Heat transfer modeling in the hot source area of flat micro heat pipe

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ABSTRACT

This paper presents a modeling of heat transfer through the vaporization zone to the flat heat micro conductor when used as an additional reservoir of liquid polysynthetic material. In the study of the intensification of heat transfer to the flat thermal microtubule, it was assumed that the blockage in operation may occur if the thermal transport capacity is exceeded by applying a higher thermal flux on the vaporization area. In this case the internal vapor flow is interrupted as the vaporization and condensation zones reach thermal equilibrium. Practically the vapors no longer condense in the evaporator and no longer perform heat transfer through biphasic thermal transformation. The increase in internal pressure in case of accumulation of liquid vapor is not taken into account in this analysis, it will be the subject of a separate study. The variation of the thermal flow in the cross section on the evaporator and the variation of the liquid flow through the capillary layers in the evaporator shall be analyzed. Heating the vaporization area by thermal conduction causes the capillary start composed of the vaporization area to create liquid vapor. Heat transfer from within the flat heat micro conducting (FMHP) will be performed conventionally by plotting the thermal variation graphs in Mathcad. The temperature variation over time on the wall of the evaporator in the area of the source with variable thermic flux (external heat source), as well as the propagation of the temperature field will be achieved by modeling in Matlab.

Keywords: evaporation, flat micro heat pipe, frittered copper and polysynthetic material.

1. HEAT TRANSFER TO FMHP THROUGH SINTERED CAPILLARY LAYERS

The study of heat transfer in the vaporization zone through sintered capillary layers is analyzed as a compromise between the degree of permeability and the size of the pores. Porous capillary layers can be classified into: low performance capillary layers at which the pore is between *80÷150µm*, and high-performance capillary layers at which the pores are between *30÷80µm*. In the case of heat transfer through the micro heat pipe, the working fluid inside will undergo biphasic transformations. The liquid diffused in the capillary start of copper, by heating, produces vapors that will transfer the thermal flow through the interior of the flat micro conductor to the end where the condensation takes place, thus eliminating the thermal flow in the environment. Inner capillary layers according to W. W. Wits and so on.a. [1] shall be chosen in such a way as to allow the fluid to move only by introducing adhesion forces which may create greater capillary pressure inside the FMHP. The conductive heat transfer between the heat source and the outer wall of the FMHP is ideally achieved without loss. As shown in figure 1, the heat will propagate by conduction, in the directions *x,y* and *z*, from the heat source (characterized by variable heat flux) through the walls of the FMHP and the sintered copper capillary layer (SCL). From SCL, heat is conventionally transmitted to the working fluid. The working fluid in the condenser turns into vapor (the evaporator area) that will flow in the direction opposite to its movement. If during heat transfer the value of the thermal flow over the vaporization area is very high, exceeding the maximum transport capacity of FMHP, the biphasic thermal transformation ceases. Basically, in the FMHP interior there will be an accumulation of liquid vapors that will no longer condense in the condensation area.

