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IMPROVING THE ENVIRONMENTAL EFFICIENCY OF GLASS FURNACE CHIMNEYS USING HEAT RECOVERY TECHNOLOGIES

Purpose. Improving the conditions for dispersing harmful emissions from gas-consuming industrial furnaces based on the development of new complex methods for their greening using modern energy-saving technologies.

Methodology. The known methods of heat exchangers and chimneys thermal calculation and methods for dispersing harmful emissions from thermal-energy plants in the environment were used.

Findings. Calculative studies were carried out on improving the chimneys operation safety of glass furnaces of regenerative type when using technologies for waste heat recovery of furnace gases using water-heating and air-heating heat exchangers and chimneys of various designs. The influence of design features of chimneys on their operating modes when using heat recovery technologies with water and air heat recovery units has been studied. In order to improve the environmental efficiency and operational reliability of chimneys, it is proposed to use the thermal method of bypassing part of exhaust gases from regenerators past the heat recovery equipment in the heat recovery technologies. The effectiveness of this method for improving the dispersion in the ground-level of harmful emissions from furnaces when using the proposed heat recovery systems has been analyzed.

Originality. For the first time, the application efficiency has been investigated of the proposed greening methods to improve the dispersion conditions of harmful emissions of gas-consuming glass furnaces in the environment under the conditions of using heat recovery technologies.

Practical value. The results obtained will be used in the development of energy-efficient gas-consuming thermal installations for technological purposes.

Keywords: *industrial furnaces, heat recovery systems, chimneys, harmful emissions, ground-level concentration, environmental efficiency*

Introduction. When creating and operating modern gas-consuming industrial furnaces for various purposes, the task is to produce competitive products along with a decrease in its specific energy consumption [1]. This problem is solved in various directions which include the creation of energy-saving environmentally perfect technological installations. Energy saving in industrial furnaces is realized mainly by applying the proposed approaches: optimization of fuel combustion processes [2, 3], improvement of regenerator and recuperator designs [2], and also by using combustion product heat recovery systems after regenerators and recuperators [4].

The use of energy-saving approaches is often associated with a decrease in the volume and temperature of flue gases. This circumstance can lead to a deterioration in the operation of chimneys regarding the dispersion of harmful emissions contained in these gases [5, 6]. In addition, the creation of more competitive products can lead to an increase in the volume and chemical aggressiveness of these emissions [6]. The level and content of harmful compounds in the combustion products of such technological thermal units is determined by their purpose. In glass production, typical harmful compounds in the combustion products are nitrogen oxides NO_x, sulfur dioxide SO_2 and process dust [7, 8]. Among these compounds, nitrogen oxides (NO_x), namely nitrogen monoxide (NO) and its dioxide (NO_2), have the greatest harmful effect on the environment (up to 80 %) [7].

This work concerns the development and study on the effectiveness of methods to improve the dispersion conditions of harmful emissions of gas-consuming regenerative glass furnaces when using systems for waste heat recover from furnace gases. The waste heat levels of these furnaces are often quite high due to the high temperature potential of the combustion products at the outlet of the regenerators. Temperature of gas emissions is usually 400–450 °C, but can reach 700 °C [9]. The loss of heat with the exhaust gases is the main loss of the glass furnace, reaching 40 % of its thermal potential. The high level of waste heat explains the high energy intensity of these process units.

Heat recovery systems are used to reduce fuel consumption for the furnace and to meet the needs of glassworks in hot water for technological needs and heat supply.

Reduction of fuel consumption is realized by improving the regenerators [2] and installing additional air-heating equipment after them, which serves to pre-heat the air before it enters the regenerators.

In the back part of such a glass melting unit, behind the regenerators, heat recovery equipment can also be installed for heating water for heating, hot water supply and technological needs of glassworks.

Appropriate heat recovery technologies and thermal schemes with the use of developed additional air heaters (so-called end recuperators), installed after the regenerators, as well as using water-heated heat recovery equipment (heat recovery units of water-heated modular HWM) are presented in [10]. The technical characteristics of the developed equipment are also given there. When using these technologies, the temperature of the furnace gases in the end recuperator is reduced by 100–200 °C, and in the water-heated heat recovery unit by 100–250 °C. In this case, the initial temperature of the air entering the end recuperator varies from minus 20 to plus 20 °C and the initial heated water temperature from 40 to 70 °C. The use of the specified heat recovery equipment provides an increase in the efficiency of using the furnace fuel (EUF) by 7–10 %.

