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Experimental determination of the temperature in a small neighborhood of the gas infrared sources

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Abstract. The results of the experiments carried out are the logical justification for the development of the heat transfer models in the air-filled enclosed areas which are determined by the walls of finite thickness and under conditions of the gas infrared sources operation. It was found that the air convection processes play an important role in formation of the thermal regimes of the areas heated by the radioactive flux coming from the upper boundary of such areas despite the low thermal conductivity of the gas.

1. Introduction

Gas infrared sources (GIS) have become increasingly promising sources of energy in the local heating systems of production facilities [1]. However, their broad utility is constrained by the fact that to date there has not been developed any model of heat transfer processes in the areas with heat supplied through the GIS operation. The latter is mainly caused by the lack of experimental data on the thermal fields in the location of exposure of such sources. Though, it still remains to be one of the core issues about the energy transfer mechanism inflight at the GIS operation.

On a provisional basis, the heat transfer area in the GIS neighborhood can be divided into three zones: the major (or working) one, in which maintaining of the air temperature is the purpose of the source operation; a zone of the GIS energy accumulation and subsequent air heating; a small neighborhood of the working sources, in which the ambient temperature may be higher than maximum allowable. So far no reliable experimental data have been published on the thermal fields of each of these zones.

The objective of the present paper is the experimental study of the regularities of the thermal temperature fields formation in a relatively small (with characteristic dimensions up to 1,5 m) neighborhood of the gas infrared source and justification of the physical heat transfer model in the GIS-heated area.

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Table 1. Results of the temperature measurements.

Distance from the radiating surface, x, m	Temperature, °C									
	Experiment #									
	1	2	3	4	5	6	7	8	9	10
0,10	354	364	369	355	357	340	349	352	358	352
0,20	305	322	320	334	345	315	322	315	305	317
0,40	280	269	255	257	240	252	240	250	257	250
0,60	200	217	215	229	240	210	217	210	200	212
0,80	214	203	191	193	175	187	175	185	192	185
1,00	152	170	168	170	172	162	170	162	152	172
1,25	147	145	143	145	127	147	127	137	145	137
1,50	98	114	113	114	115	110	114	107	100	115

Table 2. Average temperature.

x, m	100	200	400	600	800	1000	1250	1500
t, °C	355	320	255	215	190	165	140	110

2. Results and discussion

Experimental studies were performed on the large-size (with characteristic dimensions over $10\,m$) models of the heat supply facilities with the vertical and horizontal walls of a finite thickness (external envelope) under low temperatures (from $-10\,°\mathrm{C}$ to $-30\,°\mathrm{C}$) in the exogenous environment. The ambient temperature was measured at eight points in the length of $1,5$ m over the GIS radiating surface (Table 1). To ensure the reliability of the measurement results, the experiments were 10 times repeated under identical conditions (Table 1). The measurements were done under a steady-state distribution of the temperatures in the measuring range.

Correlation rate $r = -0,971$ is calculated by average temperature (Table 2).

The methods of linear regression analysis were applied to determine the type of function $t(x)$. Correlation field (Fig. 1) proves that this function is almost to be linear:

$$t = b_0 + b_1 x,$$

where b_1 – coefficient of regression.

To calculate the coefficients b_0, b_1 there has been used the least squares method – the sum of squared deviations of the measured (empirical) values t_3 from their calculated (theoretical) values t_p was minimal, i.e.,

$$\Sigma_{i=1}^{n}(t_3 - t_p)^2 \to min,$$

where t_p – value, calculated by equation of regression. The regression analysis allowed the point estimations of the equation of regression coefficients. The equation of regression is as follows:

$$t = 341,21 - 0,167x. \tag{1}$$

There was checked one of the Gauss–Markov clauses – an expectation value of deviation to be zero for all observations (Table 3), (on the average the random deviations have no effect on the dependent variables):

Determination coefficient of the derived model is equal to $R^2 = 0,943$.

At the next stage of processing of the experimental results the possibility was tested to present the equation of regression as a nonlinear function (polynom of the 2$^{\mathrm{nd}}$ degree).

