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MODELLING OF A HEAT OUTPUT OF HEAT TREATMENT EQUIPMENT IN INDUSTRIAL PREMISES OF RESTAURANT COMPLEXES

Statement of the problem. The evaluation of a temperature mode in restaurant complexes is a very important issue. Increasing temperature in the hot shop due to heat coming from thermal processing equipment leads to lower productivity and compromises the safety in the workplace. The evaluation cannot be carried out with the accurate calculation of the average temperature of the inside of a premise of a restaurant complex. These calculations are elaborate since the average temperature depends on a range of factors as well as heat emissions of the current technological equipment. The aim of this work is to develop a model of thermal processing equipment in restaurant complexes.

Results and conclusions. The results of the modeling of heat emission in the hot shop of a restaurant complex in humid and heat treatment of products are presented. A thermal and physical model of the equipment of humid and heat treatment of product was developed, which will determine the total amount of thermal energy supplied during the entire cycle of its operation in the work area of industrial premises restaurant complexes.

Keywords: restaurant complexes, thermal processing equipment, heat transfer, thermal and physical model.

Introduction

The evaluation of a heat mode of restaurants is a very pressing and complicated issue [3, 6, 7, 11, 13]. It cannot be carried out without the accurate evaluation of the average temperature of the inside surfaces of restaurants. The calculations associated with the process are complex and dependent on the number of factors as well as a heat output of the current cooking technology equipment. Heat emissions (heat inputs, heat outputs) in restaurant premises are made up of heat fluxes, Watt (Fig. 1):

- from people $Q_{люд}$;
- solar radiation (in the warm or intermediate seasons) $Q_{сол.\ рад}$;
- artificial light $Q_{осв}$;
- cooking heating system (in the cold season) $Q_{от.\ приб}$;
- thermal technology equipment in the premises $Q_{тех.\ обор}$.

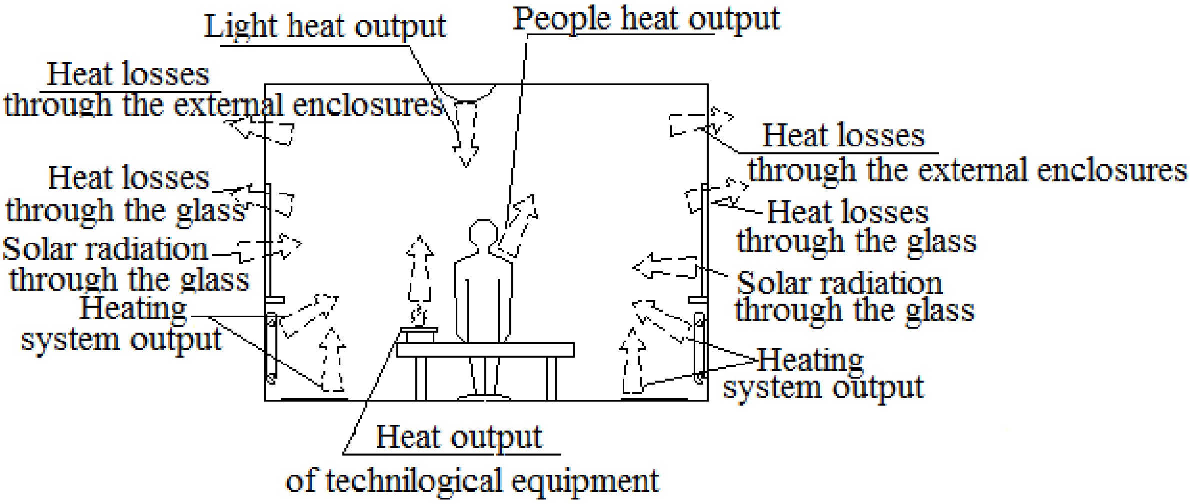

Fig. 1. Heat flows and heat losses in restaurant premises

Generally, the total heat output is thus described by the equation

$$\sum Q_{ТЕПЛОПРИТ.} = Q_{люд} + Q_{осв} + Q_{от.приб} + Q_{тех.обор} + Q_{сол.рад}. \qquad (1)$$

Heat losses in restaurant premises are made up of the heat losses through the external enclosures and glass (windows). The total heat losses can generally be described by the equation

$$\sum Q_{ТЕПЛОПОТЕРИ} = Q_{н.о} + Q_{ост}, \qquad (2)$$

where $Q_{н.\ о}$ and $Q_{ост}$ are the heat losses through the external enclosures and glass respectively, Watt.

