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The criteria of estimating risks of spreading fire to adjacent building facilities

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Abstract. The choice of heat flux receiver is justified in order to investigate the danger of spreading fire to adjacent building objects by the criterion of heat flux for measuring the heat flux density. It is suggested to use the heat flow receiver FOA-013-01. A technique was developed and experimental studies were conducted to determine the heat flux density acting on the elements of adjacent building sites. Measurements of heat flux values were performed by FOA 013-01 heat detectors, which were installed at distances of 2 m, 4 m and 6 m from the fire torch at a height of 1 m. The obtained heat flux density is, on average, for a distance of 2 m - 6.5 kW/m^2, for distances of 4 m and 6 m - 1 kW/m^2. Such data indicate a significant variability in the heat flux density over the observation period. Thus, experimental data call into question the possibility of using the “heat flux” criterion from a fire as a reliable criterion for evaluating the risk of fire spreading between adjacent building facilities. It has been suggested that the temperature criterion should be the basis for determining fire distance.

1. Introduction

Active progress of the construction technologies leads to dense development of settlements especially cities populated by millions of people. Therefore, the density of development is increasing, and when designing new facilities next to the built ones there is a need for rational use of the territories. But provision of safe fire separation distances is likely to be the most significant issue. Available approaches to the solution of this problem are somewhat outdated and generally anticipate use of tables containing prescribed values. Due to this necessity arises in the application of calculation methods when determining fire separation distances which provide possibility of taking into consideration specific features of the region, facility, fire load etc.

At the same time, development of full-value calculation method for the determination of fire separation distances between building facilities requires substantiation of the principal criterion by which their determination becomes purposeful.

2. Analysis of the studies and publications

Analysis of the available calculation methods for the determination of fire separation distances between building facilities showed unavailability of the unite approach to use of any criteria by which one could determine such distances. Criteria of heat flux underlie the method of substantiation of fire separation distances between building facilities in paper [1]. Principal drawback of such the approach is that there is no statistical database at present containing maximum allowable values by heat flux for substances and materials. Paper [2] contains procedure of calculation of heat irradiation during fires involving tank farms when oil products burn; temperature criterion was used. In [3], temperature criterion was used, too, when studying heat transfer processes. But they did not study issues related to estimation of risks of fire propagation between the fireplace and adjacent facilities in the mentioned papers.

Thus, we use “heat flux density” or “temperature” as principal criterion when studying heat transfer processes. Therefore, necessity arises in the conduction of appropriate studies for the substantiation of choice of proper criterion of estimation of fire propagation to the adjacent building facility by carrying out experimental studies of the heat flux variability in the course of time while fire affects adjacent facilities.

Measuring of heat flux density is fulfilled by various instruments and methods. One of the methods of measuring of heat flux density [4] is use of a receiver equipped with heat-sensitive elements; it should be noted that when measuring high heat fluxes receptor surface of the receiver is covered with reflective layer. The comparative calorimetry method is also noteworthy [5]; at that measuring of the energy brightness of the source by the intensity of thermal radiation (heat flux) in the infrared range is performed. Essentially, the heat fluxes generated by absorbed beam power and precisely known electric power are compared. The most widespread receiver functioning by such the principle is “Radiometer of heat radiation of “IK-metr”. In general, heat flux density can be measured using different approaches such as those described in [6] using thermographic luminescent materials. The optical method was used in [7] when measuring heat flux density. Basically, measurement of heat flux density is carried out by Schmidt-Boelter or Gardon receivers since they measure heat flux of radiation and convection with the cooling surface as indicated in [8].

3. Formulation of the purpose of the study and contribution of the principal material

The purpose of the work is to provide justification for the choice of heat flux receiver and to study based on it effect of the heat flux on the elements of the adjacent building facilities as basis for the criterion to characterize risk of fire propagation to the adjacent building facilities. To achieve this goal it is necessary to solve the following problems:

– to conduct substantiation of choice of heat flux receiver for the fulfilment of the experimental studies;

– to develop appropriate procedure and to conduct proper experimental studies for the determination of the density of the heat flux affecting elements of the adjacent facilities; and

– to substantiate choice of the criterion to characterize hazard of fire propagation to the elements of adjacent building facilities.

