1.Cvetanka MITREVSKA, 2.Kire POPOVSKI, 2.Vangelce MITREVSKI, 2.Igor POPOVSKI

COMPUTER SIMULATION FOR SELECTION OF THE ORDER FOR THE LAYERS FROM THE WALL OF INDUSTRIAL COOLERS

1.International Slavic University "Gavrilo Romanovic Derzavin", Faculty of Safety Engineering, MACEDONIA
2.Faculty of Technical Sciences, University "St. Kliment Ohridski", Bitola, MACEDONIA

Abstract: In this paper a mathematical model and computer software for calculating the thickness of the insulation layers (panels) from the walls of the industrial coolers based on the order of their installation was developed. A numerical example is given that is tested on an existing industrial cooler in Bitola, Macedonia. In order to calculate the thickness of the thermal insulation it is necessary to consider a multilayer barrier (wall) where for each layer the thickness is known, except for the insulation material which should be calculated. With the determined geometric and physical characteristics of the wall, it is necessary to determine the temperature at each point of the construction. By connecting these points, the temperature change through the construction creates dependency with its thickness. After calculating the actual specific heat flux, the temperatures between each layer of the wall are calculated. For improved monitoring of the change in the partial pressure of the saturated water vapor through the layers of the wall, the thickness of the insulating material is divided into approximately five parts, and then a table of temperature changes and the corresponding value of the partial pressure of the saturated aqueous vapor is created. In order to avoid condensation of the water vapor when it passes through the wall, a certain condition must be fulfilled. With certain measurements adopted, a computer simulation was created and measurements calculated. The computer simulation enables swift and accurate calculation of thickness of the insulation at multilayer bulkheads found at industrial coolers, and allows selection of the location for the insulation and steam barrier in the bulkhead.
Keywords: Insulation coolers, industrial cold storage, panels, multilayer bulkheads, steam barrier

CALCULATION OF THICKNESS OF THE HEATING INSULATION

A multilayer wall is considered, where for each layer the thickness is already known, except for the insulating material. The insulating material thickness is calculated by Equation (1),

$$\delta_{iz} = \lambda_{iz} \cdot \left[\frac{t_n - t_v}{q} - \left(\frac{1}{\alpha_n} + \sum \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_v}\right)\right] \quad m \qquad (1)$$

where,
λ_{iz} [W/mK] - coefficient of thermal conductivity of the insulation,
α_n [W/m²K] - coefficient of passage of heat from the external air to the outer side of the compartment,
α_v [W/m²K] - coefficient of heat transfer from the inner side of the barrier of the internal air.
The recommended value for the specific heat flux is: q=11 W/m², [1].

CHANGE OF TEMPERATURE

With the determined geometric and physical characteristics of the compartment, it is necessary to determine the temperature at each point of the construction. By connecting these points we determine the change of temperature through the construction depending on its thickness, Figure 2. If we use the heat resistance of each junction instead of the thickness of the construction, then the change in temperature is a straight line.
The designed temperature of the external air is Equation (2),

$$t_{sp} = 0{,}4 \cdot t_{sm} + 0{,}6 \cdot t_{mm} \quad °C, \qquad (2)$$

where,

t_{sp} [°C] - average monthly temperature for the warmest month of the last 10 years,
t_{mm} [°C] - the average value of the maximum temperatures of the warmest month of the last 10 years.
The external air temperature are:
$t_n = t_{sp} + 6$ [°C] - for outer bulkheads on the south side,
$t_n = t_{sp} + 15$ [°C] - for ceilings with a flat roof,
$t_n = t_{sp} + 10$ [°C] - for ceilings under roof with ceiling space,
$t_n = t_{sp} + 15$ [°C] - for floors on the ground.
After calculating the thickness of the isolation, it is adopted and then the true specific thermal flux is calculated by Equation (3),

$$q = \frac{t_n - t_v}{\frac{1}{\alpha_n} + \sum \frac{\delta_i}{\lambda_i} + \frac{\delta_{iz}}{\lambda_{iz}} + \frac{1}{\alpha_v}} \quad W/m², \qquad (3)$$

After calculating the actual specific heat flux, the temperatures between each layer in the compartment are calculated by Equation (3),

$$t_x = t_n - q \cdot R_x \quad °C, \qquad (4)$$

where, R_x [m²K/W] - heat resistance for each layer of the compartment.