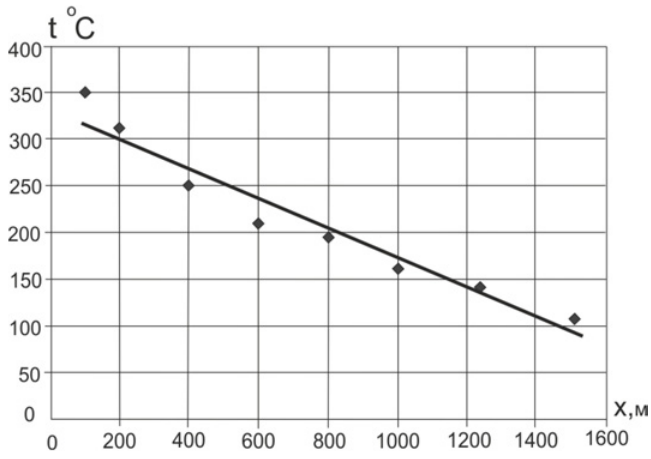

Figure 1. Temperature distribution in the coordinates x.

Table 3.

x, mm	*t*, °C	*t**, °C	ε
1	2	3	4
100	355	324,4671	30,53287
200	320	307,7199	12,28014
400	255	274,2253	−19,2253
600	215	240,7308	−25,7308
800	190	207,2363	−17,2363
1000	165	173,7417	−8,74172
1250	140	131,8735	8,126455
1500	110	90,00537	19,99463

The equation of nonlinear regression is specified as follows:

$$t = b_0 + b_1 x + b_2 x^2 + \varepsilon.$$

Upon its linearization the equation of multiple regression is derived as:

$$t = b_0 + b_1 z_1 + b_2 z_2,$$

where

$$z_1 = x; \;\; z_2 = x^2.$$

The coefficients of this equation were estimated by the least squares method. The result is a nonlinear expression as follows:

$$t = 377,89 - 0,314.x + 0,00009.x^2. \tag{2}$$

The deviations were calculated between the experimental values t and the values t^*, derived from the formula (1). It was determined that the cumulative error was small (Table 4):

The determination coefficient ($R^2 = 0,9909$) in this case proved to be higher than in the linear model. It is determined that all coefficients are statistically significant at the significance level of 0,05.

Both models have a small cumulative error of the deviations, but a nonlinear regression model is preferred.

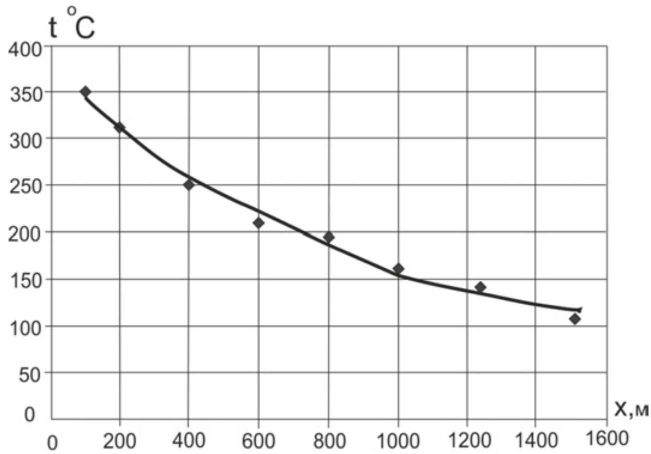

Figure 2. Temperature distribution in the coordinates x.

Table 4. Temperature values calculated by the formula (1)

x, mm	*t*, °C	*t**, °C	ε
1	2	3	4
0,10	355	347,3768	7,623247941
0,20	320	318,741	1,259018303
0,40	255	267,1217	−12,12173758
0,60	215	223,0389	−8,038888926
0,80	190	186,4924	3,507564255
1,00	165	157,4824	7,517621966
1,25	140	131,8179	8,182137975
1,50	110	117,929	−7,928963938
Cumulative error			−2,55795E-13

Based on the obtained results the conclusion can be made that the ambient temperature varies from a maximum value of 335^0 C (x = 0, 1 m) down to 110^0 C (x = 1, 5 m) in the relatively small range (about 1,5 m) in the neighborhood of the radiating surface of the gas infrared sources. Such high temperatures can be caused only by intensive air heating due to thermal conductivity. The experiments were conducted in the environment of dust-free air (which can absorb and dissipate the radiation energy). Therefore, the temperature increase in this area can not be due to the direct effect of radioactive flux.

The obtained experimental data are the rationale to conclude the necessity of allowance for the conductive heat transfer processes at the analysis of thermal fields in the area of heating by gas infrared sources.

3. Conclusions

The results of the performed experimental studies are the rationale for the development of the heat transfer models in the air-filled enclosed areas which are -defined by the walls of finite thickness, and under conditions of the gas infrared sources operation. It was determined that the air convection processes, despite the low thermal conductivity of the gas, play an important role in formation of the thermal regimes of the areas heated by the radioactive flux coming from the upper boundary of such areas.