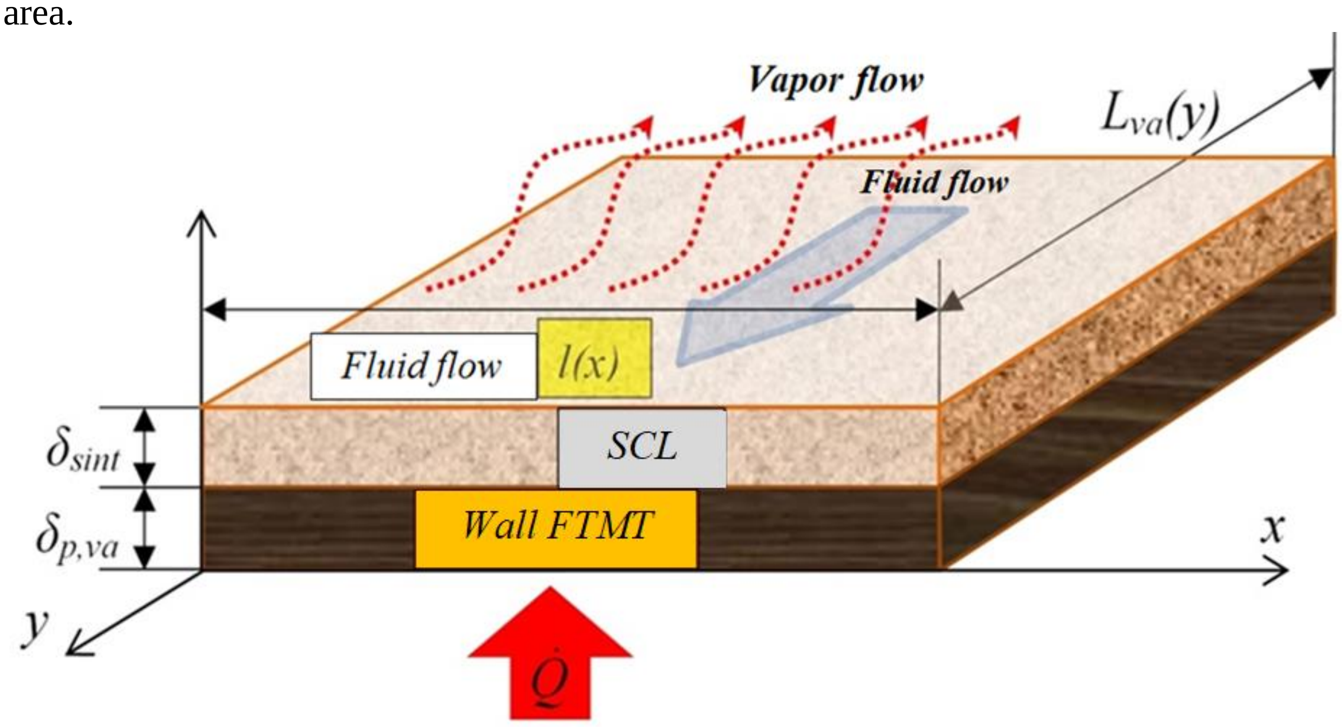


Fig.1. Representation section of a through FMHP wall with SCL.

The thermal flow generated by the heating element (hot source) applied to the outer face of the MTTP wall in the vaporization area, will cause the heating of the walls and the working fluid. As follows from figure 1, the heat will propagate by conduction, in the directions x, Y and z, from the hot source (characterized by the density of the thermal flux) through the walls of MTTP and the capillary layer sintered copper (SCL). In the porosity of the copper sintered capillary layer, a quantity of working liquid is diffused. The working liquid is heated convectively. The working liquid from the condenser turns into vapors (vaporizer area) that will flow in the opposite direction of its movement. The heat transfer regime between the hot source and the outer wall of the FMHP is time-dependent and spatially delimited. The thermal flow applied to the vaporizer can be described by applying Fourier's law for propagation directions:

$$\dot{q}_{va} = \lambda_{Cu} \nabla T_{va} = -\lambda_{Cu} \left(\frac{\partial T_{va}}{\partial x} + \frac{\partial T_{va}}{\partial y} + \frac{\partial T_{va}}{\partial z} \right). \tag{1.1}$$

The equation of conductive heat transfer on the x, y, z directions for the wall section of the considered MTTP, for transient mode, is:

$$\rho_{Cu} c_{p,Cu} \frac{\partial T}{\partial t} = \lambda_{Cu} \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right). \tag{1.2}$$

In the case of the capillary layer sintered with working fluid, the energy equation of the thermal flow can be written:

$$\frac{\partial T_{va}}{\partial t} \left(\rho_{Cu} c_{p,Cu} \right)_{\dot{m}} + \left(\rho_{Cu} c_{p,lic} \right)_{lic} \left(\frac{\partial T_{va}}{\partial x} + \frac{\partial T_{va}}{\partial y} + \frac{\partial T_{va}}{\partial z} \right) = \lambda_{Cu} \left(\frac{\partial T_{va}}{\partial x} + \frac{\partial T_{va}}{\partial y} + \frac{\partial T_{va}}{\partial z} \right). \tag{1.3}$$