CHANGE OF PARTIAL PRESSURE OF SATURATED WATER STEAM

To better monitor the change in the partial pressure of saturated water steam through the layers of the compartment, the thickness of the insulating material is divided into approximately five parts. A table of temperature changes and the corresponding value of the partial pressure of saturated steam is then made [2].

The specific water vapor flux is Equation (5),

$$W = \frac{p_n - p_v}{H_v} \quad \text{kg/m}^2\cdot\text{K},\qquad (5)$$

where,

p_n	Pa	- the partial pressure of the water steam of the external air,
p_v	Pa	- the partial pressure of the water steam of the internal air,
H_v	m^2sPa/kg	- resistance to diffusion of water steam through the barrier.

The resistance of water steam diffusion through the compartment is calculated by Equation (6),

$$H_v = \sum \frac{\delta_i}{\mu_i} \quad \text{m}^2\text{sPa/kg},\qquad (6)$$

where,

μ_i kg/msPa - coefficient of steam permeability of the layer.

The partial pressure of the water steam between each layer in the compartment is calculated by Equation (7),

$$p_x = p_n - W \cdot H_x \quad \text{Pa},\qquad (7)$$

In order not to condense the water steam, when passing through the barrier, the dependency must be fulfilled,

$$p_x < p_x^{\cdot\cdot}(t_{x)} \quad \text{i.e.,} \quad t_x < t_x^{\cdot\cdot}(p_{x)}),$$

For a stationary heat flux through a multilayer barrier it is calculation by Equation (8),

$$q = k \cdot (t_{sp} - t_v) = k' \cdot (t_{sp} - t_x) \quad \text{W/m}^2,\qquad (8)$$

where,

$$k = k' \cdot \frac{t_{sp} - t_x}{t_{sp} - t_v} \quad \text{W/m}^2\text{K},\qquad (9)$$

In order not to condensate the water steam, to the contact of the steam barrier and the compartment, the temperature t_x, which is at that place, must be greater than the amplitude of saturation $t_x^{\cdot\cdot}$, for the partial pressure that governs in that place,

$$k < c \cdot k' \cdot \frac{t_{sp} - t_x}{t_{sp} - t_v} \quad \text{W/m}^2\text{K},\qquad (10)$$

where,

$c = 0{,}95$ - coefficient of safety.

NUMERIC EXAMPLE

According to the mathematical model, a computer program was created, which was tested on an existing industrial refrigerator in Bitola.

The thickness of the insulation on the southern outer wall composed of several layers is calculated, figure 1, with the following features.

— the insulation material which is going to be used is polystyrene and it is going to be installed after the bituminous steam boiler. its features are given in table 1.
— average monthly temperature of the warmest month of the last 10 years, [4], $t_{sm} = 25$ °C.
— average value of the maximum temperatures of the warmest month of the last 10 years, [4], $t_{mm} = 30$ °C.
— coefficient of passage of heat from the external air on the outside side of the compartment, [1], $\alpha_n = 30$ W/m²K.
— coefficient of heat transfer on the inside of the internal air compartment, [1], $\alpha_v = 8$ W/m²K.
— inner temperature, $t_v = 20$ °C.
— relative humidity of the external air, [4], $\varphi_n = 40$ %.
— relative humidity of the internal air, [4], $\varphi_v = 70$ %.

Table 1. Characteristics of the compartment [1].

Type of layer	δ mm	λ W/mK	$\mu \cdot 10^{12}$ kg/msPa
1. facade plaster	20	0,870	37,500
2. brick wall	250	0,870	29,200
3. cementene mortar	20	1,280	25,000
4. bituminous steam barrier	5	0,760	0,012
5. insulating material		0,041	3,000
6. intertwined network			
7. cement mortar	20	1,280	25,000

Table 2. Change the temperature across the barrier

Starting layer number	δ m	R mK/W	t °C
1	0,000	0,000	34,660
2	0,020	0,023	34,425
3	0,270	0,310	34,490
4	0,290	0,326	34,330
iz	0,295	0,333	34,263
6	0,495	5,211	-18,564
7	0,515	5,226	-18,723

Comparison of the calculated and accepted sizes,

— Calculated outdoor temperature, $t_n = 34$ °C.
— Accepted external temperature, $t_n = 35$ °C.
— Calculated insulation thickness, $\delta_{iz} = 184$ mm.
— Accepted insulation thickness, $\delta_{iz} = 200$ mm.
— True specific heat flux, q = 10,2 W/m.

