ON A METHOD OF ASSESSMENT OF THE THERMAL TRANSFER BY CONDUCTION IN LAMINATED COMPOSITE

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Abstract. The paper explain the thermal conductivity expressions, in stationary regime, in plane, tubular and spherical, laminated composite structures, with intimate connections between layers, having defects, too. We take into account the volumes of the composite components, on the one hand, and those of the materials and fluids, contained in the defects area, on the other hand. In the corresponding relations the influences of some additional layers, representing protections or deposits during operation, are attached.

Keywords: composite layer, thermal conduction

1. INTRODUCTION

The world problem of raw materials demonstrates the need for industrial use of new materials, containing alternative compounds, so finally to obtain high thermo-mechanical characteristics. Such a desideratum has conducted to production of laminated composite materials, for example, to offer remarkable advantages: low weight, tensile strength and chemical resistance, low power consumption to obtain, compared to the metals, increased vibration damping capacity, sound isolation and/or thermal, low thermal deformation factor, etc. [1-8]. Some known disadvantages that the designers and the users seek to eliminate or reduce them, by appropriate solutions, should not be neglected. The composite materials have been used by humans since ancient times [9, 10], being called "*second generation materials*" [11, 12]. The domains of use of the composite materials were developed with the time and obtaining some specific technologies, remarking: the equipment in the process industry [13 - 17], in the aeronautic industry [18 - 21], in the ground or underwater transport industry [22 - 24], in the military industry [25 - 27], in the healthcare domain [28, 29] etc.

The industrial practice amply showed the knowledge need of the thermal processes which manifest, correlated with the industrial structures, namely those of composite laminates that are the subject of this paper. For the evaluation of the thermal solicitation states, such construction mentioned, to know the temperature levels between component layers, in case of intimate /perfect contacts or with imperfections/defects is very important.

As a result, the following setting specifies a version to set for the plane, tubular or spherical walls temperatures, mono-or multilayer construction.

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2. EXPRESSIONS FOR THE THERMAL CONDUCTIVITY

The thermal conductivity [30-32] (terminology introduced by ***Joseph Fourier*** - 1822) is the physical size that characterizes a material to transmit the heat, when is subjected to a temperature difference [31-34].
The thermal isolation capacity of a material is expressed as **the coefficient of thermal conductivity**, noted by λ and expressed in $\left[W/m\cdot K\right]$ [32, 33].

The thermal conductivity is dependent on the physical properties of the material: temperature, density, porosity, humidity [32, 33], varying, of course, from one material to another.

For ***the homogeneous materials***, the coefficient of thermal conductivity can be estimated with the expression [32-37]:

$$\lambda = \lambda_0 \cdot \left(1+\beta \cdot T\right), \tag{1}$$

where λ_0 is the thermal conductivity at the temperature with degrees K; T – the temperature; β - the dependent factor of the studied material, being negative for the most heat conductive solids [32].

For ***the porous materials*** the apparent thermal conductivity is calculated with the relation [32, 33]:

$$\lambda_a = \lambda_{mp} \cdot \frac{1-\left(1-\dfrac{3\cdot\lambda_p}{2\cdot\lambda_{mt}+\lambda_p}\right)\cdot\varepsilon}{1+\left(\dfrac{3\cdot\lambda_{mt}}{2\cdot\lambda_{mt}+\lambda_p}-1\right)\cdot\varepsilon}, \tag{2}$$

where the notations were used: λ_a - the apparent conductivity; λ_p – the thermal conductivity of the environment (gas or liquid) from pores; λ_{mt} – the thermal conductivity of the proper material; ε – the porosity (the fraction of cavities).

<u>**Note**</u>: The presence of the humidity in the porous corps substantially increases the thermal conductivity, in the same temperature conditions. At the thermo-isolator materials (thermo-isolators), which are presented as powdery or small fibers (compressed or agglomerated), is not taken into account their anisotropy in determining their thermal conductivity [32].

