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Editor-in-Chief Prof. Leszek A. Dobrzański

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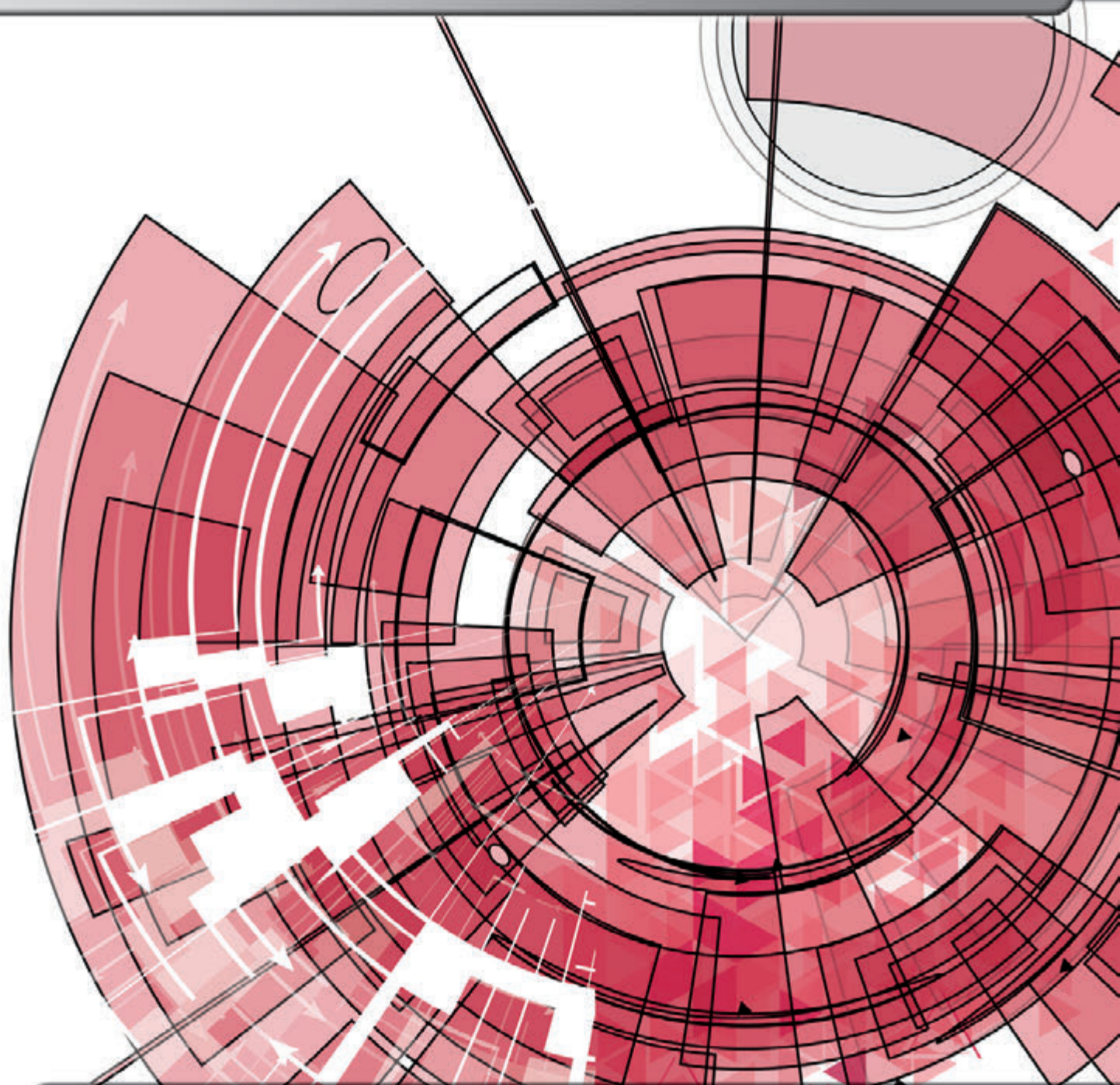
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Physical modelling of changes in the energy impact on a worker taking into account high-temperature radiation

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ABSTRACT

Purpose: The purpose of this investigation is development of an experimental installation and definition the intensity of thermal irradiation at workplaces to ensure safety under condition of increased thermal radiation. This purpose is justified as follows. Human health and well-being depend to a large extent on conditions of the internal environment of the premises, which affect the heat exchange of workers with the surrounding surfaces. With this the spectral composition and intensity of irradiation are also important for assessing the effect of thermal radiation.