Thus, the use of heat-recovery systems also provides a certain environmental effect by reducing the temperature potential of gas emissions and reducing the mass of harmful substances in them on the share of saved fuel. However, the ecological safety of the environment due to changes in the operating modes of gas-exhaust ducts in the application of heat recovery technologies, as noted, is deteriorating.

The environmental safety of the environment is significantly affected by the conditions of dispersion of harmful substances in the ground-level of chimneys, as well as toxicity and mass concentrations of harmful emissions. These concentrations are mainly determined by the technological features of industrial furnaces. The processes of dissipation of harmful emissions are mainly influenced by climatic conditions, regime parameters (velocity and temperature of emissions at the outlet to the atmosphere), height of the chimney and its location.

When using heat recovery technologies, the type of heated heat-transfer agent and its temperature levels during operation largely determine the operating modes of the gas-outlet channels. These modes also depend significantly on the type of chimney used (brick, metal, reinforced concrete, etc.), as well as on its design features.

The purpose of the research is to improve the operating modes of flue pipes of gas-consuming glass melting furnaces by applying methods of their ecologization in the systems for using the waste heat of exhaust gases.

Materials and research methods. In this work the calculated research on regime parameters of gas exhaust channels of glass melting technological installations of regenerative type in the production of tare products and application of heat recovery systems of furnace gases were carried out. An analysis of the relative changes in the maximum ground-level concentrations of harmful emissions of these installations when using the proposed methods of their ecologization and without them was also carried out. Initial data for the research are taken from the experience of operation of these furnaces [6, 9], including the use of heat recovery technologies [8, 10]. The flue gas parameters after the regenerators were taken as follows: temperature – 400–450 °C; gas consumption – 12.3 kg/s.

These furnaces are characterized by high concentrations of harmful emissions in combustion products: NO_x – 800–4000; SO_3 – 100–1000; SO_2 – 50–400 mg/m^3; technological dust – 200–300 mg/m^3 [8]. Therefore, the reduction of surface concentrations of these emissions in the application of heat recovery technologies is an important task.

The work considered the heat recovery systems using water-heating and air-heating heat-recovery exchangers developed by the authors [10]. In this case, as the heat-exchange surface of water-heating heat exchangers, packages of plates formed by tube channels with longitudinal membranes were used. Air-heating heat recovery exchangers (end recuperators) were assembled from the same plates, but as forming channels they used pipes with circular turbulators on their inner surface. The movement of the heated heat-transfer agent (water or air) is carried out in the channels, and the heating heat-transfer agent (exhaust gases) in the intertube area.

The structural circuits of these systems are presented in Fig. 1.

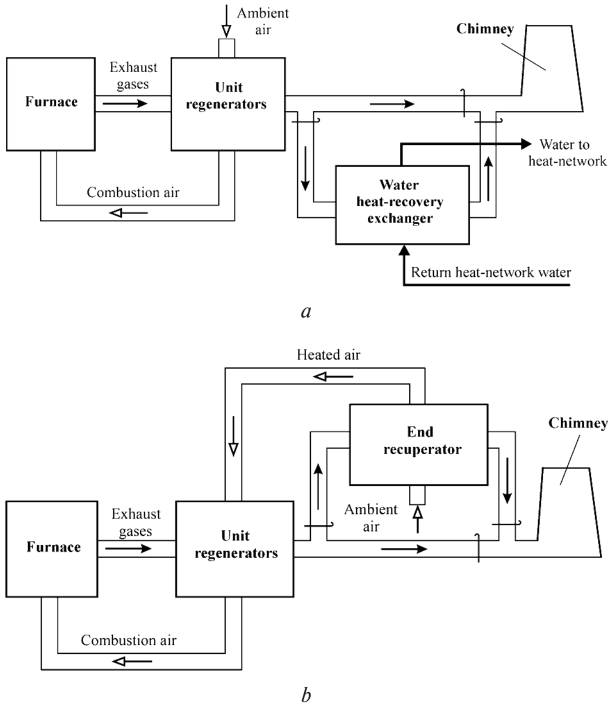


Fig. 1. Circuits of heat recovery systems of regenerative type glass melting units when using water-heated heat-recovery unit (a) and end recuperator (b)

To improve the operating characteristics (temperature and velocity) of gases in the gas-exhaust channels in heat recovery systems, a bypass of hot gases part from the furnace regenerators past the heat recovery equipment is provided. This method makes it possible to increase, if necessary, the temperature potential of the flue gases before they enter the gas exhaust duct to improve its operating mode.