1. Developing a thermal physical model of thermal technology equipment in food processing

It is of particular scientific interest to identify the heat output of technological equipment $Q_{\textit{тех. обор}}$ [2, 8, 9]**.** The previously suggested methods for calculating the heat output of technology equipment are based on large indicators and are largely too general and inaccurate. In order for the calculations to be more accurate, a thermal physical model of thermal technology equipment in restaurant premises needs to be developed for each cycle of the operation of the equipment to identify the total heat emissions from thermal technology equipment over the entire cooking cycle. The main purpose of this research is to study non-stationary processes of moist heat processing in time. The mathematical description of a spatial temperature field of thermal technology equipment will be as follows: $t = t\ (x, y, z, \tau)$ where x is a coordinate that changes inside the premises, m; y is a coordinate that changes along the premises itself, m; z is a coordinate that changes vertically throughout the premises, m; τ is time, c.

For a general mathematical description of a non-stationary temperature field of thermal technology equipment Fourier differential equation applies:

$$\frac{\partial}{\partial x}\left(\lambda_x \frac{\partial t}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda_y \frac{\partial t}{\partial y}\right)+\frac{\partial}{\partial z}\left(\lambda_z \frac{\partial t}{\partial z}\right)+q(x,y,z,\tau)-c\rho\frac{\partial t}{\partial \tau}=0, \tag{3}$$

where $q\ (x, y, z, \tau)$ is a function of the heat source distribution inside the premises and change of their productivity in time; c is a specific heat capacity, Watt/(kg·^{0}C); ρ is the density, kg/m^3; λ is a coefficient of heat conductivity, Watt/(m·K).

In this case in order to determine a spatial temperature field generated by the surfaces of the thermal technology equipment of the restaurant, it is necessary to solve the reverse problem [1, 4, 5]. There are the third order boundary conditions when there is a heat exchange between the cooking surfaces of the equipment and the environment:

$$\lambda\frac{\partial t(x_n,y_n,z_n,\tau)}{\partial n}+\alpha\left[t(x_n,y_n,z_n,\tau)-t_{\hat{a}}\right]=0, \tag{4}$$

where n is a normal to the surface of thermal technology equipment installed in the industrial facility of the restaurant.

In this chapter the function $\alpha[t\ (x, y, z, \tau)]$ applies to the initial function. Moist heat processing of foods produces heat on the surface of thermal technology equipment on one hand and there is a heat exchange between the equipment and environment of the restaurant premises on the other. The major types of heat exchange are heat conductivity, convection and solar radiation. We thus have the equation of heat balance of heat input into the premises from the thermal technology equipment $Q_{об}$:

$$Q_{об} = Q_{т} + Q_{л} + Q_{к}, \tag{5}$$

where $Q_{т}$, $Q_{л}$, $Q_{к}$ is the heat power that comes into the environment due to heat conductivity, solar radiation and convection, Watt, respectively.

Developing a complex thermal physical model of the equipment, we designed and solved thermal and physical equations considering the cycles involved in the operation of the equipment. The following allowances were made:

- heating temperature is distributed evenly throughout the surface of the operating parts;
- for each stage of the cycle the thermal and physical parameters of technological equipment are assumed to be stable;
- heat impact of the nearby equipment is not considered;
- cooking parts of the equipment are parallelepiped like;
- the heat exchange surface at less than 25 degrees to the vertical is assumed to be vertical;
- the heat exchange surface at 25 to 40 degrees is assumed to be vertical; with the correction factor in determining the heat exchange coefficient;
- transitional process taking place between the cycles are not considered.

The solution of the problem involved the development of such a thermal and physical model of the equipment which would enable the calculation of the coefficients of convective and radiative heat exchange.

2. Design thermal and physical model (using the example of an electric pan)

For further research an electric pan (equipment for further references) will be used as one of the most common thermal technology equipment for moist and heat processing of foods (or production for further references) in restaurant premises [10, 12, 16]. T

he equipment is designed to consist of two parts: the cooktop (which serves as a shield) and the lower part (pans proper). The cycle of moist heat processing of the production is presented as consisting of several; stages characterized by different temperatures and position of individual construction parts of the equipment (each cycle is in seconds) (Table 1).

Table 1

Cycle of the operation of thermal technology equipment

Cycle of moist heat processing of the production	Time after the start of the cycle, sec				
	120	600	1200	120	900
The equipment is open, the production is placed on the lower part of the cooking surface	■				
The equipment is shut, the production is steam-treated		■			
The equipment is shut, the production is cooking			■		
The equipment is open, the production is taken off				■	
The equipment is open					■

Since different types of heat exchange are independent, it would be advisable to consider them in isolation.

The first stage. Let us discuss convective heat exchange. For the first stage of moist heat processing of the production (Fig. 2) the following typical surfaces are identified:

- cooking surface 1 of the cooktop, vertical;

- cooking surface 2 of the lower part (horizontal) where the production is placed;
- side surfaces 3 of the cooktop, vertical or horizontal;
- side surfaces 4 of the lower part, vertical.

