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ANALYSIS OF THE PROCESSES OF HEAT EXCHANGE ON INFRARED HEATER SURFACE

Vasyl ZHELYKH*, Malgorzata ULEWICZ**, Nadiia SPODYNIUK***, Stepan SHAPOVAL****, Volodymyr SHEPITCHAK*****

* Lviv Polytechnic National University, Department of Heat and Gas Supply and Ventilation
St. Bandery, 12, 79013, Lviv - 13, Ukraine, e-mail: v_zhelykh@msn.com
** Czestochowa University of Technology, Department of General Building Engineering and Building Physics
Akademicka 3, 42-201 Czestochowa, Poland, e-mail: ulewicz@onet.eu
*** Lviv Polytechnic National University, Department of Heat and Gas Supply and Ventilation
St. Bandery, 12, 79013, Lviv - 13, Ukraine, e-mail: n_spoduniuk@meta.ua
**** Lviv Polytechnic National University, Department of Heat and Gas Supply and Ventilation
St. Bandery, 12, 79013, Lviv - 13, Ukraine, e-mail: shapovalstepan@gmail.com
***** Lviv Polytechnic National University, Department of Civil Safety
3 Svyatyi Yuriy sq., 79013, Lviv, Ukraine, e-mail: shepitchak@gmail.com

Abstract

The article deals with the research results of temperature distribution on infrared heater surface. Mathematical model of the process of heat exchange on infrared heater surface was developed. The experimental measurements have been carried out and the data of the temperature on infrared heater surface have been obtained for verification the reliability of the results of theoretical studies. The results of the studies showed that the temperature gradient of the area of heater changed no more than 4.5°C.

Key words: infrared heating, boundary conditions, surface temperature

INTRODUCTION

Heating of industrial buildings is a complicated task. In most great height, insufficient heat insulation of external protections, significant replacement of air is typical for such premises. Using traditional water, steam or air systems is technically difficult and economically unprofitable. In large premises work area, where it’s necessary to create a required microclimate parameters, usually has a height of 2m. It is about 20-30% of the total volume. The results of the domestic and foreign scholars’ recent research suggest that the most effective way of industrial heating is the use of infrared systems [6], [10], [13]. The principle of work is based on local heating by radiation. The radiant heating is heated only that area where the heating is required. As a result, due to radiation it’s heated only individual objects. Thus, we can achieve different heating zones of premises or separate working positions.It is important to design the infrared heating systems according to existing building codes and taking into account the methods of calculation based on modelling of heat transfer processes on the heated surface [1]. In [3], [4], [5] is shown the results of thermal modelling bodies of different shapes and hot surfaces.

During the use of infrared heater is important the density and uniformity of the field of radiant energy in the work area. So, during radiant heating the distribution density of the heating energy in area the surface of exposure is not uniform.

Figure 1 is shown a graph of the intensity distribution of radiation in the cross-section room, the analysis shows that the use of infrared radiant energy density decreases with increasing distance from the radiation source [1].

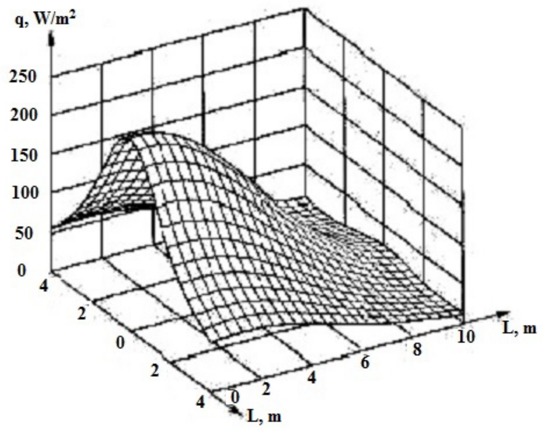


Fig. 1. The surface distribution of the radiation intensity with radiant heating

By that means, the calculations of heating with infrared sources it is necessary to find the point of maximum and minimum intensity of radiation in order to ensure proper temperature regime.

The temperature on the surface of the infrared heater influences on the distribution of radiation intensity in the premises. Therefore, the study of temperature distribution on the surface in a permanent conditions is an topical task.