Chimneys of different types were considered (Fig. 2). The internal geometric dimensions of these gas-outlet channels were close and corresponded to those actually used. The height was taken as 55 m. The inner diameter of the orifice of metal, brick and reinforced concrete chimneys was 3.1 m. The total cross-sectional area of the three plug-in shafts of the three-trunks pipe corresponded to the cross-sectional area of the main trunk of the other chimneys under consideration at their orifice.

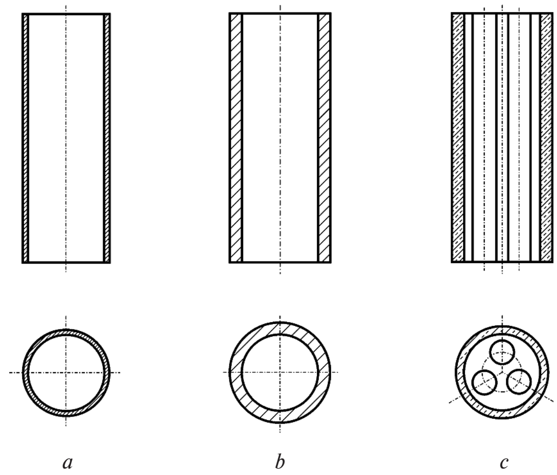


Fig. 2. Fragments of the investigated chimneys:
a – metal; b – brick; c – three-trunk

The regime parameters of the indicated gas-outlet channels were determined: temperature t_g and velocity W_g of gas flows at their orifice for the considered heat recovery systems (Fig. 1) under different performance modes of water and air heating equipment during the year.

The main parameters of these systems to perform computational studies are indicated in Table 1.

When bypassing a furnace gases part from regenerators of furnace into the gas duct before the chimney, the share of this part in the total volume of the mixture varied from 0 to 40 %.

The improvement in the environmental efficiency of gas exhaust ducts when using the bypass method was determined using the coefficient k, which shows the relative change in the maximum ground-level concentrations of harmful emissions when applying the method (C_m) and without it (C_o).

$$k = (C_o - C_m)/C_o \cdot 100. \quad (1)$$

When calculating the maximum ground-level concentrations of C_o and C_m in accordance with method [11], expression (1) can be converted to the form

Table 1

Initial data

Parameter name	Value
Initial temperature of heated air, °C	–20 —+20
Final temperature of heated air, °C	80—120
Heating surface area of the end recuperator, m^2	480
Heated air consumption, kg/s	8.95
Initial temperature of heated water during the heating period with ambient temperature from –20 to +10 °C	60—35
Final temperature of heated water, °C	62—87
Heating surface area of water heat-recovery exchanger, m^2	440
Heated water consumption, kg/s	13.9

$$k = 1 - \left(\frac{V_{1o} \Delta t_o}{V_{1m} \Delta t_m} \right)^{\frac{1}{3}}. \quad (2)$$

where V_{1m} and V_{1o} are volume consumptions of gas emissions; Δt_m and Δt_o are difference between the outlet temperature of these emissions from the chimney orifice tori and the ambient air temperature t_{amb} respectively, when conditions of the bypassing method and without it.

As can be seen, the value of the noted relative value *k* of the change in the maximum ground-level concentrations of *C* does not depend on the mass concentrations of harmful emissions, the terrain, the temperature gradient of the atmosphere, conditions of the exit of gases from the gas channels into the atmosphere, and other conditions. The coefficient k is influenced only by the regime characteristics of the chimney, which are determined by its type and cooling conditions.

Results. The research results of mode parameters of different chimneys (Fig. 2), determining conditions of harmful emissions dispersion of glass furnaces during the year, for heat recovery system with application of air-heating equipment (end recuperators) and method of bypassing of waste gases from furnace regenerators past heat recovery equipment (Fig. 1, *b*) are presented in Table 2.