Initial conditions require that at t = 0, the initial temperature of the entire system is at ambient temperature, thus *T (0, t)=25°C* and *T (l,t)*. Initially the temperature is distributed in the FMHP wall after *T (x,y,0) = T0sin (nxy/l)*. We consider that the square surface on which the heating resistance of the vaporization zone is located has the side *l=10mm*. In this case the energy equations will be reduced to a bidirectional heat transfer on the *x* and *y* directions, equations 1.1 – 1.3 become:

$$\dot{q}_{va} = \lambda_{Cu} \nabla T_{va} = -\lambda_{Cu} \left(\frac{\partial T_{va}}{\partial x} + \frac{\partial T_{va}}{\partial y} \right), \tag{1.4}$$

$$\rho_{Cu} c_{p,Cu} \frac{\partial T}{\partial t} = \lambda_{Cu} \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right), \tag{1.5}$$

$$\frac{\partial T_{va}}{\partial t} \left(\rho_{Cu} c_{p,Cu} \right)_{\dot{m}} + \left(\rho_{Cu} c_{p,lic} \right)_{lic} \left(\frac{\partial T_{va}}{\partial x} + \frac{\partial T_{va}}{\partial y} \right) = \lambda_{Cu} \left(\frac{\partial T_{va}}{\partial x} + \frac{\partial T_{va}}{\partial y} \right). \tag{1.6}$$

By integrating equations 1.5 and 1.6 after the l side and taking into account the size of the surface subject to heating, we obtain:

$$\rho_{Cu} c_{p,Cu} \int_0^l dx \int_t^{t+\Delta t} \frac{\partial T}{\partial t} dt = \lambda_{Cu} \left[\int_0^l dx \int_t^{t+\Delta t} \frac{\partial}{\partial x} \left(\frac{\partial T}{\partial x} \right) dt + \int_0^l dz \int_t^{t+\Delta t} \frac{\partial}{\partial y} \left(\frac{\partial T}{\partial y} \right) dt \right], \tag{1.7}$$

for the capillary layer of sintered copper with the working fluid related to the l-side area:

$$\left(\rho_{Cu} c_{p,Cu} \right)_{\dot{m}} \int_t^{t+\Delta t} \frac{\partial T_{va}}{\partial t} dt + \left(\rho_{lic} c_{p,lic} \right)_{lic} \left(\int_t^{t+\Delta t} \frac{\partial T_{lic}}{\partial x} dx + \int_t^{t+\Delta t} \frac{\partial T_{lic}}{\partial y} dy \right) = \lambda_{Cu} \left(\int_t^{t+\Delta t} \frac{\partial T_{va}}{\partial x} dx + \int_t^{t+\Delta t} \frac{\partial T_{va}}{\partial y} dy \right). \tag{1.8}$$

The variation of the temperature field lines after the two directions x and y highlights the heating mode of the vaporization area. For modeling in Matlab[2] the variation of the temperature field lines were considered temperature values in the range *25°C* respective *75°C*. The temperature variation over time is determined by a thermal flux of *20W* applied to the surface considered, respectively $1 \cdot 10^{-4} m^2$.

2. HEAT TRANSFER TO FMHP THROUGH POLYSYNTHETIC CAPILLARY LAYERS

Polysynthetic materials inside the FMHP used as an additional liquid reservoir (figure 2), have the role of intensifying the thermal transdermal in the event of a lock in operation of the FMHP. As a principle of Operation; additional liquid tanks using polysynthetic materials will release an additional amount of liquid that already exists inside the FMHP only when there is no heat exchange between the evaporator and the condenser. Thus, the heat transfer through FMHP by the accumulation of only the vapors of the initial working liquid [3] is no longer carried out, the vaporization zone and the condensation zone reaching thermal equilibrium.

