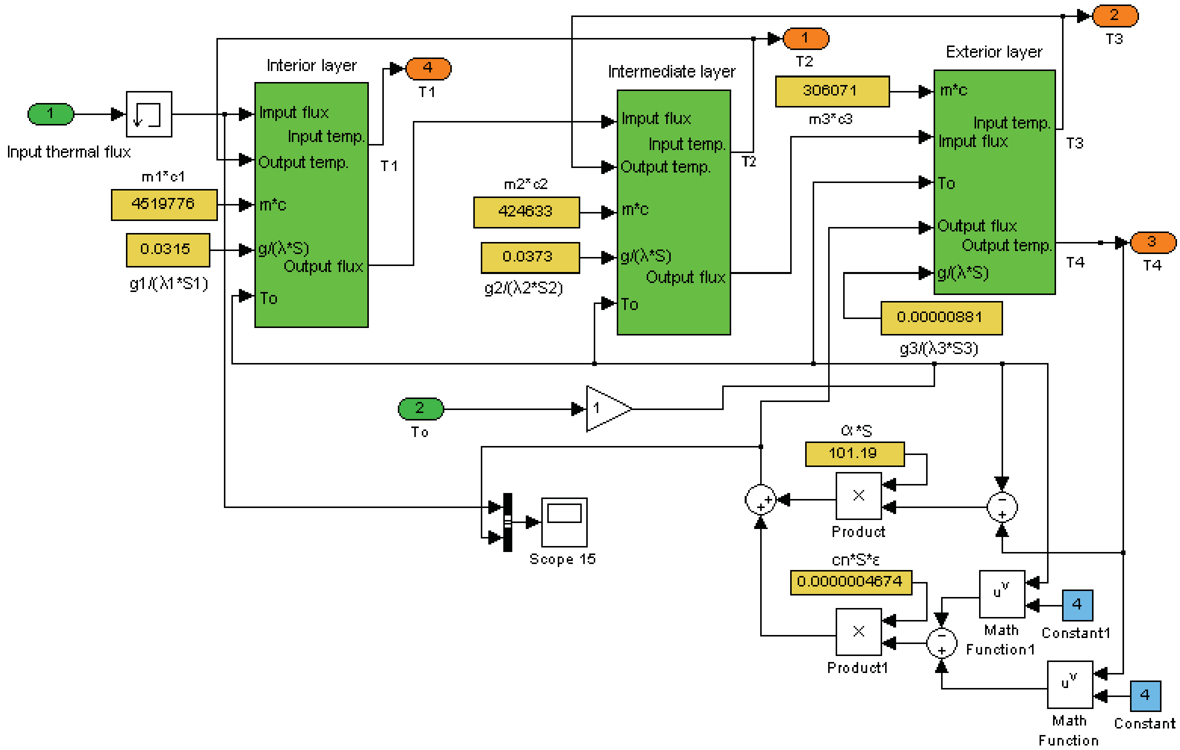

Figure 5: The block diagram of the wall

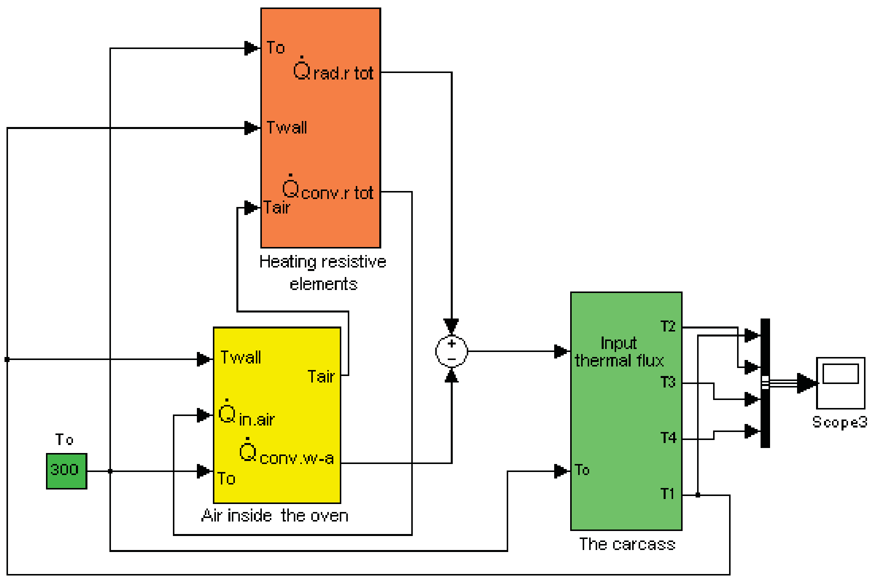

Figure 6: The bock diagram of the oven

Knowing the temperature of the wall inside the oven (T_1), allows us to calculate the input thermal flux ($\dot{Q}_{in.w}$) according to relation (1).

This thermal flux composed by the flux radiated by the heating resistors to the wall, and by the thermal flux exchanged by convection between the wall and the air from inside the oven, is calculated within the modeling, in other interior blocks. It is important to remark that, within the dynamic calculations, these blocks simulate a series of nonlinearities and temperature dependencies, as the electrical resistance of the heating resistors, the specific heat of the air

from inside the oven or the convection coefficient between the air and the refractory layer [4].
In Figure 6 is presented a block diagram of the whole oven which has permitted us to simulate the transient regime.

4. SIMULATION RESULTS

The SIMULINK model allowed us to realize some simulations extremely complex for different installed powers of the heating resistors. A part of the results are presented nearby. Within the model are studied relatively fast processes, such as the heating of the resistive elements, but also slow processes (the heating of the walls of the oven). To emphasize the phenomena produced during the transient regime of heating the oven, we realized simulations with two different periods of time (50s and $15 \cdot 10^5$s).
In Figure 7 and Figure 8 are presented the temperatures of the three types of heating elements.
In Figure 9 and Figure 10 are presented the variation ways of the convection and radiation fluxes, produced by the heating resistors.