Use of FOA 013-01 heat flux receiver in order to study hazard of fire propagation to the adjacent facilities by heat flux criterion in order to measure heat flux density was proposed.

FOA 013-01 heat flux receiver is intended for one-time measuring of total heat flux density measuring.

Principle of functioning of the receiver lays in the measuring difference of the temperatures arising between the centre and the side of thin constantan disk (1) fastened to the heat radiator made of copper (2) while heat flux affects. Difference of the temperatures is measured with a differential thermocouple formed by central and side copper thermal electrodes (3). Schematic circuit of functioning of FOA 013-01 heat flux receiver is shown on Figure 1.

Construction layout of FOA 013-01 heat flux receiver is shown on Figure 2.

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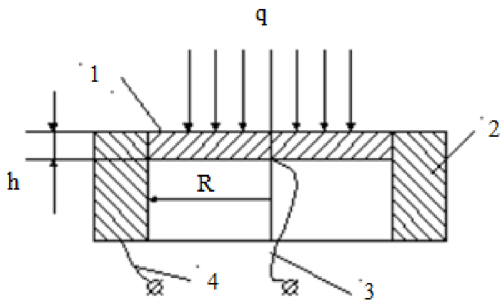
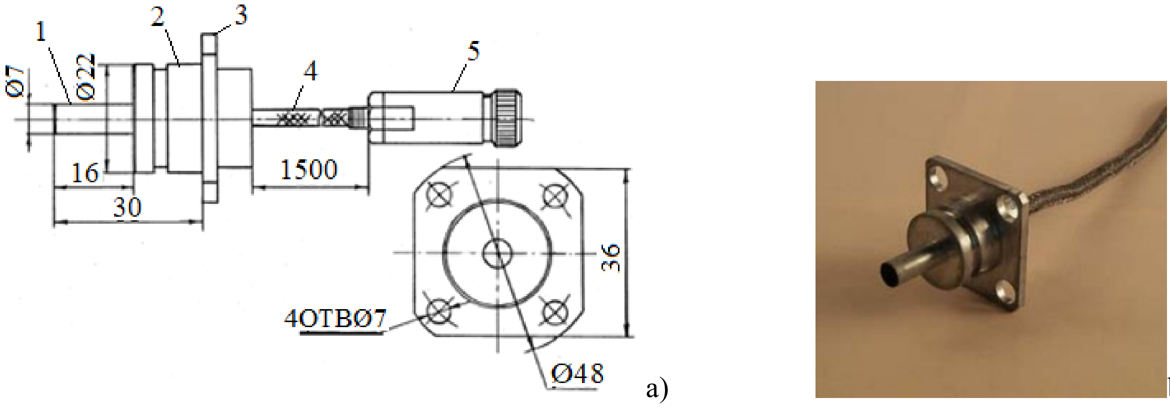


Figure 1. Schematic circuit of functioning of FOA 013-01 heat flux receiver:
1 – periphery of thin constantan disk (PTCD); 2 – heat radiator; 3, 4 – central and side thermal electrodes; h, R – thickness and width of constantan disk; q – actual heat flux.



a) b)

Figure 2. Schematic graphical representation of FOA 013-01 receiver (a): 1 – constantan disk, 2 – receiver housing, 3 – cooling jacket, 4 – wire, 5 – connection socket; (b) photo of FOA 013-01 heat flux receiver.

Performance characteristics of FOA 013-01 receiver are submitted in Table 1.

Table 1. Performance characteristics of FOA 013-01 receiver.

No.	Parameter	FOA 013-01
1	Measuring range of heat flux density, kW/m2	0 0 to 630
2	Overall dimensions, mm	36×36×30
3	Receiver weight, kg	<0.350

Density of total heat flux being measured with FOA 013-01 heat flux receiver [9] is calculated using the following formula:

$$q = E/k \cdot 10^3 \quad (1)$$

where q is heat flux density, kW/m^2 ;
E is output signal of the heat flux receiver, mV;
k is sensitivity of the heat flux receiver, mcV·m^2/kW.