The results obtained (Table 2), indicate that the type of the applied gas exhaust duct and the temperature parameters of the atmospheric air significantly affect its mode characteristics. At the same time, the higher the thermal insulation properties of the channel shell, the higher the values of t_g^{ori} and W_g^{ori} of gas emissions from its orifice. The values of these quantities increase with increasing ambient air temperature t_{amb} due to the decrease in heat losses from the surface of the pipe shell. As the results show, the best performance is characterized by the three-trunk chimney. So in it at application of heat recovery system t_g^{ori} and W_g^{ori} are higher by 1.13 and 1.55 times accordingly compared with the metal chimney, having low thermal insulation properties. A more significant increase in W_g^{ori} velocity compared to the growth of t_g^{ori} in the gas-outlet channel is explained by the possibility of reducing the cross section for the passage of gas emissions due to a reduction in the number of trunks used. Thus, the structural changes of chimneys (installation of three trunks in one shell) compared with the traditional (single-trunk brick and metal) have advantages in terms of improving the mode parameters of gas exhaust ducts.

Structural changes in chimneys in terms of improving the conditions for dispersion of harmful emissions in their ground-layer can be considered as a separate important method of ecologization industrial furnaces. In particular, for traditional flue ducts in order to improve their mode parameters when applying heat recovery technologies, it is possible to thermally insulate the duct shell.

As for the application of the bypass method in heat recovery systems, it allows improving the operating modes of all

Table 2

Results of calculations of regime parameters of chimneys with and without the use of air-heating heat exchanger equipment (HR)

Name of operating parameters		Share of bypassed gases, %	Value in operating modes									
			with HR	without HR	with HR	without HR	with HR	without HR	with HR	without HR	with HR	without HR
			ambient air temperature, °C									
			–20		–10		0		10		20	
three-trunk chimney												
Gas temperature, °C	at the input	0	223	410	232	420	241	430	251	440	261	450
		10	230		239		249		258		267	
		20	200		247		256		266		275	
		30	224		256		266		279		289	
		40	248		267		277		286		296	
	at the orifice	0	222	409	232	419	240	429	250	439	260	449
		10	229		238		248		257		266	
		20	237		246		256		265		274	
		30	246		255		265		278		288	
		40	257		266		276		285		295	
Gas velocity at the orifice, m/s		0	3.4	3.1	3.4	3.1	3.5	3.2	3.5	3.2	3.6	3.3
		10	3.5		3.5		3.5		3.6		3.7	
		20	3.5		3.5		3.6		3.6		3.7	
		30	3.5		3.6		3.6		3.7		3.8	
		40	3.7		3.7		3.7		3.8		3.8	

End of Table 2

brick chimney												
Gas temperature, °C	at the input	0	223	410	232	420	241	430	251	440	261	450
		10	230		239		249		258		267	
		20	238		247		256		266		275	
		30	247		256		266		279		289	
		40	258		267		277		286		296	
	at the orifice	0	213	393	223	403	232	413	241	423	251	433
		10	220		229		239		248		258	
		20	227		237		246		256		265	
		30	236		246		255		269		278	
		40	247		256		266		275		285	
Gas velocity at the orifice, m/s		0	2.2	3.0	2.2	3.0	2.3	3.1	2.3	3.1	2.4	3.2
		10	2.2		2.3		2.3		2.4		2.4	
		20	2.3		2.3		2.3		2.4		2.4	
		30	2.3		2.3		2.4		2.4		2.5	
		40	2.3		2.4		2.4		2.5		2.5	
metal chimney												
Gas temperature, °C	at the input	0	223	410	232	420	241	430	251	440	261	450
		10	230		239		249		258		267	
		20	238		247		256		266		275	
		30	247		256		266		279		289	
		40	258		267		277		286		296	
	at the orifice	0	196	357	206	367	215	377	224	387	234	397
		10	202		211		221		230		240	
		20	208		218		228		237		247	
		30	217		226		236		249		259	
		40	226		236		246		255		265	
Gas velocity at the orifice, m/s		0	2.1	2.8	2.2	2.9	2.2	2.9	2.2	3.0	2.3	3.0
		10	2.1		2.2		2.2		2.3		2.3	
		20	2.2		2.2		2.3		2.3		2.3	
		30	2.2		2.3		2.3		2.4		2.4	
		40	2.3		2.3		2.3		2.4		2.4	

considered chimneys. So, in the orifice of these pipes, the temperature t_g^{ori} and the velocity W_g^{ori} of exhaust-gases increase the more when using the method, the higher the share of bypassing σ and the better the thermal insulation properties of the gas-exhaust channel shell. In this case, the relative increase in t_g^{ori} is 1.13–1.16 times, and in the velocity W_g^{ori} it is 1.05–1.09 times with σ changing from 0 to 40 %