Design/methodology/approach: The investigation was carried out using special experimental device. Uniformly lit semitransparent screen was used as a source of thermal radiation source. We used photo film with heat flow sensor ДТТ 02 – ДТТ 03 developed by Institute of Engineering Thermophysics under Academy of Science of Ukraine as model of the elementary surface of human body.

Findings: Based on results of conducted research and optimization, we propose protective compositors that are nonflammable. This fact allows the increase in safety of facilities during operation and evacuation routes in emergency case due to high-temperature effects.

Research limitations/implications: In this study, was focused on the dependence of the local angular coefficient of irradiation and maximum thermal loads, as well as the transition from indirect measurements to direct ones. This allows us to predict working conditions by the thermal factor in the workplace.

Practical implications: The results of this study can be recommended to the Ministry of Health and the Ministry of Industry for the development to reduce the incidence of occupational morbidity among workers who work under conditions of exposure of thermal radiation.

Originality/value: It was disclosed that it is possible to determine the distance to the source of thermal radiation from the point of measurement and the angle at which the source of thermal radiation is visible with high accuracy. Moreover, measurement point may be located at a distance safe for the researcher.

Keywords: Excessive heat of radiation, Workplace safety, Worker protection

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MANUFACTURING AND PROCESSING

1. Introduction

As of 2017, more than 3 million people work in hazardous conditions [1-4], more than 800 thousand machines, mechanisms and equipment that do not meet the requirements of labour safety regulations (about 80% of the total number) are in operation [5,6]. According to data from the Ministry of Health and the International Labour Organization, mortality from injury and occupational diseases in the world takes the third place after cardiovascular and oncological diseases. Today, issues that relate to maintenance of the safety of production process, equipment and facilities remain unresolved in many countries, including Ukraine. Working conditions at facilities that emit or use heat sources [7,8] is still need research and improvement [9].

Human health and well-being depend to a large extent on conditions of the internal environment of the premises, which affect the heat exchange of workers with the surrounding surfaces. These conditions are determined by a combination of temperature, relative humidity, air velocity, the temperature of the surfaces surrounding the person, and the intensity of thermal (infrared) irradiation.

The spectral composition and intensity of irradiation are also important for assessing the effect of thermal radiation. Due to the fact that thermal radiation intensity is characterized by unevenness in space, it should be assessed separately for each point. The irradiance value of the elementary body surface depends on its orientation in space relative to the source of thermal radiation. This value has a vector character and is multivalued at each point of space. To obtain a visual picture of the mutual influence of the radiant energy component from all surfaces faced to human, it is necessary to choose a model that could be used in physical modelling.

Methods for determination the intensity of thermal radiation on nomographs and formulas proposed by a number of authors in some scientific works give a large error [10-12]. A significant error is due to the adoption of a

number of assumptions of many variables, closely related to each other. These include the temperature of the furnace inner surface, size of windows in furnaces and wells, etc. [9]. Moreover, it is a need to determine the intensity of thermal irradiation at distances of 1-2 m, etc. [6].

For effective research is necessary development of an experimental installation that allows measurement of thermal radiation at workplaces. Therefore the purpose of this investigation is development of an experimental installation and definition the intensity of thermal irradiation at workplaces to ensure safety under condition of increased thermal radiation.

2. Materials and methods of investigations

To solve the problems of thermal protection at workplaces, actual data of measurement of thermal radiation at all workplaces are required. For example, when remelting basalt in electric furnaces, the basalt turns from solid monolithic state into a melt state that resembles melted lava. Melting temperature of basalt rocks is about 1500°C. (Fig. 1.)



