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ASSESSMENT OF ECONOMIC EXPEDIENCY OF HEAT UTILIZATION TECHNOLOGY USE AT FOOD INDUSTRY ENTERPRISES

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Summary. *The objective of the investigation is to reveal the effect of exhaust technological gases on the environment while reducing the consumption of primary fuel and energy resources due to the decrease of exhaust technological gases temperature. The problem of saving fuel resources while reducing the energy-intensity cost of the product unit with simultaneous increase of its quality in the baking process in industrial furnaces and drying in dryers is considered and analyzed. Analysis of the constructions of thermal installations with the improvement of the combustion process and the form of contact of the thermal agent with products and materials undergoing heat treatment is carried out. As the result of the carried out analysis, it is established that the expected result in this problem solution can be achieved by implementing such technological solution for the reduction of the exhaust gases temperature, is the reuse of heat obtained as the result of their cooling for technological and household needs, using heat pumps. Preliminary calculations of heat exchange processes show that at current prices for energy carriers, it is expedient to organize maximum cooling of spent process gases. At the same time, at the first stage, the spent process gases are cooled in heat exchangers. To organize the second stage of cooling, it is advisable to use heat pumps. Positive results in solving this problem can be achieved using various technological solutions. The methodical approach for the calculation of heat amount and cost which should be spent for heating, or can be obtained during one hour as the result of cooling of* $1m^3/s$ *of technological gases at different temperatures is developed. It is proposed to use heat exchanger with* $30m^2$ *heat exchange surface for exhaust technological gases cooling. The obtained data make it possible to confirm that the use of cooled exhaust technological gases from thermal installations will significantly reduce the negative effect of production on the environment, while the reuse of recuperative heat will result in significant decrease of the energy carriers volume. Moreover, the obtained calculation results can be used for preliminary analysis of the feasibility of using heat recovery technology.*

Key words**:** *heat loss, combustion process, net heat, thermal acceptor, thermal process, heat pump.*

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ОЦІНЮВАННЯ ЕКОНОМІЧНОЇ ДОЦІЛЬНОСТІ ВИКОРИСТАННЯ ТЕХНОЛОГІЇ УТИЛІЗАЦІЇ ТЕПЛА НА ПІДПРИЄМСТВАХ ХАРЧОВОЇ ПРОМИСЛОВОСТІ

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Резюме. *Мета дослідження полягає в розкритті впливу відпрацьованих технологічних газів на оточуюче середовище при зменшенні споживання первинних паливно-енергетичних ресурсів за рахунок зниження температури відпрацьованих технологічних газів. Розглянуто й проаналізовано питання економії паливних ресурсів при зниженні вартості енергоємності одиниці продукції при одночасному підвищенні її якості в процесі випікання у промислових печах та сушіння в сушарках. Проведено аналіз конструкцій теплових установок з удосконаленням процесу горіння та форми контакту теплового агента з виробами та матеріалами, які зазнають теплову обробку. В результаті проведеного аналізу встановлено, що очікуваний результат при розв'язанні даної проблеми можна досягнути, впроваджуючи таке технологічне рішення для зменшення температури відпрацьованих газів – це повторне використання отриманого в результаті їх охолодження тепла для технологічних і побутових потреб, із використанням теплових насосів. Попередньо проведені розрахунки теплообмінних процесів показують, що при сучасних цінах на енергоносії доцільно організувати максимальне охолодження відпрацьованих технологічних газів. При цьому на першому етапі відпрацьовані технологічні гази охолоджують у теплообмінниках. Для організації другого етапу охолодження доцільно використовувати теплові насоси. Позитивних результатів у вирішенні даної проблеми можна досягнути, використовуючи різні технологічні рішення. Розроблено методичний підхід до розрахунку кількості й вартості тепла, які необхідно затратити для нагрівання, або можна отримати протягом години в результаті охолодження 1м*^{3}*/с технологічних газів за різних температур. Запропоновано для охолодження відпрацьованих технологічних газів використати теплообмінник з поверхнею теплообміну 30м*^{2}*. Отримані дані дозволяють стверджувати, що використання охолоджених відпрацьованих технологічних газів від теплових установок дозволить суттєво зменшити негативний вплив виробництва на навколишнє середовище, при цьому повторне використання рекуперативного тепла призведе до суттєвого зменшення об'ємів енергоносіїв. Отримані результати розрахунків можна використовувати для попереднього аналізу доцільності використання технології утилізації тепла.*

Ключові слова: *втрата тепла, процес горіння, тепловий агент, енергоносії, теплообмінні процеси, тепловий насос.*

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Introduction. In the context of global warming and unprecedented growth in the cost of fuel and energy resources, particularly of natural gas, it is especially important to solve simultaneously two problems on which the fate of mankind depends.