Appropriate experimental studies were conducted in order to determine sensitivity of FOA 013-01 heat flux receiver. Essence of the study laid in that three FOA 013-01 heat flux receivers were affected by flux of prescribed values equal to 20 kW/m^2 and 40 kW/m^2. Procedure of measuring with each receiver was conducted three times (Figure 3).

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Figure 3. Procedure of FOA 013-01 calibration using radiation panel.

Results of the experimental studies are submitted in Table 2.

Table 2. Characteristics of heat flux derived with FOA 013-01 receiver.

No.	Heat flux value, kW/m^2	Indications of FOA 013-01 No. 1, mV, $(kW/m^2)^a$	Indications of FOA 013-01 No. 2, mV, $(kW/m^2)^a$	Indications of FOA 013-01 No. 3, mV, $(kW/m^2)^a$
1	20	90.01 (14.90)	120.36 (19.92)	148.91 (24.65)
2	40	198.02 (32.78)	246.84 (40.86)	289.01 (47.84)

[a] **Note**. Values in kW/m^2 are submitted based on the derived value of the sensitivity factor k=6.04 mcV·m^2/kW and formula (1)

Based on the data of the receivers' indications in mV obtained we derived sensitivity factor. In order to realize this we determined average values of voltage at 3 heat flux receivers for heat flux densities equal to 20 kW/m^2 and 40 kW/m^2. The values derived were divided by values of heat flux densities equal to 20 kW/m^2 and 40 kW/m^2 and mean value of the calculated figure was accepted. In this way we derived sensitivity factor which was equal to k=6.04 mcV·m^2/kW based on the studies having been conducted.

The results derived were compared with the results derived when using RAP 12.M.2 heat flux meter that was metrologically attested [10]. Indications of heat flux density determined with RAP 12.M.2 receiver are submitted in Table 3.

Table 3. Characteristics of heat flux derived with RAP 12.M.2 receiver.

No.	Heat flux value, kW/m^2	Indications of RAP 12.M.2 No. 1, kW/m^2	Indications of RAP 12.M.2 No. 2, kW/m^2	Indications of RAP 12.M.2 No. 3, kW/m^2
1	20	16.49	19.34	20.96
2	40	35.01	39.98	40.87

Evaluation of the results derived using FOA 013-01 and RAP 12M heat flux receivers was conducted as specified by Guidelines [11].

Check-up of belonging of the dispersions derived when conducting measurements with the receivers to single general population was fulfilled. Null hypothesis was put forward and Fisher factor was calculated in order to estimate dispersions.

This check-up showed that root-mean-square deviation was equal to 7.53 % for FOA 013-01 receiver and to 3.15 % for RAP 12.M.2 receiver, and Fisher criterion at that was equal to 5.7 which does not exceed appropriate tabular value. Difference between the indications of the receivers was within 8 %. Thus, the data derived using heat flux meters belong to single general population. This provides bases for use of FOA 013-01 heat flux receiver for the conduction of measurements of heat flux density while performing experimental studies.

We used 55B as test fire in order to create flames induced by fire while performing studies; the former was metal tray (1480 ± 15) mm in diameter; height of its wall was (150 ± 15) mm and depth of the wall was (2.5 ± 0.5) mm; 18 l of water and 37 l of diesel fuel were poured into it. Measuring of heat flux density was carried out with FOA 013-01 heat flux receivers installed at the distances of 2 m, 4 m and 6 m from the flames. The heat flux receivers were installed at a height of 1 m. Arrangement of the test fire and heat flux receivers is shown on Figure 4.