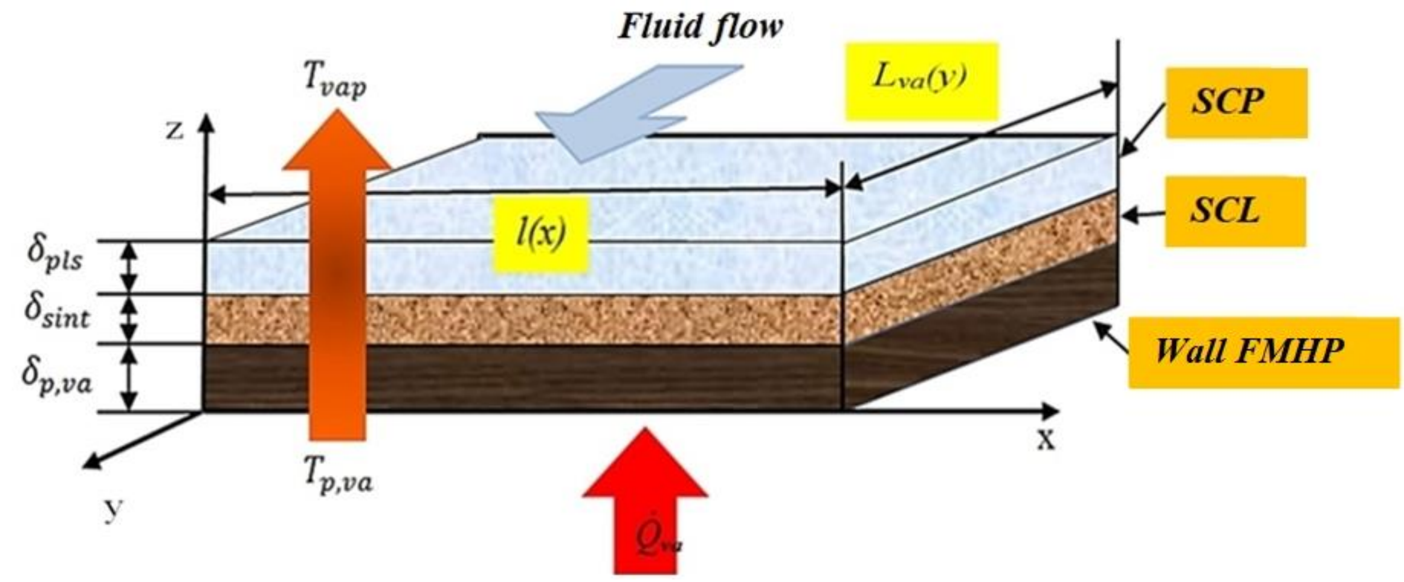


Fig.2. Schematic section representation of a through FMHP wall with SCL and SCP

Since the simultaneous analysis of the two forms of heat transfer may be complex, the heat transfer in the polysynthetic porous material shall be analyzed separately. By hypothesis it is considered in calculations that the polysynthetic material is incompressible. The data needed to perform the calculations: $\delta_{p,va}$ -vaporizer wall thickness, δ_{sint} -sintered layer thickness, $\delta_{p,scp}$ - polysynthetic material thickness, $T_{p,va}$ -vaporizer wall temperature, *l*, *L*-width and length of the active area of MTTP, *SCL* - sintered capillary layer of copper balls, *SCP* - polysynthetic capillary layer. It is considered that the polysynthetic porous medium is isotropic and hypotheses exclude the effects generated by changes in pressure in the liquid and heat dissipation due to the change in the viscosity of the liquid. It is assumed that there is a local thermal equilibrium. It was noted with T_{scp} and T_{lic} the temperature of the respective polysynthetic material of the liquid. General equation of thermal conduction [4],[5],[6],[7] for polysynthetic material:

$$\left(1-\varepsilon_{scp}\right)\left(\rho_{scp}c_{scp}\right)\frac{\partial T_{scp}}{\partial t}=\left(1-\varepsilon_{scp}\right)\nabla\cdot\left(\lambda_{scp}\nabla T_{scp}\right)+\left(1-\varepsilon_{scp}\right)\dot{q}_{scp}\,, \tag{1.9}$$

for liquid diffused in the pores of polysynthetic material:

$$\varepsilon_{scp}\left(\rho_{lic}c_{p,lic}\right)\frac{\partial T_{lic}}{\partial t}+\left(\rho_{lic}c_{p,lic}\right)v\cdot\nabla T_{lic}=\varepsilon_{scp}\nabla\cdot\left(\lambda_{lic}\nabla T_{lic}\right)+\varepsilon_{scp}\,\dot{q}_{lic}\,, \tag{1.10}$$

where: (1-ε_{scp}) - how much of the total volume of the material, is the volume of macro porosity, the ε_{scp} - represent the actual amount of of macro porosity also referred to as the degree of porosity, smarter c_{scp} - the specific heat of the material polysynthetic, the $c_{p,lic}$ - specific heat of fluid at constant pressure, $\dot{q}_{scp}$, $\dot{q}_{lic}$ - the density of the heat flux applied to the material polysynthetic, and the liquid per unit volume [*W/m3*]. Since the three materials composing the thermal Assembly are in direct contact with each other, it is considered that the thermic flux density applied to the FMHP wall will be accelerated in all the structures mentioned in figure 2. In this case $\dot{q}_{lic}=\dot{q}_{va}=\dot{q}_{scp}$. From 1.9 and 1.5 it follows:

$$\left(1-\varepsilon_{scp}\right)\left(\rho_{scp}c_{scp}\right)\frac{\partial T_{va}}{\partial t}=\left(1-\varepsilon_{scp}\right)\lambda_{Cu}\left(\frac{\partial^2 T_{va}}{\partial x^2}+\frac{\partial^2 T_{va}}{\partial y^2}\right)+\left(1-\varepsilon_{scp}\right)\dot{q}_{scp}\,, \tag{1.11}$$

$$\dot{q}_{scp}=\left(\rho_{scp}c_{scp}\right)\frac{\partial T_{va}}{\partial t}-\lambda_{Cu}\left(\frac{\partial^2 T_{va}}{\partial x^2}+\frac{\partial^2 T_{va}}{\partial y^2}\right). \tag{1.12}$$

It can be considered, in a simplified form, that the porosity of a material represents the total volume of voids in the total volume of the material. In the analysis of heat and mass transfer through porous media, the two forms of heat transfer - conductive and convective-cannot be separated. To simplify the calculations, in the analysis of the results, only the heat transmission component in conductive mode was considered.

3. ANALYSIS OF THE RESULTS

Starting from the initial conditions imposed on the it was analyzed the variation of the temperature of the interior surface of the FMHP, when it is applied to a heat flux value of *20 W*. The analysis of the phenomenon of the transmission of the heat-conductive wall of the FMHP and the layers of the interior entering into contact with it, shall be carried out for a period of time of *50* minutes, and the maximum temperature at which it is going to warm up the area of the boil-off was determined to be *75°C*. The displacement of the thermal field in the analysis will be done for the two directions of propagation, corresponding to the *x,y* axis. The simulation carried out in Mathcad shows that after applying the thermal flow there is an increase in temperature in the FMHP wall. This points out that for the time interval *0÷30* minutes there is an increase in temperature $\Delta T=48°C$. In figure 3 the graph of the temperature variation in the chosen time interval highlights the above statement.