Fig. 1. The workplace of the worker during the melting of basalt rocks

It is unsafe to conduct such studies at the distance of 1.5-2 m from open window of the electric furnace. This also results in reduction of data reliability because of the decrease in the efficiency of measurements in extreme conditions of work. Figures 2 and 3 show the diagram of irradiation at workplaces during thermal processes: a) basalt melting; b) loading of glass furnace; c) lime burning; d) stone casting in the integral range on the arc of 360° through 45° [5,6,9].

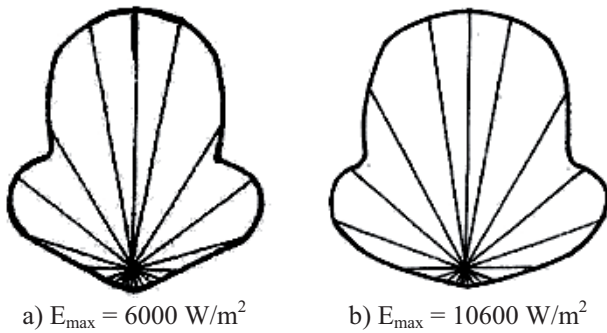


Fig. 2. Diagrams of thermal irradiation at workplace during basalt melting and loading of a glass furnace

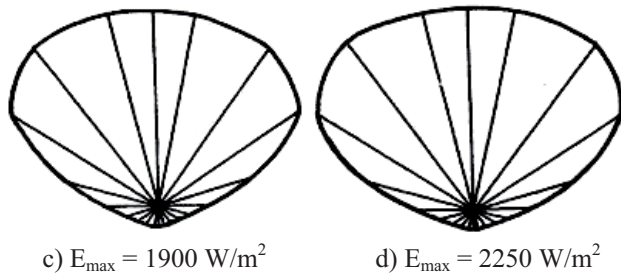


Fig. 3. Diagrams of thermal irradiation at workplaces of lime burning and stone casting

To determine the intensity of heat flux irradiation, it is necessary to perform a significant number of intermediate calculations or use several graphs or nomographs, which makes these calculations labour-intensive and not convenient for practical use [9].

Figure 4 shows calculations and experimental data of zonal distribution of energy of thermal furnaces.

Was made an attempt to summarize the results of research carried out in this field in order to improve working condition, significantly reduce the number of variables and ensure more efficient use of existing instruments when carrying out measurements [9].

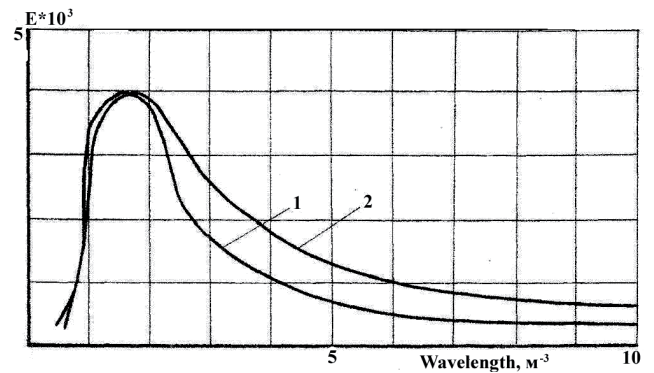


Fig. 4. Experimental and calculated data of zonal distribution of radiation energy of basalt melting furnace with open windows: 1 – estimated data; 2 – experimental data; E – emission spectral intensity, W/m^2

3. Results of investigation and discussion

Based on our theoretical studies of thermo-radiation intensity at workplaces, it was disclosed that it is possible to determine the distance to the source of thermal radiation from the point of measurement and the angle at which the source of thermal radiation is visible with high accuracy. Moreover, measurement point may be located at a distance safe for the researcher. Was considered this fact during development of an experimental measuring equipment for our study of thermal radiation at workplaces [5,6].