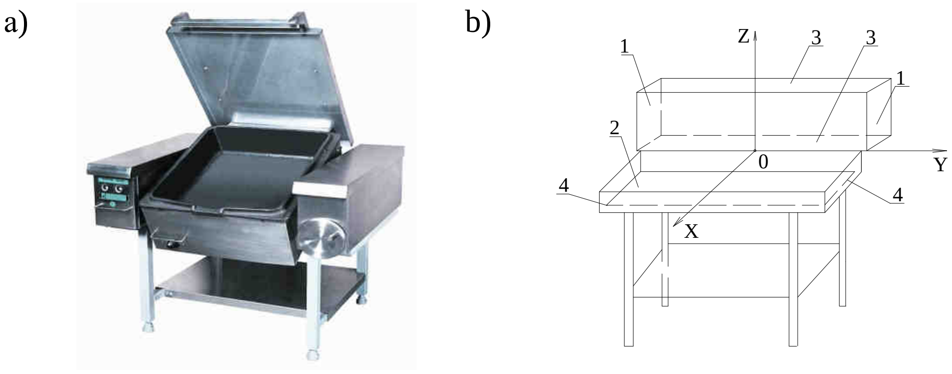

Fig. 2. Electric pan СЭСМ-02, the first stage of the cycle of moist heat processing:
a) general view; b) calculation scheme: 1 is a cooking surface of the cooktop, vertical;
2 is a cooking surface of the lower part (horizontal) where the production is placed;
3 are side surfaces of the cooktop; 4 are side surfaces of the lower part

Second stage. For the second stage of the cycle moist heat processing (Fig. 3) of the production, the following typical surfaces are identified:

- side surfaces 1 of the cooktop, vertical;
- side surfaces 2 of the lower part, vertical.

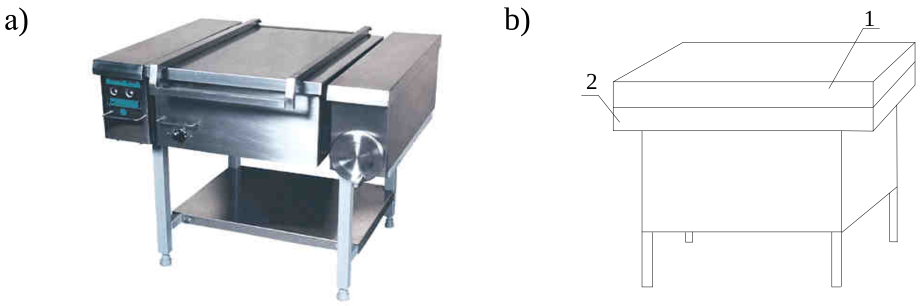

Fig. 3. Second stage of the cycle of moist heat processing:
a) general view; b) calculation schemes:
1 are side surfaces of the cooktop, vertical;
2 are side surfaces of the lower part, vertical

Third stage. For the third stage of the cycle of moist heat processing the typical heat exchange surfaces are identical to those in the second stage, their temperature changes and there is no more steam treatment of the air of the restaurant premises.

Fourth stage. For the fourth stage of the cycle of moist heat processing, the following typical heat exchange surfaces are identified (Fig. 4):

- cooking surface 1 of the cooktop, vertical;
- side surfaces 4 of the cooktop, vertical and horizontal;
- cooking surface 2 of the lower part, horizontal, closed with the production placed on it 3;
- side surfaces 5 of the lower part, vertical.

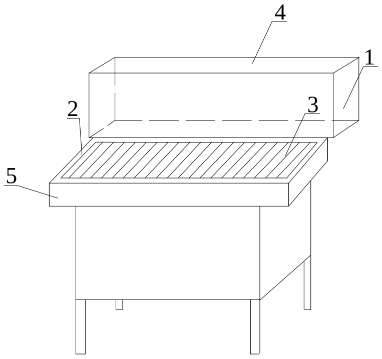

Fig. 4. The fourth stage of the cycle of moist heat processing: 1 is a cooking surface of the cooktop, vertical; 2 is a cooking surface of the lower part (horizontal), where the production is placed; 3 is the production; 4 are side surfaces of the cooktop, vertical; 5 are side surfaces of the lower part, vertical

Fifth stage. During the fifth stage of the cycle the equipment is open with the production on it with corresponding the temperatures of the surfaces.