The first problem is to reduce the temperature of waste technological gases and carbon dioxide emissions. In this century, according to the statements of the conference in Glasgow, it is necessary to keep global warming within 1.5^{0}C. According to the scientists forecasts, by the end of the century the planet's temperature will rise by 2.7^{0}C, resulting in global catastrophe on the planet. In order to avoid this, it is necessary to reduce global carbon emissions compared to 2010 by 45% by 2030.

The second problem involves the production energy intensity decrease and reduction of fuel and energy resources consumption. Reduction of fossil fuel use is the most devastating for the ecology of our planet. In this case, it is reasonable to pay special attention to the work of the most energy-consuming equipment. Such equipment includes furnaces and dryers.

Furnaces and dryers are widely used at the food industry enterprises. In particular, at bakery and confectionery industries they are referred to as basic technological equipment. The quality and price of many types of products depends on the efficiency of furnaces and dryers.

Thus the price of bakery products by 70% depends on the price of electricity consumed for their production.

Analysis of available researches and objective of the work. The issues of energy resources saving and reducing the energy intensity of the unit of production while improving its quality have been considered as the main ones throughout the history of operation and improvement of furnaces and dryers [1, 2].

It should be noted that at different times the goals and tasks, the solutions of which provided the above mentioned issues, changed. Thus, in the 50s of the last century, researchers believed that ensuring the conditions of complete fuel combustion, heating fuel and air providing the combustion process, and minimizing heat losses into the environment should ensure high equipment productivity and product quality. In particular, P.V. Levchenko noted that heating the air used for the combustion process contributes to the temperature increase and fuel consumption reduction. The eighties of the last century are characterized by the increase of fuel prices and its deficit. During this period, researchers paid special attention to the design of thermal installations, improvement of the combustion process and the form of contact of the thermal agent with products or materials subjected to heat treatment [3, 4, 5]. Special attention should be paid to the works aimed at thermal processes modeling and creating of reconstructive mathematical and physical models [6]. The results of research in this area have made it possible to reduce significantly the cost of the product, optimal solutions and accelerate the process of designing new promising samples of technological equipment. Nowadays, the issues of environmental protection are added to the above-mentioned issues [7, 8]. In particular, the issue of reducing global warming is particularly common for industry. Positive results in solving this problem can be achieved by implementing different technological solutions. Among such solutions, a special place is occupied by the decrease of the temperature of the waste technological gases and the reuse of the heat obtained as a result of their cooling for technological and household needs. In this direction it is necessary to highlight the work of scientists of the Institute of Thermophysics of the Academy of Sciences of Ukraine in which the expediency of using recuperative heat of waste drying agent is proved, and the use of heat pumps is proposed and energy-saving methods of drying and original drying structures are developed [9, 10].

Previously carried out calculations of heat exchange processes show that at current energy prices it is advisable to organize the maximum cooling of waste technological gases [11]. In this case, the process should be carried out in two stages. At the first stage, the waste technological gases are cooled in heat exchangers. In order to organize the second stage of cooling, it is reasonable to use heat pumps.

Despite the unconditional expediency, the utilization of the heat of waste technological gases does not find proper attention at the food industry enterprises. Thus, the aim of the work is to substantiate the feasibility and calculation of the economic benefits of utilization and reuse of thermal energy of waste technological gases at the food industry enterprises.

The result of the investigations and their analysis. Productivity and parameters of technological gases of thermal installations operating at the enterprises fluctuate within very large limits. Accordingly, the temperature and volume of waste technological gases are also significantly different. Therefore, in order to substantiate the expediency of using utilization and reuse of heat of the waste gases at the enterprises, we begin by calculating the heat required to heat 1m^3 of air per 10^0. For calculation we the use the known dependence

$$Q = L \cdot \rho_п \cdot c_п \cdot \Delta t, \quad (1)$$

where L = 1м^3 is air volume;
$c_п$ = 0.24 kcal/kg deg is heat capacity of air;
$\rho_п$ = 1.293kg/m^3 is air density густина повітря;
$\Delta t = 10^0$ is temperature difference.

Therefore, to heat 1m^3 of air per 10^0 heat consumption is Q = 3.1 kcal = 13 kJ. Thus, the cost of heating 1m^3/s of air per 10^0 at specific heat of natural gas combustion 8000 kcal and price of 12 UAH/m^3 is 16.74 UAH/hour. It should be noted that the companies use electricity in addition to natural gas to organize heat treatment of products. Excluding the efficiency of equipment that converts electricity into heat and electricity prices for businesses that consume up to 20,000 kWh 3.9 UAH similar costs are 50.7 UAH/hour.

Calculated by formula (1), the amount and cost of heat that must be used for heating or can be obtained within an hour as a result of cooling 1m^3/s of technological gases for different Δt are given in Table1.

The analysis of the obtained calculation results confirms the expediency of maximum cooling of waste technological gases with the application of heat exchangers and heat pumps. Since the use of heat pumps requires significant financial costs for their purchase, installation and maintenance, the reconstruction of waste technological gases removal systems should be organized in two stages.