For a **reinforced composite layer**, the thermal conductivity, $\lambda_{c,}$ in ***the direction of reinforcement***, can be calculated with the expression [38, 39]:

$$\lambda_c = \lambda_f \cdot p_{vf} + \lambda_m \cdot p_{vm}, \tag{3}$$

where p_{vf}, p_{vm} are the volume percentages of the fibers, respectively of the matrix; λ_f, λ_m - the thermal conductivities of the fibers and the matrix, respectively, for the **transversal direction** of the reinforcement direction [38, 39]:

$$\lambda_c = \left(1-2\cdot\sqrt{p_{vf}/\pi}\right)\cdot\lambda_m + \frac{\lambda_m}{2\cdot\left(\lambda_m/\lambda_f\right)}\cdot\left(\pi-\frac{4}{\beta_1}\cdot\arctan\frac{\sqrt{\beta_1}}{\beta_2}\right), \tag{4}$$

with the notations:

$$\beta_1 = 1 - \frac{4 \cdot p_{vf}}{\pi} \cdot \left(\lambda_m / \lambda_f - 1 \right)^2 ; \; \beta_2 = 1 + \frac{2 \cdot p_{vf}}{\pi} \cdot \left(\lambda_m / \lambda_f - 1 \right). \tag{5}$$

For a ***dispersed reinforced composite***, can be used the equality [38]:

$$\lambda_c = \lambda_f \cdot \lambda_m \Big/ \left[\lambda_f \cdot \left(1 - p_{vf} \right) + \lambda_f \cdot \lambda_m \right]. \tag{6}$$

<u>Note</u>: The indicated temperatures in the following cases are considered at the level of the surfaces of the walls - plane, cylindrical and spherical, in the existence of the conduction phenomenon between the inner and outer surface of the considered wall.

The following, the thermal influence of the boundary layers positioned near the free surface of a wall (plane, cylindrical, spherical, etc.) are not considered, where convection can occur. Therefore, appropriate explanations for the thermal conductivity, characteristic at the different geometric types of walls will be. Note that the study aims to spread heat from the inside to the outside of the wall.

3. EXPRESSIONS FOR THE TEMPERATURES BETWEEN LAYERS

3. 1. Plane wall

3. 1. 1. Monolayer plane wall

The heat flux q_{pp} in W / m^2 - Figure 1a, in stationary regime, can be calculated with the relation [32-34]:

$$q_{pp} = \frac{\lambda}{\delta} \cdot \left(T_1 - T_2 \right) = k_1 \cdot \left(T_1 - T_2 \right) = k_1 \cdot \Delta T , \tag{7}$$

where we have used: $\delta -$ the wall thickness, m; $T_1, T_2 -$ the temperatures of the wall faces, K $\left(T_1 \rangle T_2 \right)$, which are considered the same as the interior enclosure, respectively exterior; $\Delta T -$ the thermal gradient, K ; $k_1 = \lambda / \delta -$ **the thermal conductance** of the wall, $W \Big/ \left(m^2 \cdot K \right)$ [32, 40].

3. 1. 2. Multilayer plane wall, without imperfections and without protections and/or deposits

For a **plane wall, multilayer –** Figure 1b, with **<u>intimate contact</u>** between the n layers, the thermal flux is characterized by the equalities:

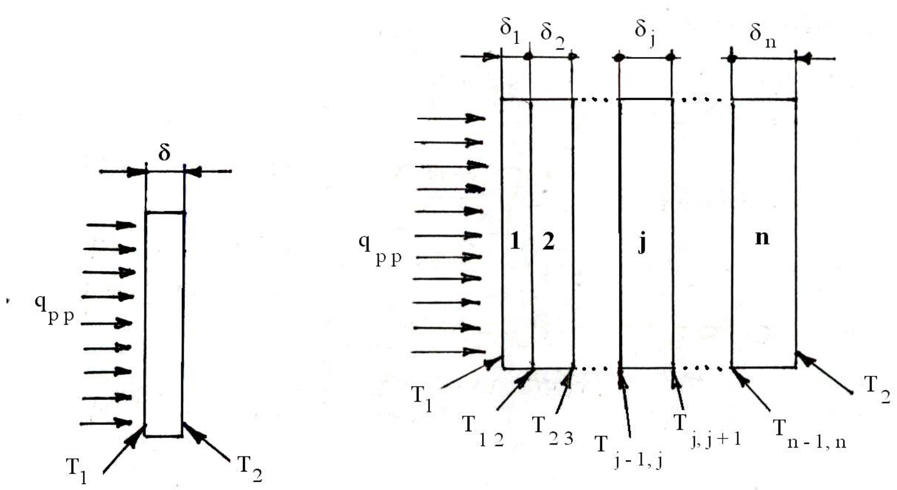
$$q_{pp} = \frac{T_1 - T_{1,2}}{\frac{\delta_1}{\lambda_1}} = \frac{T_{1,2} - T_{2,3}}{\frac{\delta_2}{\lambda_2}} = \cdots = \frac{T_{j-1,j} - T_{j,j+1}}{\frac{\delta_j}{\lambda_j}} = \cdots \frac{T_{n-1,n} - T_2}{\frac{\delta_n}{\lambda_n}} \;, \tag{8}$$