Heat exchange during moist heat processing is accounted for by the fact that almost all bodies are capable of emitting radiation or absorbing electromagnetic waves of the thermal range [1, 14, 15]. The density of the radiative heat flow is given by Stephen- Boltzmann formula:

$$Q_л = \varepsilon \cdot C_0 \cdot \left[\left(\frac{t_п + 273}{100} \right)^4 - \left(\frac{t_в + 273}{100} \right)^4 \right], \tag{6}$$

where C_0 is a coefficient of the radiation of an absolutely black body which is 5.7 Watt/($m^2 \cdot K^4$); ε is blackness of the radiation body.

The rate of convective heat exchange Q_k is described by the heat output coefficient and is dependent on the temperature difference:

$$Q_к = \alpha_к \cdot F \cdot \left(t_п - t_в \right), \tag{7}$$

where α_k is heat output coefficient, Watt/(m$^2\cdot$degree); F is area of surface, m^2; t_n is the temperature of the surface of the equipment, ^{0}C; $t_в$ is the temperature of the air inside the premises, ^{0}C.

The solution of the thermal physical model is the expression for determining heat emissions Q_k in one cycle of moist heat processing of the production with the total of T, sec:

$$Q_k = \int_0^F \int_0^T \alpha[\tau, F]\cdot\left(t_n[\tau, F]-t_в\right)\cdot d\tau\cdot dF, \tag{8}$$

$$\alpha = \alpha_к + \alpha_л. \tag{9}$$

The total amount of heat losses in thermal technology equipment in one cycle can be expressed as the sum of the integrals in individual stages of the cycles:

$$\begin{gathered} Q=\int_F\int_0^{\bar{\tau}_1} \alpha[\tau, F]\cdot\left(t_n[\tau, F]-t_в\right)\partial\tau\partial F+\int_F\int_{\bar{\tau}_1}^{\bar{\tau}_2} \alpha_2[\tau, F]\cdot\left(t_n[F]-t_в\right)\partial\tau\partial F+ \\ +\int_F\int_{\bar{\tau}_2}^{\bar{\tau}_3} \alpha_3[\tau, F]\cdot\left(t_n[F]-t_в\right)\partial\tau\partial F+\int_F\int_{\bar{\tau}_3}^{\bar{\tau}_4} \alpha_4[\tau, F]\cdot\left(t_n[F]-t_в\right)\partial\tau\partial F+ \\ +\int_F\int_{\bar{\tau}_4}^{\bar{\tau}_5} \alpha_5[\tau, F]\cdot\left(t_n[F]-t_в\right)\partial\tau\partial F. \end{gathered} \tag{10}$$

3. Calculation example

A calculation example using the suggested thermal physical model is identified in Table 2.

Table 2

Calculation data for a heat exchange coefficient

Stage	Typical surfaces	Temperature of the stage, ^{0}C	Heat exchange coefficient, Watt/(m$^2\cdot{}^0$C)	Time of the stage, sec	Heat, Watt
1	Cooking surfaces of the cooktop, vertical	57	2.8	120	226.8
2	Side surfaces of the cooktop, vertical or horizontal	46	2.16	600	151.2

Table 2 (continuous)

Stage	Typical surfaces	Temperature of the stage, ^0C	Heat exchange coefficient, Watt/($m^2 \cdot {}^0C$)	Time of the stage, sec	Heat, Watt
2	Cooking surfaces of the lower part (horizontal) where the production is placed	65	3.2	600	284.8
	Side surfaces of the lower part, vertical	48	2.24		161.3
2	Side surfaces of the cooktop, vertical	94	5.0	600	590.0
	Side surfaces of the lower part, vertical	97	5.16		624.4
3	Side surfaces of the cooktop, vertical	95	5.05	1200	600.9
	Side surfaces of the lower part, vertical	97	5.16		624.4
4	Cooking surface of the cooktop, vertical	78	4.12	120	420.2
	Side surfaces of the cooktop, vertical and horizontal	83	4.4		470.8
	Cooking surface of the lower part, horizontal and closed by the production placed on it	89	4.74		535.6
	Side surfaces of the lower part, vertical	87	4.63		513.9

End of Table 2

Stage	Typical surfaces	Temperature of the stage, ^0C	Heat exchange coefficient, Watt/($m^2 \cdot {}^0C$)	Time of the stage, sec	Heat, Watt
5	Cooking surface of the equipment, vertical	66	3.22	900	278.1
	Side surface of the cooktop, vertical	60	3.1		260.4
	Cooking surface of the lower part, horizontal	68	3.56		327.5
			Total:	**2940**	**6415.2**

Conclusions

1. The suggested thermal physical model of the moist heat processing of foods enable the calculation of the total heat energy throughout the entire operation coming into the cooking zone of the industrial facility of restaurant premises.

2. A calculation example using this thermal physical model is presented. The values and calculation parameters of the total heat emissions (in one cooking cycle) from thermal technology equipment over 49 minutes of moist heat processing; the total amount of heat was 6415.2 kWatt.

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