Comfortable conditions due to ensure the production process with using infrared heater depend on uniform temperature over the all area of the heater.

The aim of the study is to investigate the temperature distribution on infrared heater surface, through mathematical modeling and the verification of results through experimental measurements.

1. ANALYTICAL STUDIES

The process of heat conduction on infrared heater area caused by heating of the surface radiation was reviewed. In consequence of analysis the temperature distribution on the heater surface can be obtained.

Suppose the thermal radiation field is of the form $\Delta y = f\ (x,\ y)$, temperature of the heater in the thickness direction of the z-axis at all points has the same rate [7], [8]. Laplace equation for this task in the excessive temperatures will be:

$$\frac{\partial^2 \Delta t}{\partial x^2} + \frac{\partial^2 \Delta t}{\partial y^2} = 0 \tag{1}$$

where: Δt - excessive surface temperature, °C.

In problems associated with heat transfer two-dimensional Laplace equation describes the steady distribution of temperature $\Delta t = f(x,\ y)$ in the plane of xy. Solution of the problem requires boundary conditions for the two independent variables x and y.

Laplace equation is solved in a rectangular domain so that $0 < x < L$, $0 < y < H$, where L - heater length, H - width of the heater. Therefore, a suitable set of boundary conditions may be:

$\Delta t = f(x,\ 0) = 0$, $\Delta t = f(x,\ H) = f(x)$, $\Delta t = f(0,\ y) = 0$, $\Delta t = f(L,\ y) = 0$,

|as illustrated in the figure below (Fig. 2) [9]:

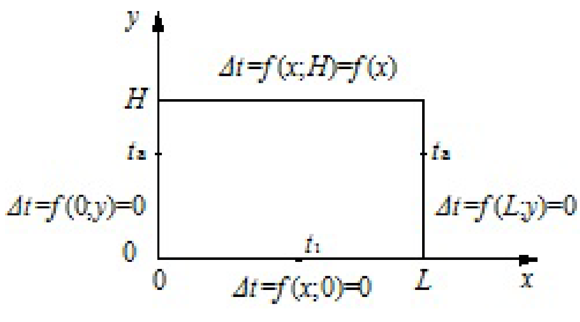


Fig. 2. Determination of boundary conditions for the independent variables x and y

According to the method of distribution of variables the solution of the equation is in the form:

$$\Delta t = f(x,y) = X(x)Y(y) \tag{2}$$

where: $X(x)$ - function only variable x; $Y(y)$ - function only variable y.

Solving the equation through separation of variables proceeds in the following fashion:

$$Y(y)\frac{\partial^2 X(x)}{\partial x^2} + X(x)\frac{\partial^2 Y(y)}{\partial y^2} = 0 \tag{3}$$

Dividing by $X(x)$ and $Y(y)$ is obtained:

$$\frac{1}{X(x)}\frac{\partial^2 X(x)}{\partial x^2} = -\frac{1}{Y(y)}\frac{\partial^2 Y(y)}{\partial y^2}. \tag{4}$$

As the left side of the equation doesn`t depend on $y$, and the right side doesn`t depend on x, the total value of equation doesn`t depend on y and x. For the two sides of the resulting equation to be equal, they both must be equal to a constant, λ^2. Equation (4) divided into two ordinary differential equations:

$$\frac{\partial^2 X(x)}{\partial x^2} + \lambda^2 X(x) = 0, \tag{5}$$

$$\frac{\partial^2 Y(y)}{\partial y^2} - \lambda^2 Y(y) = 0. \tag{6}$$

The solution to the first ordinary differential equation is:

$$X = C_1 e^{i\lambda x} + C_2 e^{-i\lambda x} \tag{7}$$

where: C_1 and C_2 - arbitrary constants.

However, expressions $e^{i\lambda x}$ and $e^{-i\lambda x}$ have real value only when $x = 0$. Using the Euler`s equation

$$e^{\pm i\lambda x} = \cos\lambda x \pm i\sin\lambda x, \tag{8}$$

can be represented equation (7) as:

$$X = A\cos\lambda x + B\sin\lambda x. \tag{9}$$

The solution of the second ordinary differential equation is:

$$Y = Ce^{\lambda y} + De^{-\lambda y}, \tag{10}$$

where: C and D - are arbitrary constants.