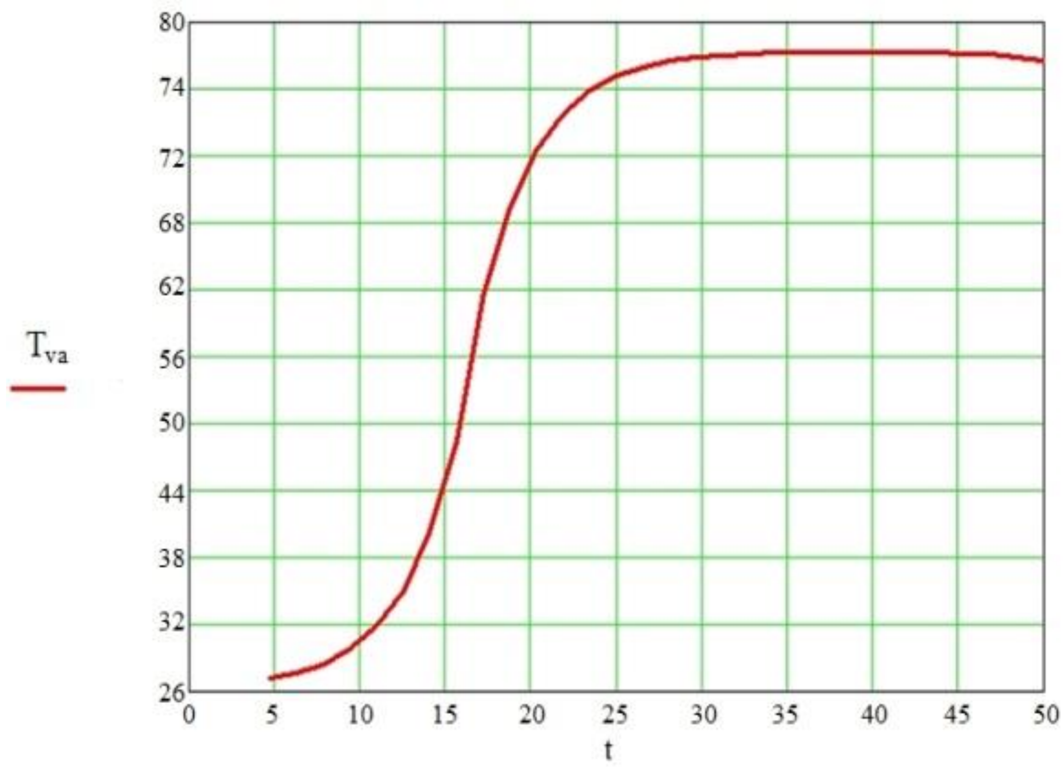


Fig.3. Temperature change in the wall FMHP in 50-minute interval time

After reaching the maximum temperature, on the graph in figure 3, it can be seen that even if the thermal flow is continued application on the vaporization zone of FMHP temperature does not change. After the *30* minutes when the temperature variation is obvious, the thermal balance appears. The vaporization area will be found for the rest of the time at the same temperature. The temperature field variation in the vaporization zone for the defined surface was modeled by a T_{plate} function. In figure 4 a, b, the displacement of the temperature field was graphically represented.