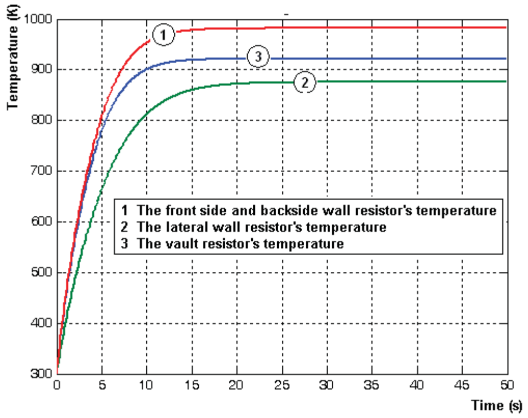

Figure 7: The temperature of the resistors – short time simulation

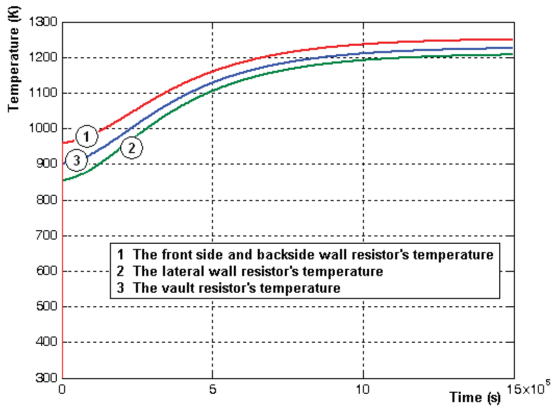

Figure 8: The temperature of the resistors - long time simulation

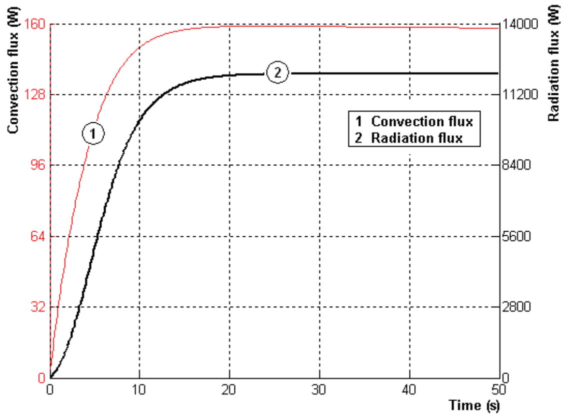

Figure 9: Total thermal fluxes - short time simulation

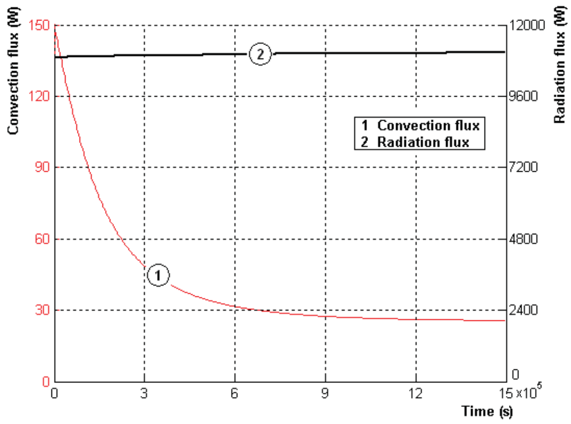

Figure 10: Total thermal fluxes - long time simulation

In Figure 11 and Figure 12 are presented the evolutions in time of the wall's input thermal flux and of the flux transferred in the exterior of the oven.
Figure 13 present the evolution of the temperatures of the separation zones between the layers of the walls.

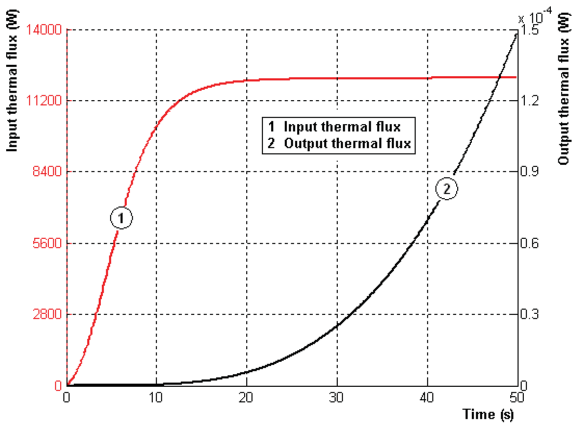

Figure 11: Thermal fluxes through the wall - short time simulation