The first stage involves cooling of waste technological gases in gas-gas heat exchangers to the temperature of 30^0–40^0 C and supplying heated air to the natural gas combustion area or to electric heater. The temperature of the waste technological gases at the heat exchanger exit is determined by the operating conditions of the heat pump where they are cooled at the second stage.

In order to organize the heat exchange at the first stage we accept the recuperative flowing plate heat exchanger «gas – gas». In the process of heat exchange we use waste technological gases as hot heat agent, atmospheric air as cold heat agent.

Table 1. The amount and cost of heat at different temperatures Δt^0

Temperature difference, Δt^0		10	20	30	40	50
The amount of heat, kcal / h		11160	22320	33480	44640	55800
Natural gas	Volume, m^3	1.395	2.79	4.185	5.58	6.975
	Cost, UAH	16.74	33.48	50.22	66.96	83.7
Electric energy	Quantity, kW · h	13	26	39	52	65
	Cost, UAH	50.7	101.4	152.1	202.8	253.5

Heat transfer can be organized in two modes. The first provides heating of the constant amount of cold heat agent to constant temperature. In this case, the final temperature of the hot coolant will change as the initial temperature of the cold heat transfer agent changes. The second mode provides cooling of the hot heat agent to constant temperature. The final temperature of the cold coolant will change. As for stable operation of the heat pump it is necessary to provide receipt in the evaporator of the heat source with constant temperature, it is expedient to carry out heat exchange at the first stage in the second mode.

Thus, the process of heat transfer at the first stage takes place under conditions of constant initial and final temperatures of the hot coolant and variables, depending on the season, initial and final temperatures of the cold coolant. Preheated cold coolant enters the furnace or dryer where it is necessary to maintain the technological and aerodynamic conditions provided by technological conditions. Therefore, the change in the final temperature of the cold coolant results in the change of the amount of energy used to ensure the technological process. To calculate the required amount of energy and the economic effect of the supply of preheated atmospheric air at different initial temperatures, you should know to which maximum temperature you can heat cold coolant under the given conditions of heat transfer. It is not possible to use the known dependences [12] for such calculations, because in order to determine the number the cold coolant parameters its final temperature should be known. Therefore, to solve this problem, it is necessary to calculate the dependence of the volume flow rate of the cold coolant on its initial temperature at different values of the final temperature. Such calculations are carried out for specific equipment and specific technological conditions.

In our case, the conditions of operation of the tunnel gas furnace A2SHBG, which provides operation of one of the technological lines at the confectionery factory «Tera», are used for calculations. During the operation of this furnace, 1.31 m^3/s of waste technological gases are emitted into the atmosphere at temperature of 90^0C. It is proposed to use the heat exchanger with 30m^2 heat exchange surface to cool the exhaust gases. The heat exchanger should provide cooling of the hot coolant to 40^0C. The initial temperature of the cold heat carrier varies from – 30^0C to +30^0C during the year.

Using the above given calculations, we determine to what temperature under these heat exchange conditions it is possible to heat the required amount of atmospheric air at different initial temperatures and calculate the economic efficiency of preheated atmospheric air.

The results of the calculation of the dependence of the volume flow rate of the cold coolant on its initial temperature at different values of the final temperature are given in Table. 2.

Table 2. Volume consumption of cold coolant at different values of the final temperature

Temperature of exhaust gases, ^{0}C	Initial temperature of cold heat carrier, ^{0}C						
	-30	-20	-10	0	10	20	30
40	0.85	0.93	1.18	1.44	2.05	2.99	6.14
50	0.68	0.81	0.96	1.17	1.48	2.01	3.08
60	0.56	0.72	0.83	0.99	1.2	1.52	2.08
70	0.54	0.66	0.75	0.86	1.02	1.24	1.58
80	0.51	0.6	0.68	0.77	0.89	1.05	1.28

The results of calculations of the heating temperature 1.31 m^3/s of atmospheric air and the economic efficiency of its use in the combustion area of the gas tunnel furnace A2SHBG are given in Table 3.

Table 3. Dependence of economic efficiency of the use of preheated atmospheric air in combustion area of the gas tunnel furnace A2SHBG on its temperature

Initial temperature,^{0}C	-6	+4	+13	+20	+30
Final temperature,^{0}C	+40	+50	+60	+70	+80
Volume of natural gas, m^3/h	7.31	9.14	10.97	12.8	14.63
The cost of natural gas, UAH	87.72	109.65	131.58	153.51	175.44

Conclusions. The above mentioned results show that the use of waste technological gases cooling technology of thermal installations can significantly reduce the negative impact of production on the environment, and the reuse of recuperative heat results in significant reduction in energy, which ultimately reduces production costs and increase production efficiency. The obtained results of calculations can be used for preliminary analysis of expediency of heat utilization technologies application in industrial conditions.

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