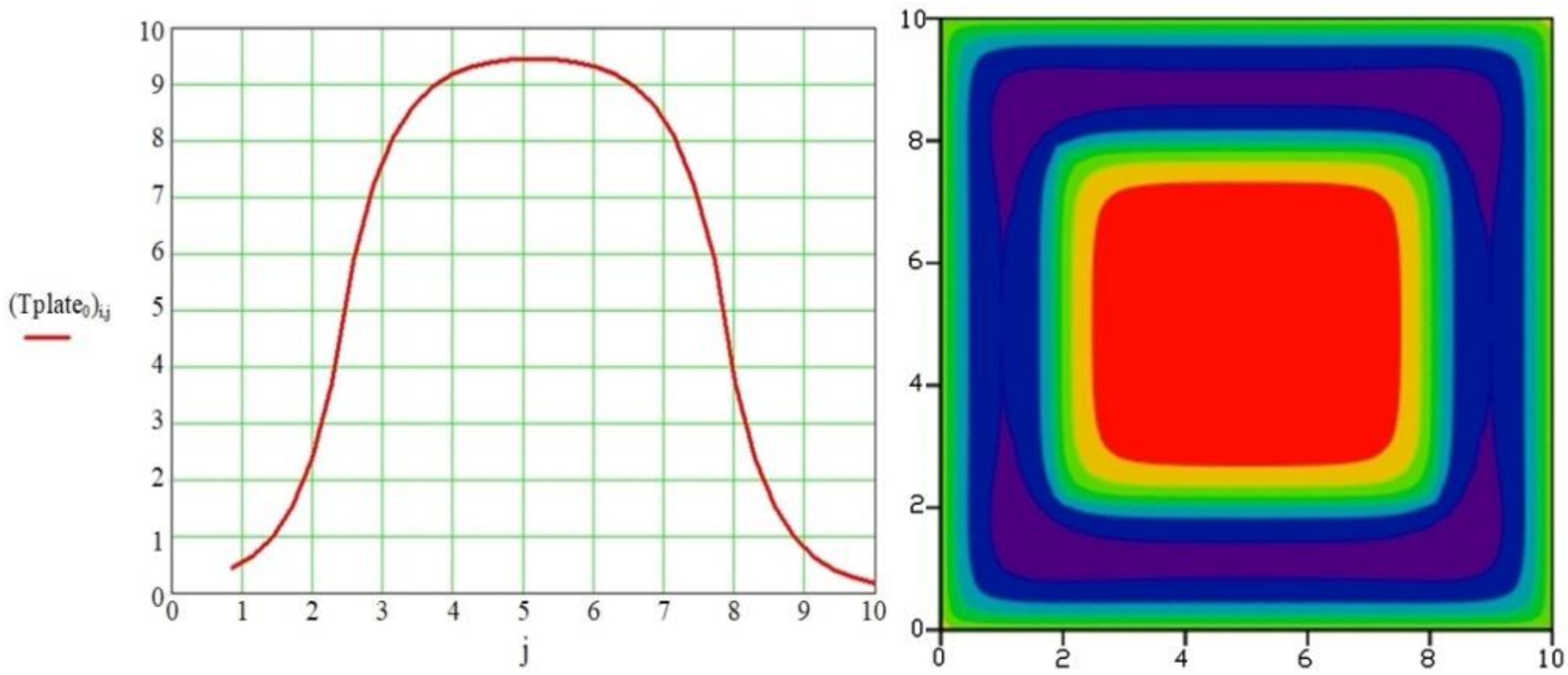


Fig.4. Graphical representation of field temperature variation by function T_{palte}.

A simulation shall be performed in Matlab to verify that the temperature field variation in the area under analysis is correct. In equation 1.5 after integration the partial derivative of the temperature in relation to time can be written:

$$\frac{\partial T}{\partial t} = \frac{T_i^{t+1} - T_i^t}{\Delta t}. \tag{1.13}$$

In the case of the two partial derivatives of the temperature variation on the two directions can be written:

$$\frac{\partial^2 T}{\partial y^2} = \frac{T_{i-1;j}^t - 2T_{i;j}^t + T_{i+1;j}^t}{(\Delta y)^2}, \tag{1.14}$$

$$\frac{\partial^2 T}{\partial z^2} = \frac{T_{i;j-1}^t - 2T_{i;j}^t + T_{i;j+1}^t}{(\Delta z)^2}. \tag{1.15}$$