or, using the proportions rule, is reached at [33]:

$$q_{pp} = \left(\sum_{j=1}^{n} \frac{\lambda_j}{\delta_j} \right) \cdot \left(T_1 - T_2 \right) = \left(\sum_{j=1}^{n} \frac{\lambda_j}{\delta_j} \right) \cdot \Delta T = k_n \cdot \Delta T , \tag{9}$$

with the specific notations: $\delta_j -$ the thickness of the j order number layer; $\lambda_j -$ the thermal conductivity of the j layer; $T_1, T_2 -$ the free surface temperature of the first layer, respectively the external temperature of the last layer $\left(T_1 \rangle T_2\right)$, in stationary regime; $k_n = \sum_{j=1}^{n} \frac{\lambda_j}{\delta_j}$ – **the total conductance** of the layered wall; $T_{j-1,\,j}, T_{j,\,j+1}$ – the inside, or outside j layer temperatures (the temperature $T_{n,\,n+1} \equiv T_2$)

The (8) equality, in terms of knowledge the T_1, T_2 temperatures and the layer thicknesses, respectively the corresponding conductivity coefficients, allows to determine the interfacial temperatures, required for estimating the thermo-mechanical solicitations from the component layers, which can be of different nature materials.



a) **b)**

Fig. 1. Thermal transfer in plane wall
a – monolayer wall; b – multilayer wall.

<u>**Note**</u>: The sizes:

$$\Re_1 = \frac{\delta}{\lambda}, \text{ respectively } \Re_n = \sum_{j=1}^{n} \frac{\delta_j}{\lambda_j}, \tag{10}$$

called **thermal resistance** [33, 40] or **caloric resistance** [32] of a monolayer wall, respectively the thermal resistance/caloric for a monolayer wall, $m^2 \cdot K / W$.

The (8) equalities allow determining the temperatures created between the wall layers:

$$T_{1,\,2} = \left(1 - \frac{\delta_1}{\lambda_1 \cdot \Re_n}\right) \cdot T_1 + \frac{\delta_1}{\lambda_1 \cdot \Re_n} \cdot T_2; \tag{11}$$

$$T_{2,\,3} = T_{1,\,2} - \frac{\delta_2}{\lambda_2 \cdot \Re_n}\left(T_1 - T_2\right); \tag{12}$$

....

$$T_{j,\,j+1} = T_{j-1,\,j} - \frac{\delta_j}{\lambda_j \cdot \Re_n}\left(T_1 - T_2\right);\ j \in \left\{1, \cdots, n-1\right\}; \tag{13}$$

....

$$T_{n-1,n} = \frac{\delta_n}{\lambda_n \cdot \Re_n} \cdot T_1 + \left(1 - \frac{\delta_n}{\lambda_n \cdot \Re_n}\right) \cdot T_2 . \tag{14}$$

According to [41], may be accepted for calculation a **low conductivity/equivalent** value in terms of a mono-block wall, with the same thickness as that constituted of several layers:

$$\lambda_m = \sum_{j=1}^{n} \delta_i \Big/ \sum_{j=1}^{n} \left(\delta_j / \lambda_j\right). \tag{15}$$

<u>**Note**</u>: When the temperature varies on the total area of the analyzed wall, the methodology indicated by the paper [32], for example, can be used.