The general equation for solving specific problem now becomes:

$$\Delta t = XY = (A\cos\lambda x + B\sin\lambda x)(Ce^{\lambda y} + De^{-\lambda y}) \tag{11}$$

To determine the values λ; A; B; C; D were used such boundary conditions: $\Delta t = 0$ та $x = 0$. This implies:

$$\Delta t(0,y) = A(Ce^{\lambda y} + De^{-\lambda y}) = 0 \tag{12}$$

The expression that stands in parentheses, can have an arbitrary value, in particular, it doesn`t necessarily have to be zero. Thus, there is only one possibility to satisfy the boundary condition at x=0 is the adoption A=0. Therefore:

$$\Delta t(0,y) = B\sin\lambda x(Ce^{\lambda y} + De^{-\lambda y}). \tag{13}$$

At x=L and with boundary condition $\Delta t = 0$ follows:

$$\Delta t(L,y) = B\sin\lambda x(Ce^{\lambda y} + De^{-\lambda y}) = 0. \tag{14}$$

Provided that expression in parentheses doesn`t necessarily have to be zero, and also that B≠0, otherwise function $\Delta t(x,y)$ identically will be equal to zero, follows:

$$\sin\lambda L = 0. \qquad (15)$$

This is possible only under the condition $\lambda L = i\pi$, where i = 1; 2; 3 ... - natural numbers. Therefore:

$$\lambda_i = \frac{i\pi}{L}. \qquad (16)$$

A partial solution of the equation (for the particular value i) will be as follows:

$$\Delta t_i(x,y) = B_i \sin\left(\frac{i\pi}{L}x\right)(C_i e^{\frac{i\pi}{L}y} + D_i e^{-\frac{i\pi}{L}y}). \qquad (17)$$

We write this expression for y=0, where the boundary conditions $\Delta t = 0$:

$$\Delta t_i(x,0) = B_i \sin\left(\frac{i\pi}{L}x\right)(C_i e^{\frac{i\pi}{L}0} + D_i e^{-\frac{i\pi}{L}0}) = \qquad (18)$$
$$= B_i \sin\left(\frac{i\pi}{L}x\right)(C_i + D_i) = 0$$

Provided that B ≠ 0 it follows that $(C_i + D_i) = 0$, or $D_i = -C_i$. Therefore:

$$\Delta t_i(x,y) = B_i C_i \sin\left(\frac{i\pi}{L}x\right)(e^{\frac{i\pi}{L}y} - e^{-\frac{i\pi}{L}y}) =$$
$$= 2B_i C_i \sin\left(\frac{i\pi}{L}x\right)\mathrm{sh}\left(\frac{i\pi}{L}y\right) = E_i \sin\left(\frac{i\pi}{L}x\right)\mathrm{sh}\left(\frac{i\pi}{L}y\right)$$

The general solution looks like a sum of partial solutions, therefore:

$$\Delta t(x,y) = \sum_{i=1}^{\infty} E_i \mathrm{sh}\left(\frac{i\pi}{L}y\right)\sin\left(\frac{i\pi}{L}x\right) \qquad (19)$$

To determine the constant E_i fourth boundary condition was used: $\Delta t(x,H) = f(x)$. A function view $f(x)$ should be conditioned. In this case it must be such that its value at x = 0 and x = L will be equal to zero, otherwise the temperature field on the border of the calculated area will be discontinuous.