Calculations regarding the impact of the considered ecologization methods also performed for the heat recovery systems with and without water-heating equipment (heat-recovery units HWM). The results obtained are presented in Table 3. As can be seen, for this variant of the heat recovery circuit (Fig. 1, *a*), the effect of thermal insulation properties of the flue duct shells has the same trends as for the air-heating heat recovery exchangers. However, for this variant, the bypassing method gives a more significant increase in the temperature potential of the gas flow and its velocity at the outlet of these channels than when using air-heating equipment (Fig.1, *b*).

The obtained research results indicate that the bypassing method in the application of water-heated heat recovery units provides a relative increase in t_g^{ori} by 1.6–1.8 times, and W_g^{ori} by 1.2–1.3 times at the growth in the share of σ from 0 to 40 %. A more significant effect of this method in this case is caused by a deeper cooling of the furnace gases. This is due to the high value of the heat transfer coefficient from the water side, and hence the heat transfer coefficient of the heat exchanging surface of the heat exchanger, when using the heat-transfer agent – water.

Based on the data obtained for the temperature t_g^{ori} and velocity W_g^{ori} in orifice of different chimneys for two heat recovery systems (Fig. 1) at different modes operation of water-heating and air-heating equipment during the year, calculations were made regarding the impact of the bypass method on changes in the maximum ground-level concentration of harmful emissions of flue gases. For the conditions of application in heat recovery systems of air-heating heat recovery units, the results of determining the relative values of *k* reduction of maximum ground-level concentrations are shown in Fig. 3. As noted, the results refer to all harmful emissions of glass furnaces, including the most characteristic ones: sulfur oxides SO_2, nitrogen NO_x and process dust. The quantity of growth in the relative value of maximum ground-level concentration decrease k does not depend on the type of harmful substance, but is determined by the mode parameters of gas emissions at the outlet from the chimney. These are temperature t_g^{ori} and velocity W_g^{ori} (2), which change when varying the bypass part share σ of emissions from the furnace regenerators past the heat recovery equipment.

Table 3

Results of calculations of regime parameters of chimneys with and without the use of water-heating heat exchanger equipment (HR)

Name of operating parameters		Share of bypassed gases, %	Value in operating modes							
			with HR	without HR	with HR	without HR	with HR	without HR	with HR	without HR
			ambient air temperature, °C							
			–20		–10		0		10	
three-trunk chimney										
Gas temperature, °C	at the input	0	154	410	149	420	143	430	136	440
		10	177		173		169		163	
		20	200		198		195		191	
		30	224		223		222		220	
		40	248		249		249		249	
	at the orifice	0	153	409	148	419	143	429	135	439
		10	176		173		169		163	
		20	200		198		195		191	
		30	223		223		221		219	
		40	247		248		249		248	
Gas velocity at the orifice, m/s		0	2.8	3.0	2.8	3.1	2.8	3.1	2.7	3.2
		10	3.0		3.0		2.9		2.9	
		20	3.2		3.1		3.1		3.1	
		30	3.3		3.3		3.3		3.3	
		40	3.5		3.5		3.5		3.5	
brick chimney										
Gas temperature, °C	at the input	0	154	410	149	420	143	430	136	440
		10	177		173		169		163	
		20	200		198		195		191	
		30	224		223		222		220	
		40	248		249		249		249	
	at the orifice	0	147	393	143	403	138	413	131	423
		10	169		166		162		157	
		20	191		190		188		184	
		30	214		214		213		211	
		40	238		239		239		239	
Gas velocity at the orifice, m/s		0	1.9	3.0	1.8	3.0	1.8	3.0	1.8	3.1
		10	2.0		1.9		1.9		1.9	
		20	2.1		2.1		2.0		2.0	
		30	2.2		2.2		2.2		2.1	
		40	2.3		2.3		2.3		2.3	
metal chimney										
Gas temperature, °C	at the input	0	154	410	149	420	143	430	136	440
		10	177		173		169		163	
		20	200		198		195		191	
		30	224		223		222		220	
		40	248		249		249		249	
	at the orifice	0	135	356	132	366	128	377	123	387
		10	155		154		151		148	
		20	176		175		174		172	
		30	197		197		198		197	
		40	218		220		221		222	
Gas velocity at the orifice, m/s		0	1.8	2.8	1.8	2.8	1.8	2.9	1.8	2.9
		10	1.9		1.9		1.9		1.9	
		20	2.0		2.0		2.0		2.0	
		30	2.1		2.1		2.1		2.1	
		40	2.2		2.2		2.2		2.2	