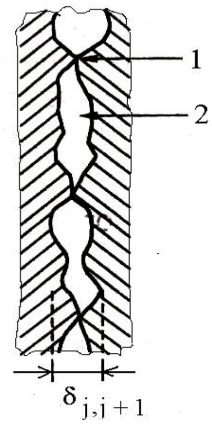


Fig. 2. Imperfect contact area between two neighborhood layers [40]
1 – intimate contact; 2 – cavity occupied of a gas or liquid fluid, eventually mixtures.

3. 1. 3. Multilayer plane wall with imperfections between layers, without protections and/or deposits

When between the layers forming the wall don't exist an **intimate/perfect contact** (Fig. 2) - so-called $\Re_c$ **contact thermal resistance** are manifested, so the (9) equality transforms into [42]:

$$q^{\bullet}_{p\,p} = \frac{T_1 - T_2}{\Re_{T1}} ; \Re_{T1} = \sum_{j=1}^{n} \frac{\delta_j}{\lambda_j} + \sum_{j=1}^{m_i} \Re_{c,j} = \sum_{j=1}^{n} \frac{\delta_j}{\lambda_j} + \sum_{j=1}^{m_i} \frac{h_{r,e,j} + h_{r,i,j+1}}{\lambda_{j,j+1}} , \tag{16}$$

keeping the previous meanings of the used sizes and with j are noted the surfaces with contact defects, being the m_i maximum number $\left(1 \le m_i \le n-1\right)$. These contact resistances have the values dependent on the nature of gaseous or liquid environment found in these interstices, if it is stationary or in motion, of the areas values contact and the pressure in contact [40, 42]. Neglecting the influence on the proper layers thickness, the layer size containing the imperfections is conditioned of the two surface roughness values: $h_{r,e,j}$ – the maximum size of the roughness on the outer surface of the j layer; $h_{r,i,j+1}$ – the maximum size of the roughness on the inner surface of the $j+1$ layer. The thermal conductivity of this $\lambda_{j,j+1}$ zone can be evaluated with an expression of the (3) form, where the partial conductivity of the existing fluid and material/materials of the neighboring layers are present. In this regard:

$$\lambda_{j,j+1} = p_{v,j} \cdot \lambda_j + p_{v,j+1} \cdot \lambda_{j+1} + p_{v\,f\,g} \cdot \lambda_{f\,g} , \tag{17}$$

when the neighboring layers have materials of different nature, namely:

$$\lambda_{j,\,j+1} = p_{v,\,j,j+1} \cdot \lambda_{j,\,j+1} + p_{v\,f\,g} \cdot \lambda_{f\,g}\,, \tag{18}$$

using the notation: $p_{v,\,j}$, $p_{v,\,j+1}$, $p_{v,\,j,\,j+1}$ – the volume percentages of the j and $j+1$ layers surfaces with materials of different natures, under imperfect contact, respectively the volume percentage of the common roughness, for the same material; $p_{v\,f\,g}$ – the volume percentage of the fluid from cavities; λ_j, λ_{j+1}, $\lambda_{j,\,j+1}$ – the conductivities of the j and $j+1$ layers material, $(1 \le j \le n-1)$, respectively the common conductivity of the layers of the same nature; $\lambda_{f\,g}$ – the thermal conductivity of the fluid from cavities.

Note: In the (16) $_2$ equality, if the roughness heights are zero, we deduce the expression (10) $_2$.

3.1.4. Multilayer plane wall with imperfections between layers, with protections and/or deposits

If on the studied wall is considered the existence of some deposits, too, during the operation (the example of some heat exchangers, with plates in this case) or it is considered the layer of external protection, by painting, for example, **it is proposed** to adapt the (16) equality as:

$$\dot{q}_{p\,p} = \frac{T_i - T_e}{\Re_{T\,2}};\ \Re_{T\,2} = \sum_{j=1}^{n} \frac{\delta_j}{\lambda_j} + \sum_{j=1}^{m_i} \Re_{c,\,j} + \sum \Re_d + \sum \Re_p \tag{19}$$