The thickness of the isolation is divided into five equal parts, and the temperature change through the insulating layers is shown in Table 3.

Table 3. Change of the temperature through the insulation layer

Serial Number	δ m	t °C
1	0,000	31,263
2	0,040	21,297
3	0,080	11,332
4	0,120	1,376
5	0,160	-8,598
6	0,200	-18,564

Table 4. Penetration of moisture through the compartment

Starting layer number	δ m	$H_v \cdot 10^{-9}$ m²sPa/kg	p Pa	p" Pa
1	0,000	0,000	2251	5522
2	0,020	0,533	2249	5450
3	0,270	9,095	2211	4619
4	0,290	9,895	2207	4577
iz	0,295	426,562	370	4559
6	0,495	493,228	76	118
7	0,515	494,028	72	116

Table 5. Moisture penetration through the insulating layer

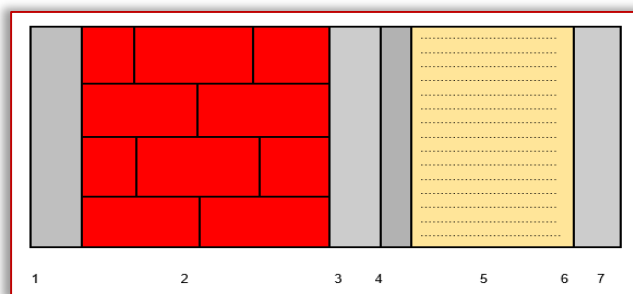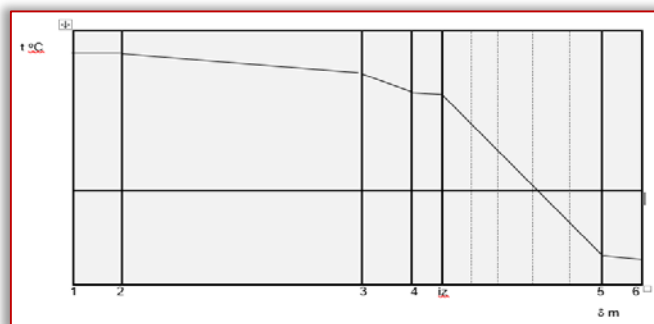| Starting layer number	δ m	$H_v \cdot 10^{-9}$ m²sPa/kg	p Pa	p" Pa
1	0,000	426,562	370	4559
2	0,040	439,895	311	2534
3	0,080	453,228	252	1342
4	0,120	466,562	193	674
5	0,160	479,895	134	294
6	0,200	493,228	76	110

Figure 1. Construction of an external wall

Figure 2. Change in temperature depending on the thickness of the compartment
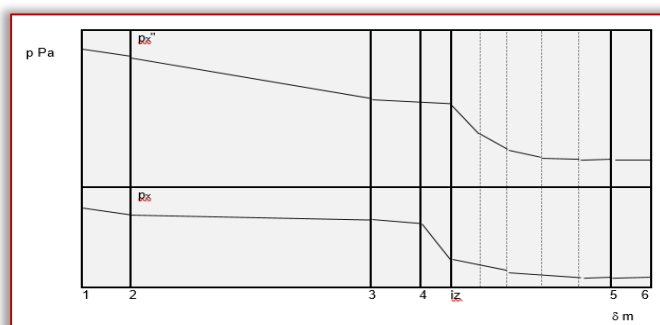

Figure 3. Change in the pressure depending on the thickness of the compartment

CONCLUSION

The aim of the paper is to provide a quick and accurate calculation of the insulation thickness at industrial coolers with multi-layered compartments. In addition it allows selecting the location of the insulation and the steam barrier in the compartment, in order to prevent the condensation of the steam somewhere between the layers of the compartment.

Note:

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