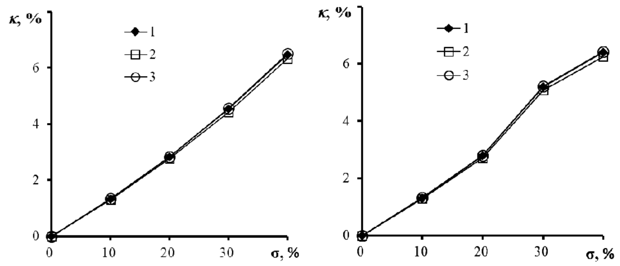
The data obtained concerning the value k of reduction of maximum ground-layer concentration of harmful emissions for heat recovery systems with air-heating heat recovery units indicate an increase in this value with the growth of gas bypass share for all types of flue ducts under consideration. Thus, when changing the bypassing gases share from 0 to 40 %, the value of k increases from 0 to 6.5 %.

The results of the performed computational studies also indicate an insignificant influence of the design features of the considered flue ducts and the ambient air temperature t_{amb} on the value of k.

The relative values of k for harmful emissions contained in the exhaust gases of glass furnaces are also determined, provided that water-heated heat exchangers and the method of bypassing hot gases past the heat recovery equipment are used in the heat recovery systems. The corresponding data are shown in Fig. 4.

The obtained data indicate that the magnitudes of relative values k of the decrease in the maximum ground-level concentration of the considered emissions when using water-heating heat recovery exchangers are larger compared to the use of air-heating heat recovery exchangers. So, if the share of bypassing gases increases from 0 to 40 %, the value of k increases from 0 to 30 %. Moreover, the influence of the design features of the gas-outlet channels on the value of k is more noticeable. The higher the thermal insulation properties of the channel shell, the higher the level of growth of k.

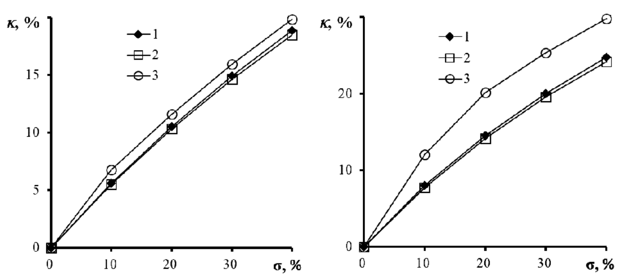
An even greater influence on the relative value of reducing the ground-level concentration of harmful emissions k when applying the thermal method of bypassing the furnace gases for heat recovery systems with water-heated heat recovery units has the ambient air temperature t_{amb}. So, when t_{amb} changes from –20 to +10 °C, the value of k increases by 1.5 times. This is explained by a deeper cooling of furnace gases for this heat recovery system when the t_g^{ori} temperature rises, which corresponds to a decrease in the return heat-network water heated in the heat recovery unit. Accordingly, the values of Δt (1) between the gas temperature t_g^{ori} at the orifice of the chimney and the ambient air temperature t_{amb} decrease.



a *b*

Fig. 3. Dependence for the heat recovery system with air-heating heat recovery units of the relative value of k decrease in the harmful emissions maximum ground-layer concentration from the share of bypass σ for different chimneys at the minimum winter temperature of –20 °C (*a*) *and the maximum summer temperature of* +20 °C (*b*):

1 – brick; 2 – metal; 3 – three-trunk chimney



a *b*

Fig. 4. Dependence for the heat recovery system with air-heating heat recovery units of the relative value of k decrease in the harmful emissions maximum ground-layer concentration from the share of bypass σ for different chimneys at the minimum temperature of –20 °C (*a*) *and the maximum temperature of* +10 °C (*b*) *of the heating period*:

1 – brick; 2 – metal; 3 – three-trunk chimney

The effect of the type of gas-exhaust duct on the value of k for water-heating heat exchangers is also more significant compared to air-heating heat exchangers. The difference between the corresponding coefficients k is especially evident during the warm (autumn-spring) heating period. At this time, the value of k for a three-trunk chimney is 1.01 and 1.15 times higher compared to brick and metal, respectively. This is also due to deeper cooling of exhaust gases in water-heating heat exchangers during this heating period.