Note: In the (19) equality, $\sum \Re_d = \delta_{d\,i} / \lambda_{d\,i} + \delta_{d\,e} / \lambda_{d\,e}$ can represent the sum of the thermal resistances of the deposited layers in operation (interior and/or exterior, after case): $\delta_{d\,i}$, $\delta_{d\,e}$ – the deposited layers thickness; $\lambda_{d\,i}$, $\lambda_{d\,e}$ – the thermal conductivities of the deposited layers, respectively $\sum \Re_p = \delta_{p\,i} / \lambda_{p\,i} + \delta_{p\,e} / \lambda_{e\,e}$ the sum of the thermal resistances of the protection layers (interior and/or outside, after case); $\delta_{p\,i}$, $\delta_{p\,e}$ – the layers thickness having protective aim; $\lambda_{p\,i}$, $\lambda_{p\,e}$ – the thermal conductivity of the protection layers. Obviously the deposited layers in the operation on the proper wall or if we don't consider the protection layers wall affect negative the heat transfer. This thing is easily noticed if we take into account the (11) - (14) equalities, under the T_i, T_e. known temperatures. In this way the intermediate temperatures have the expressions, on the base on the heat flux continuity between layers:

$$T_{d\,p\,i} = \left(1 - \frac{\delta_{p\,i}}{\lambda_{p\,i} \cdot \Re_{T\,2}}\right) \cdot T_i + \frac{\delta_{p\,i}}{\lambda_{p\,i} \cdot \Re_{T\,2}} \cdot T_e\,; \tag{20}$$

$$T_1 = T_{d\,p\,i} - \frac{\delta_{p\,i}}{\lambda_{p\,i} \cdot \Re_{T\,2}} \cdot \left(T_i - T_e\right); \tag{21}$$

$$T_{1,\,2} = T_1 - \frac{\delta_1}{\lambda_1 \cdot \Re_{T\,2}} \cdot \left(T_i - T_e\right); \tag{22}$$

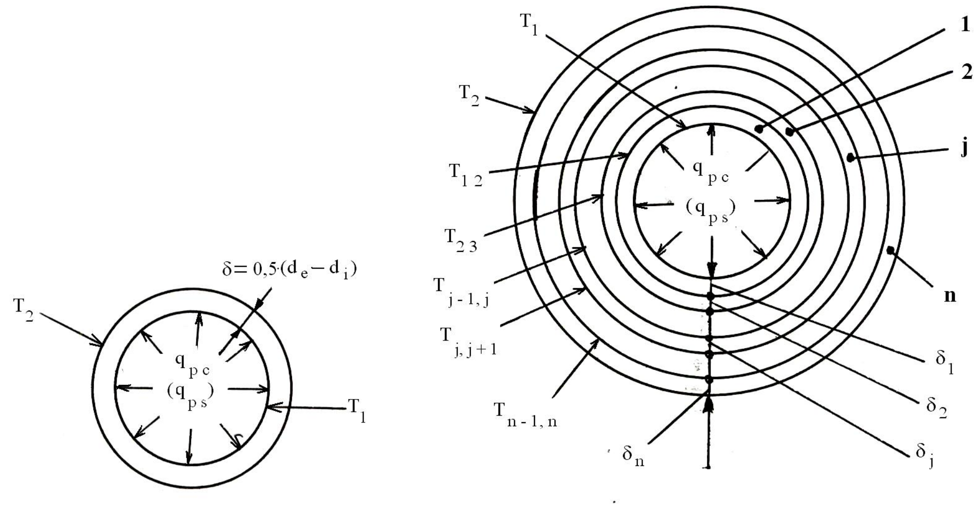
....

$$T_{j,\,j+1} = T_{j-1,\,j} - \frac{\delta_j}{\lambda_j \cdot \Re_{T\,2}} \cdot \left(T_i - T_e\right);\ j = \overline{1,\,n-1}\,; \tag{23}$$

$$T_{n,\,n+1} = T_2 = T_{n-1,\,n} - \frac{\delta}{\lambda \cdot \Re_{T\,2}} \cdot \left(T_i - T_e\right); \tag{24}$$

$$T_{dpe} = T_2 - \frac{\delta_{pe}}{\lambda_{pe} \cdot \Re_{T2}} \cdot \left(T_i - T_e \right). \tag{25}$$

<u>Note</u>: By appropriate explanations, the (20) - (25) equalities are similar to (11) - (14).



a) b)

Fig. 3. Thermal transfer in cylindrical or spherical wall
a – monolayer wall; b – multilayer wall.