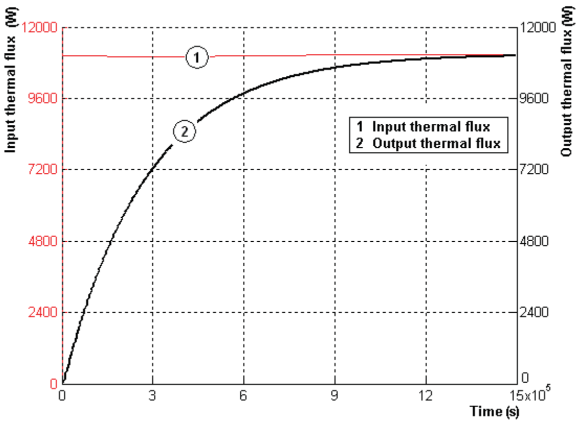

Figure 12: Thermal fluxes through the wall - long time simulation

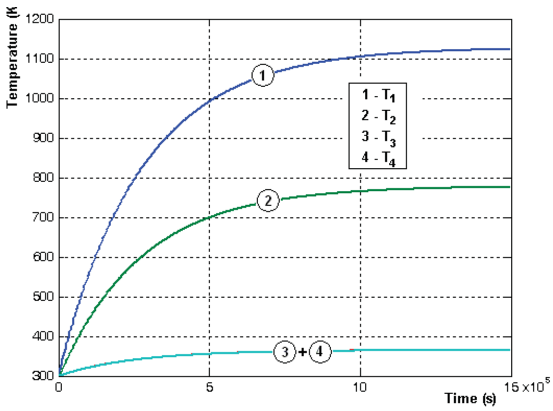

Figure 13: The temperatures of the wall – long time simulation

5. CONCLUSIONS

The presented model has the advantage of a modular approach. This allows us to introduce pretty easy extra insulated layers, and to adapt the simulation parameters to the change of the dimensions of the layers, or of the materials from which they are made.

The simulations realized at higher powers of the heating resistors, have showed the necessity of ensuring an automated control of the oven. Without an automated control, the damage of the resistors by overheating is almost imminent.

Acknowledgments

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