The function $f(x)$ is decomposed in Fourier series in sine:

$$f(x) = \sum_{i=1}^{\infty} a_i \sin\left(\frac{i\pi}{L}x\right), \qquad (20)$$

The constant a_i is determined by:

$$a_i = \frac{2}{L}\int_0^L f(x)\sin\left(\frac{i\pi}{L}x\right)dx. \qquad (21)$$

Therefore:

$$\Delta t(x,H) = \sum_{i=1}^{\infty} E_i \mathrm{sh}\left(\frac{i\pi}{L}H\right)\sin\left(\frac{i\pi}{L}x\right) = \sum_{i=1}^{\infty} a_i \sin\left(\frac{i\pi}{L}x\right),$$

where $E_i \mathrm{sh}\left(\frac{i\pi}{L}H\right) = a_i$, or $E_i = \dfrac{a_i}{\mathrm{sh}\left(\frac{i\pi}{L}H\right)}$.

Provided that y = H and considering the boundary dimensions of the plate x = [0 ... 0.6 m] function $f(x)$ will look like:

$$\Delta t(x,H) = 30x - 50x^2 \qquad (22)$$

Using equation (22) with the above boundary conditions the temperature distribution along the x-axis on the surface of the heater was obtained (Fig. 3).

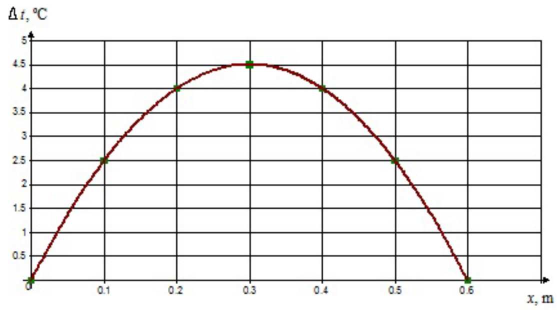


Fig. 3. Changing the temperature on the surface of the heater along the x-axis on condition y=H

As shown in the figure, the temperature distribution along the x-axis of the heater surface is uneven, while the surface temperature is in acceptable limits, according to the given boundary conditions and changes in the x-axis with difference no more than 4.5°C.

2. EXPERIMENTAL STUDIES

To confirm the authenticity of the theoretical results the experimental study of the temperature on the surface of the infrared heater has been done.

As the object of study the electric infrared heater 0.54x0.1 m size of panel type QH 1500 with variable thermal capacity of 500, 1000 and 1500 W was chosen (Fig. 4) [2].

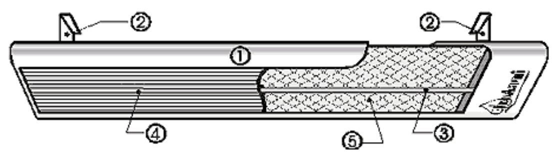
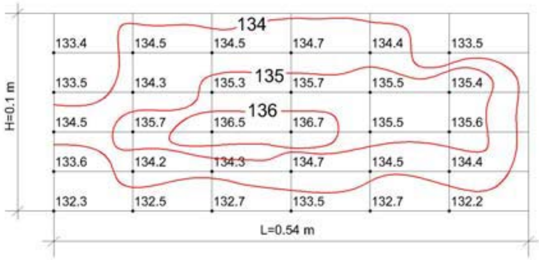


Fig. 4. The design of the infrared heater panel.
1 - metal case; 2 - mounting; 3 - low-temperature THE in quartz husk; 4 - aluminum profile; 5 – protective screen

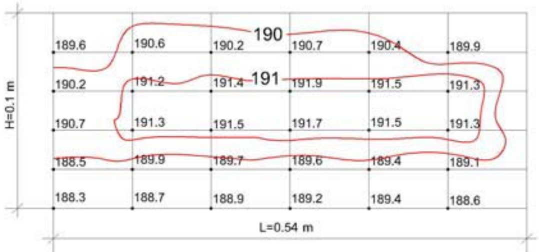
The infrared heater consisted of a rectangular metal case covered with a heat-resistant paint 1; with the elements of the ceiling mount 2; low TEN 3 was built in the heating plate - anodised aluminum profile 4; with high-quality insulating material 5 [2], [14] and [16].

The temperature on the surface of aluminum profiles measured by an infrared pyrometer "Nimbus -530/1" absolute error of the device ± 0.08°C [11] and [12]. The experiments were conducted at various thermal power heater: Q_{heat} = 500 W; Q_{heat} = 1000 W; Q_{heat} = 1500 W.