3. 2. Tubular wall/cylindrical – Figure 3

3. 2. 1. Tubular wall/ monolayer cylindrical, without imperfections between layers and without protections and/or deposits

In this case – Figure 3a, the heat flux per unit of length, q_{pc}, in W/m, in stationary regime, can be evaluated by the [31, 32, 40, 42] expression:

$$q_{pc} = \frac{T_1 - T_2}{\Re_{T3}} = \frac{\Delta T}{\Re_{T3}}; , \quad \Re_{T3} = \frac{\ln\left(d_e / d_i \right)}{2 \cdot \pi \cdot \lambda}, \tag{26}$$

with the specific notations: d_i, d_e − the inner diameter, respectively the outer diameter $\left(d_e \rangle d_i \right), m$; ΔT − the thermal gradient $\left(T_1 \rangle T_2 \right)$, K.

For a **tubular wall/ multilayer cylindrical –** Figure 3b, the thermal flux can be measured by the expression [31, 40, 42]:

$$\dot{q}_{pc} = \frac{T_1 - T_2}{\Re_{T4}} = \frac{\Delta T}{\Re_{T4}}; \qquad \Re_{T4} = \sum_{j=1}^{n} \frac{\ln\left(d_{ej} / d_{ij} \right)}{2 \cdot \pi \cdot \lambda_j}, \tag{27}$$

with j signifying the current sequence number of the component layer (n – layers); T_1, T_2 – the inner surface temperature of the wall, respectively the outer of the layer $n, \left(T_1 \rangle T_2\right), K$.

3.2.2. Tubular wall/ monolayer cylindrical, with imperfections between layers and with protections and/or deposits

When protections are provided on the inner and/or outer wall surface or when operating deposits are present, the (27) equality **is adapted** accordingly:

$$q^{\bullet}_{pc} = \frac{T_1 - T_2}{\Re_{T5}} = \frac{\Delta T}{\Re_{T5}}; \tag{28}$$

$$\Re_{T5} = \frac{1}{2\cdot\pi}\cdot\left(\frac{1}{\lambda_{pi}}\cdot\ln\frac{d_{i1}}{d_{i1}-\delta_{pi}} + \frac{1}{\lambda_{di}}\cdot\ln\frac{d_{i1}-\delta_{pi}}{d_{i1}-\delta_{pi}-\delta_{di}} + \sum_{j=1}^{n}\frac{1}{\lambda_j}\cdot\ln\frac{d_{ej}}{d_{ij}}\right) +$$

$$+\frac{1}{2\cdot\pi}\cdot\left(\sum_{j=1}^{m_i}\frac{1}{\lambda_{j,\,j+1}}\cdot\ln\frac{d_{ej}+h_{r,\,j+1}}{d_{ej}-h_{r,\,j}} + \frac{1}{\lambda_{pe}}\cdot\ln\frac{d_{en}+\delta_{pe}}{d_{en}} + \frac{1}{\lambda_{de}}\cdot\ln\frac{d_{en}+\delta_{pe}+\delta_{de}}{d_{en}+\delta_{pe}}\right),$$

(29)

specifying the corresponding influences of the mentioned protections and of the accidental deposits.

Note: For the evaluation of the thermal resistances between the layers with imperfections, the inclusion in calculation of the conductivity evaluated with the relationships of forms (17) or (18) are proposed, neglecting the roughness dimensions compared with the nominal dimensions of the inner diameters, respectively outer of the layers. Canceling the roughness values, the imperfections influence over all heat transfer are deleted automatically. By canceling the thickness of the protection layers or of the deposits from inside or outside, the corresponding influences are deleted.

The intermediate temperatures between layers can be determined by relations of the form (20) - (25), introducing the expression $\Re_{T5}$. instead of the $\Re_{T2}$ total thermal resistance. Being low sizes of the asperities, we can consider the equal temperatures between layers to those of the areas with imperfections.

Note: In the previous data we can do appropriate particularizations to introduce or no the imperfections effects, respectively of the protections and deposits, after case.