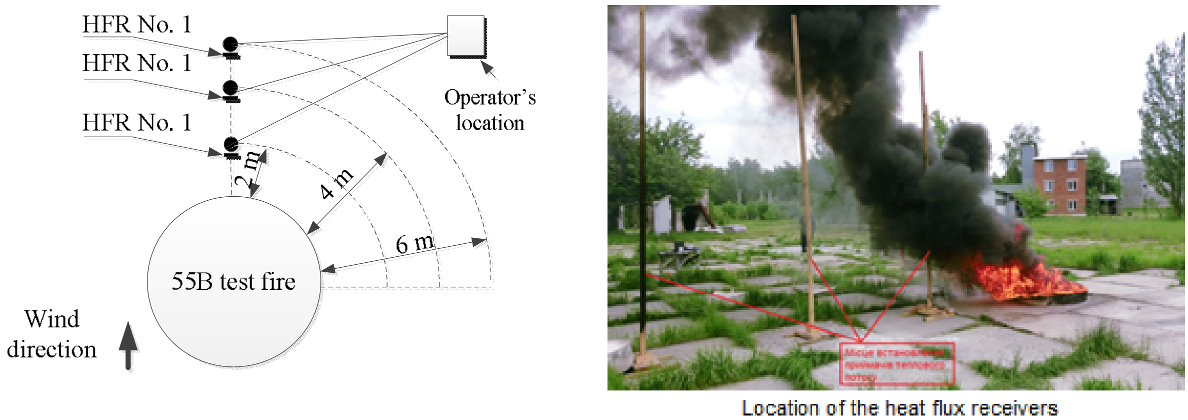

Figure 4. Arrangement of the test fire and heat flux receivers.

The studies were conducted three times with 10-minutes exposure to the test fire. Using results of the three experiments having been conducted we derived some data as to fluctuation of heat flux density depending on their separation distance from the burning site and duration of heat exposure. Average data of the experiments are shown on Figure 5.

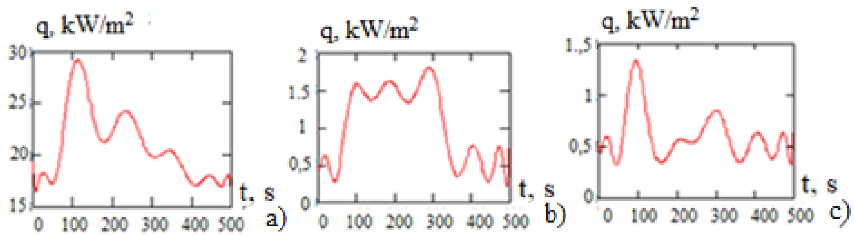

Figure 5. Data on heat flux density vs. duration of fire exposure for the following distances: a) 2 m from the test fire; b) 4 m from the test fire; c) 6 m from the test fire.

It was revealed from the experimental data that average fluctuation of the heat flux density was 6.5 kW/m^2 for the distance equal to 2 m, but for distances of 4 m and 6 m it was equal to 1 kW/m^2 which is a third part of the average absolute heat flux density magnitude. Such data give evidence on significant variability of the heat flux density in the course of the observation period. Thus, data of the experimental studies question possibility of use of the heat flux density caused by fire as reliable criterion for the estimation of hazard of fire propagation between adjacent building facilities.

Heat flux is not a direct figure that can be associated with the causes of fire propagation and involving adjacent building facilities by it. In turn parameters to affect determination of fire separation distances, in particular, such ones as fire load, coefficient of orifices in the external envelopes and duration of irradiation are expressed through the temperature criterion, but ignition temperature of substances and materials should be taken as comparison criterion. This is due to the fact that causes of fire propagation and involving of adjacent building facilities by it are heating-up of combustible constructions of the buildings to temperatures causing their ignition; these are in fact direct figures which can be criteria of estimation of hazard of fire propagation between the adjacent building facilities.

4. Conclusion

The following was determined in the course of the studies conducted:

1. Choice of heat flux receiver for measuring heat flux density was substantiated: such the one can be FOA 013-01 device; its sensitivity factor was derived.
2. It was revealed that it was not expedient to use heat flux density as principal criterion of estimation of hazard of fire propagation to adjacent building facilities because of the fact that fluctuation of heat flux with time could not be compared with fire hazard performance of the materials used in the adjacent building being irradiated by fire.
3. An approach was proposed for the criteria of hazard of fire propagation to adjacent facilities; at that ignition temperature of the materials of the adjacent building affected by heat radiation from the flames induced by fire shall be used in order to observe condition of direct indication of possible fire occurrence in the adjacent building.

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