As a result the graphical distribution of isotherms on infrared heater surface was built (Fig.5).



a)



b)

c)

Fig. 5. Distribution of temperatures on the surface of infrared heater, t_{heat}, ºC at the thermal capacity of the heater: a) Q_{heat} = 500 W; b) Q_{heat} = 1000 W; c) Q_{heat} = 1500 W

The graphs show that the temperature fields are equable over the area of heater with a gradient of 2-3°C.

It is possible thanks to the design of heating aluminum, through which heat flow enters the premises. Graphic temperature distribution confirms the authenticity of the results of theoretical research.

The influence of temperature distribution on the surface of the heater for uniform field of radiation energy in the working area of industrial premises was evaluated. By this experimental method was determined the temperature of the floor, under the infrared heater, which is aimed directly by heat flow from the heater. The graphical temperature distribution on the floor at thermal power heater Q_{heat} = 500 W and the air temperature in the premises at the time of measurement t_{pr} = 17.5ºC is shown on Fig. 6.

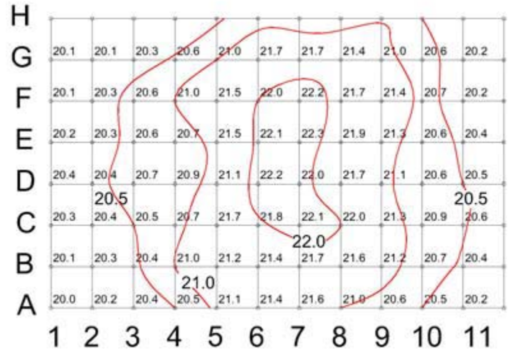


Fig. 6. The temperature of the heated floor in the premises t_{floor}, ºC about Q_{heat} = 500 W and t_{pr} = 17.5ºC

So, the temperature gradient at the surface of the infrared heater corresponds to the recommended for production facilities [15], the temperature distribution on the floor did not exceed the permissible parameters, such as $\Delta t_{floor} \leq 2$ ºC (Fig. 6).

3. SUMMARY

This article presents the results of theoretical and experimental studies of temperature distribution on infrared heater surface. The main features of the heat exchange processes on infrared heater surface were reviewed. Temperature distribution on the surface of the heater for two-dimensional Laplace equation was built. Simulation under these boundary conditions made it possible to identify that temperature changes on the surface of the heater doesn`t exceed 4.5°C.

Experimental study of temperature distribution on the infrared heater surface has been done. The temperature change on the surface of radiator was 2-3°C.

Thus, the even heat flow is made in such a difference from the infrared heater in the area of exposure. The temperature on the floor surface was further verified by experimental studies. The temperature distribution on the floor did not exceed the permissible parameters, such as $\Delta t_{floor} \leq 2$ ºC.

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Vasyl ZHELYKH received his MSc (1990) in Building, Ph.D. (1995) and DSc (2013) in Technical Sciences (Engineering Thermophysics). Currently, he is Head of the Department of Heat, Gas Supply and Ventilation at Lviv Polytechnic National University, Ukraine.

Malgorzata ULEWICZ received her MSc (1993) in Chemistry, PhD (2001) and DSc (2012) in Technical Sciences (Metallurgy). Currently, she is Head of the Department of General Building Engineering and Building Physics at Czestochowa University of Technology, Poland.

Nadiia SPODYNIUK, received her MSc (2007) in Building, PhD (2011). Thesis: Energy efficient Heating provision of the poultry houses. Currently, she is lecturer in the Department of Heat and Gas Supply and Ventilation at Lviv Polytechnic National University, Ukraine.

Stepan SHAPOVAL, received his MSc (2006) in Building, PhD (2010). Thesis: Combined system of heat supply with the triple oriented solar collectors and heat-accumulating. Currently, he is lecturer in the Department of Heat and Gas Supply and Ventilation at Lviv Polytechnic National University, Ukraine.

Volodymyr SHEPITCHAK, received his MSc (2005) in Power Engineering. Currently, he is lecturer in the Department of Civil Safety, Lviv Polytechnic National University, Ukraine. Research interests: Infrared heating systems.