3. 3. Spherical wall

3. 3. 1. Monolayer spherical wall

In the case – Figure 3a, of the existence of an **interior cavity of a homogeneous sphere**, with diameters d_i and d_e, the "**thermal power**", q_{ps},measured in W, has the expression [35, 40]:

$$q_{ps} = \frac{T_1 - T_2}{\Re_{T6}} = \frac{\Delta T}{\Re_{T6}}, \quad \Re_{T6} = \frac{d_e - d_i}{2\cdot\pi\cdot\lambda\cdot d_i\cdot d_e}, \tag{30}$$

with the corresponding notations: d_i, d_e – the inner, respectively the outer sphere diameter $\left(d_e \rangle d_i\right), m$; $\Re_{T6}$- the thermal resistance of the spherical wall, K/W.

3.3.2. Multilayer spherical wall, with intimate contact between layers, without protections and/or deposits

In the case of the existence of a **sphere with multilayer wall –** Figure 3b, with homogeneous layers, in **intimate contact**, the thermal power can be evaluated by the relationship [35, 40]:

$$q_{ps} = \frac{T_1 - T_{1,2}}{\frac{d_{e1} - d_i}{2\cdot\pi\cdot\lambda_1}} = \frac{T_{1,2} - T_{2,3}}{\frac{d_{e2} - d_{i2}}{2\cdot\pi\cdot\lambda_2}} = \cdots = \frac{T_{j-1,j} - T_{j,j+1}}{\frac{d_{ej} - d_{ij}}{2\cdot\pi\cdot\lambda_j}} = \cdots = \frac{T_{n-1,n} - T_2}{\frac{d_e - d_{in}}{2\cdot\pi\cdot\lambda_n}} = \frac{\Delta T}{\Re_{T7}}; \quad (31)$$

$$\Re_{T7} = \frac{1}{2\cdot\pi}\cdot\sum_{j=1}^{n}\frac{d_{ej} - d_{ij}}{\lambda_j\cdot d_{ij}\cdot d_{ej}}, \quad (32)$$

Noting this time: d_{ij}, d_{ej} – the inner, respectively the outer diameter, of the wall with the order number j, $j = \overline{1, n}$; $\Re_{T7}$ – the total thermal resistance of the spherical body, K/W.

The intermediate temperatures between layers have the relations:

$$T_{1,2} = \left[1 - \frac{d_{e1} - d_i}{2\cdot\pi\cdot\lambda_1\cdot d_i\cdot d_{e1}\cdot\Re_{T7}}\right]\cdot T_1 + \frac{d_{e1} - d_i}{2\cdot\pi\cdot\lambda_1\cdot d_i\cdot d_{e1}\cdot\Re_{T7}}\cdot T_2; \quad (33)$$

$$T_{2,3} = T_{1,2} - \frac{d_{e2} - d_{i2}}{2\cdot\pi\cdot\lambda_2\cdot d_{i2}\cdot d_{e2}\cdot\Re_{T7}}\cdot\left(T_1 - T_2\right); \quad (34)$$

....

$$T_{j,j+1} = T_{j-1,j} - \frac{d_{ej} - d_{ij}}{2\cdot\pi\cdot\lambda_j\cdot d_{ij}\cdot d_{ej}\cdot\Re_{T7}}\cdot\left(T_1 - T_2\right); \; j = \overline{1, (n-1)}; \quad (35)$$

$$T_{n,n+1} = T_2; \; j = n; \; d_{en} = d_e. \quad (36)$$

3.3.3. Multilayer spherical wall, with imperfections between layers, with protections and/or deposits

If the imperfections are accepted between the proper wall layers, neglecting the eventual defects between protections and deposits, on the one hand, or between the base wall and protections, on the other hand, in the presence of the inner and outer enclosure temperatures, T_i and T_e, we can write:

$$\Re_{T8} = \Re_{T7} + \frac{1}{2\cdot\pi}\cdot\left[\frac{\delta_{di}}{\lambda_{di}\cdot\left(d_i - \delta_{di}\right)\cdot\left(d_i - \delta_{di} - \delta_{pi}\right)} + \frac{\delta_{pi}}{\lambda_{pi}\cdot d_i\cdot\left(d_i - \delta_{pi}\right)}\right] +$$
$$+ \frac{1}{2\cdot\pi}\cdot\left[\begin{array}{c}\frac{\delta_{de}}{\lambda_{de}\cdot\left(d_e + \delta_{pe}\right)\cdot\left(d_e + \delta_{de} + \delta_{pe}\right)} + \frac{\delta_{pe}}{\lambda_{pe}\cdot d_e\cdot\left(d_e + \delta_{pe}\right)} + \\ + \sum_{j=1}^{m_i}\frac{h_{r,e,j} + h_{r,i,j+1}}{\lambda_{j,j+1}\cdot\left(d_{e,j} - h_{r,e,j}\right)\cdot\left(d_{e,j} + h_{r,i,j+1}\right)}\end{array}\right], \quad (37)$$

and, further, the intermediate temperatures expressions:

$$T_{dpi} = \left[1 - \frac{\delta_{di}}{2\cdot\pi\cdot\lambda_{di}\cdot\left(d_i - \delta_{pi}\right)\cdot\left(d_i - \delta_{di} - \delta_{pi}\right)\cdot\Re_{T8}}\right]\cdot T_i +$$
$$+ \frac{\delta_{di}}{2\cdot\pi\cdot\lambda_{di}\cdot\left(d_i - \delta_{pi}\right)\cdot\left(d_i - \delta_{di} - \delta_{pi}\right)\cdot\Re_{T8}}\cdot T_e; \quad (38)$$

$$T_1 = T_{d\,p\,i} - \frac{\delta_{p\,i}}{2\cdot\pi\cdot\lambda_{p\,i}\cdot d_i\cdot\left(d_i - \delta_{p\,i}\right)\cdot\Re_{T\,8}}\cdot\left(T_i - T_e\right); \tag{39}$$

$$T_{1,\,2} = T_1 - \frac{d_{e\,1} - d_i}{2\cdot\pi\cdot\lambda_1\cdot d_i\cdot d_{e\,1}\cdot\Re_{T\,8}}\cdot\left(T_i - T_e\right); \tag{40}$$

....

$$T_{j,\,j+1} = T_{j-1,\,j} - \frac{d_{e\,j} - d_{i\,j}}{2\cdot\pi\cdot\lambda_j\cdot d_{i\,j}\cdot d_{e\,j}\cdot\Re_{T\,8}}\cdot\left(T_i - T_e\right);\;\; j = \overline{1,\,(n-1)}; \tag{41}$$

$$T_{n,\,n+1} = T_2 = T_{n-1,\,n} - \frac{d_e - d_{i\,n}}{2\cdot\pi\cdot\lambda_n\cdot d_{i\,n}\cdot d_e\cdot\Re_{T\,8}}\cdot\left(T_i - T_e\right); \tag{42}$$

$$T_{d\,p\,e} = T_2 - \frac{\delta_{p\,e}}{2\cdot\pi\cdot\lambda_{p\,e}\cdot\left(d_e + \delta_{p\,e}\right)\cdot d_e\cdot\Re_{T\,8}}\cdot\left(T_i - T_e\right). \tag{43}$$

4. CONCLUSIONS

In this paper is tackled the engineering problem referring on the thermal transfer produced in plane, tubular and spherical walls, in monolayer or multilayer construction, with identical or different natures. Both the structures without defects between layers, or with possible imperfections in manufacturing or operating phase, are taken into account, in the analysis. Also the presumed influence of some protection layers or of some deposits in operation, which burdening the values of the intermediate temperatures are noticed. These thermal fields are particularly important to assess, further, the state of deformations and stresses, the limit states existing in the elastic or elastic-plastic domain, respectively estimating the stability of plane or curved forms planes, which were the subject of this study. It is proposed, for perspective, determining the effects of thermal transfer developed in the existence of the convection on the inner and outer wall surface and obviously the conduction, state where the above aims are pursuing.

The methodology of analysis, in this case, takes into account the knowledge of the ambient temperature inside and the outside of the wall, allowing the possibility of the layers geometry organization, of the number and the nature of these materials. Another study way may be this when the inside ambient temperature and the thermal flux value are specified. So, in terms of these parameters for a concrete wall, it can reach to the outside wall temperature setting or outside ambient, convenient to the given technological process.

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