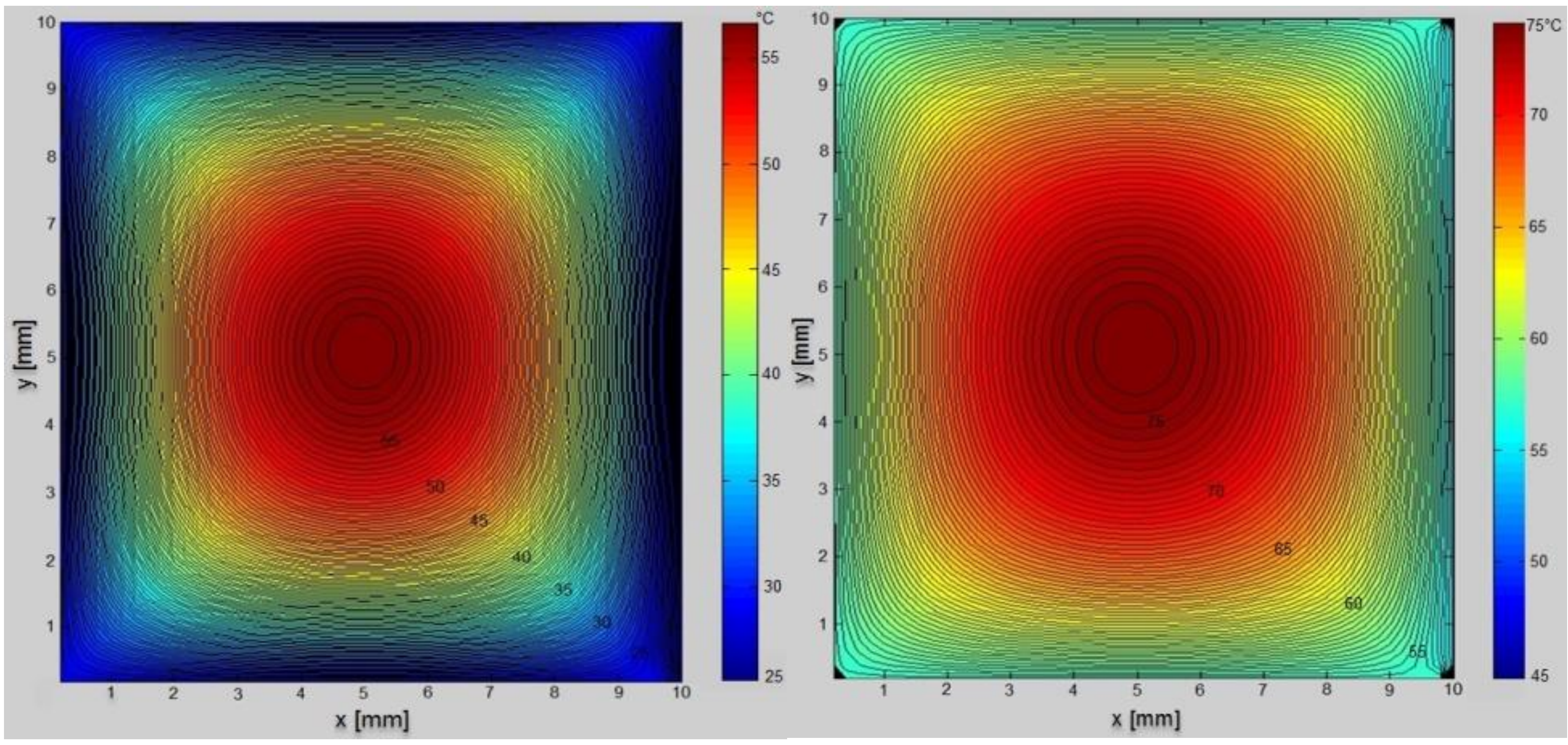
Results:

$$\rho_{Cu} c_{p,Cu} \frac{T_i^{t+1} - T_i^t}{\Delta t} = \lambda_{Cu} \left(\frac{T_{i-1;j}^t - 2T_{i;j}^t + T_{i+1;j}^t}{(\Delta y)^2} + \frac{T_{i;j-1}^t - 2T_{i;j}^t + T_{i;j+1}^t}{(\Delta z)^2} \right). \tag{1.16}$$

From the condition that the side *l = 10 mm* corresponds to a square surface, it follows that $\Delta y = \Delta z$ in which case:

$$\frac{\rho_{Cu} c_{p,Cu} \left(T_i^{t+1} - T_i^t \right)}{\Delta t} = \lambda_{Cu} \left(\frac{T_{i-1;j}^t - 4T_{i;j}^t + T_{i+1;j}^t + T_{i;j-1}^t + T_{i;j+1}^t}{\left(\Delta y \right)^2} \right). \tag{1.17}$$

The variation of the temperature field lines after the two directions y and z highlights the heating mode of the vaporization area. Figure 5 shows the result of the MATLAB modeling of heat transfer in the transient, bidirectional vaporization zone when applying a thermal flux of *20W* on an area of $1 \cdot 10^{-4} m^2$.



a) t=60s *b) t=180s*

Fig.5. Modeling the temperature field in the area of the warm source.

Modeling of heat transfer in the hot source area of FMHP shown in figure 2, $T_{ini} = 20°C$ and a pre-set maximum temperature $T_{fin}=80°C$. After a time, *t=60s*, the temperature field lines show a circular shape (figure 2-a), and at *t=180s* these or increased forward to the outside of the area (figure 2-b). Of the two figures 2.a-b is observed as the temperature field lines evolve over time.

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