Thus, the methods of ecologization of glass melting technological installations considered in this work allow improving significantly the ecological situation in the ground-layer of these installations.

Conclusions.

1. For glass furnaces equipped with heat recovery systems with water and air heating equipment, regularities of changes in mode parameters (temperature t_g^{ori} and velocity W_g^{ori}) of furnace gases at the outlet from the orifice of chimneys of different types were investigated. It has been established that the use of these systems worsens the technological modes of chimneys due to a decrease in these parameters. It is shown that systems with air-heated heat recovery units compared to systems with water-heated equipment are characterized by higher values of t_g^{ori} and W_g^{ori} at the outlet from the orifice of the considered flue ducts.

2. The effects of the influence of the type of chimney used on its mode parameters are established. It is shown that the higher the thermal insulation properties of the pipe shell, the higher the temperature t_g^{ori} and the velocity W_g^{ori} of gas emissions at the outlet of its orifice. It has also been established that structural changes in chimneys (three-trunk) compared to traditional (single-trunk brick and metal) have advantages in terms of improving their operating parameters.

3. An analysis of the effectiveness of using the method of bypassing exhaust gases past the heat recovery equipment to improve the operating conditions of chimneys was carried out. It has been established that this method provides in the orifice of the gas-outlet channels a relative increase in the gas temperature by 1.13–1.16 times, and their velocity by 1.05–1.09 times with an increase in the share of σ from 0 to 40 % for systems with air-heated heat exchangers and by 1.6–1.8 and 1.2–1.3 times respectively, when using water-heated heat recovery equipment.

4. Data on the relative decrease k of the ground-level concentration of harmful emissions from glass melting furnaces when applying the method of bypassing waste gases past the heat recovery equipment have been obtained. It is shown that the efficiency of this method is higher for heat recovery systems with water-heated heat recovery units. Thus, with an increase in the gas bypassing share from 0 to 40 %, the values of k increase to 6.5 % for heat recovery systems with air-heating heat exchangers and up to 30 % when using water-heating heat recovery units.

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Підвищення екологічної ефективності димових труб скловарних печей при застосуванні теплоутилізаційних технологій

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Мета. Покращення умов розсіювання шкідливих викидів газоспоживальних промислових печей на основі розроблення нових комплексних методів їх екологізації при застосуванні сучасних енергоощадних технологій.

Методика. Використовувались відомі методики теплового розрахунку теплообмінних апаратів і димових труб і методики щодо розсіювання в навколишньому середовищі шкідливих викидів теплоенергетичних установок.

Результати. Виконані розрахункові дослідження щодо покращення безпеки експлуатації димових труб скловарних печей регенеративного типу при застосуванні технологій утилізації скидної теплоти запічних газів із використанням водо- й повітрогрійних теплоутилізаторів і димових труб різних конструкцій. Досліджено вплив конструкційних особливостей димових труб на їхні режими експлуатації при застосуванні теплоутилізаційних технологій з водо- й повітрогрійними теплоутилізаторами. Запропоновано для підвищення екологічної ефективності та експлуатаційної надійності димових труб застосування в теплоутилізаційних технологіях теплового методу байпасування частини відхідних від регенераторів димових газів повз теплоутилізаційне устаткування. Виконано аналіз ефективності даного методу для покращення показників розсіювання у приземному шарі шкідливих викидів печей, за умов використання запропонованих теплоутилізаційних систем.

Наукова новизна. Уперше досліджена ефективність застосування запропонованих методів екологізації на покращення умов розсіювання в навколишньому середовищі шкідливих викидів газоспоживальних скловарних печей за умов застосування теплоутилізаційних технологій.

Практична значимість. Отримані результати досліджень використовуватимуться при розробленні енергоефективних газоспоживальних теплових установок технологічного призначення.

Ключові слова: *промислові печі, системи теплоутилізації, димові труби, шкідливі викиди, приземна концентрація, екологічна ефективність*

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