Was decided to use light simulations in the assessment of thermal irradiance in the workplace. Since optical and energy illuminations change under the same laws, uniformly lit semitransparent screen was used as a source of thermal radiation source. Additionally was used photosensitive film with heat flow sensor ДТТ 02 – ДТТ 03 developed by Institute of Engineering Thermo-physics under Academy of Science of Ukraine as model of the elementary surface of human body. In our study, we focused on the dependence of the local angular coefficient of irradiation and maximum thermal loads, as well as the transition from indirect measurements to direct ones. This allows us to predict working conditions by the thermal factor in the workplace. At the same time, the method allows simulating and showing the results of the research for sources with complex geometry of the radiation surface in the form of radiation fields that are maximally close to real ones in order to provide designers at the stage of designing technological aggregates and technologies with a universal methodological guide [7,10].

The ratio of viewing point (visibility of radiation sources) ϕ_1/ϕ_2 has a physical meaning, i.e. the ratio of the

density of the thermal radiation flux at this and the design point of space, which allows solving the problem of prediction of thermal radiation on the surface of the object that is exposed to radiation and has several advantages in carrying out measurements.

The experimental task of determining the relative thermal coefficient of irradiation in the physical arc coincides with the physical task of simulation, for which the ratio of values at arbitrary points of space with the subsequent transition to the desired units through fixed

point is determined. In our case, screen illumination point and object of illumination may be used as fixed point.

Measurements were made on the light simulating equipment developed by us (Fig. 5). The measurement process can be divided into the following steps:

- Preparation of measuring equipment for study;
- Simulation of thermal radiation phenomenon in accordance with the principles of physical similarity;
- Measurements and conversion of measured values into graphic images.

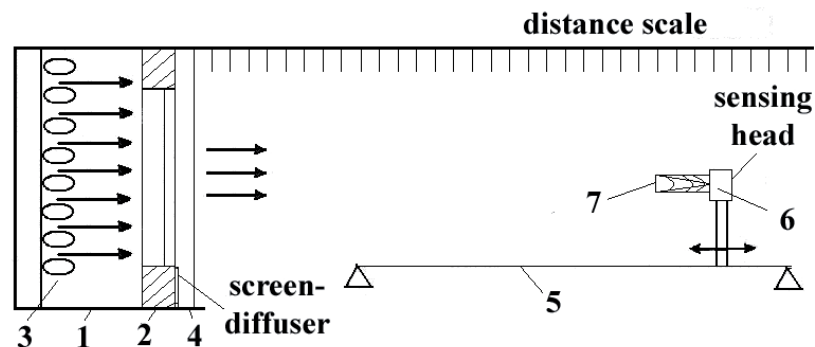


Fig. 5. Principal diagram of the research equipment for physical simulation of irradiance: 1 – light camera; 2 – semi-transparent screen; 3 – matrix of ultra-bright LEDs; 4 – moving curtains; 5 – optical face; 6 – sensing head; 7 – light shield

It is necessary to consider that fact that the light simulation on the developed methodology includes two experimental tasks: simulation of natural phenomenon and measurement. Each of these tasks forms its own errors, total number of which determines method error.

The analysis of errors allows disclosure and consideration of systematic components related to the similarity of the light model and the angular orientation of the sensor, i.e. sensing head for background illumination. The average quadratic error due to these sources is no more than 6-8% for the whole space, not more than 72° for angular orientation and not more than 19% for angular orientation within the range of 72°-86°. Measurements within angles 86-90° are irrelevant due to high error [9].

The definition of φ_1/φ_2 from the physical point of view can only be made correctly for model screen that shines uniformly since φ is determined for isothermal heat exchange fields. However, the measurement results can be used with sufficient accuracy for engineering calculations to a fairly wide class of unevenly heated surfaces.

This class covers surfaces that can be divided into approximately equal areas, point temperature difference, not exceeding 20°C; the average temperatures of the neighbouring sites do not differ by more than 20°C; during

the transition from one site to the neighbouring one, the temperature may change unevenly.

In this case, density of measured flow is determined through the value φ_1/φ_2 for the elementary surface placed at a given point, from the entire radiating surface by means of light simulation.

Systematization and selection of the main forms and sizes as well as location of workplaces near them were based typical sizes (taking into account fixed jobs). We considered horizontal distribution of thermal fields and the vertical component was assumed to be equal to 2 m considering the location of workplaces due to absence of higher elevation points of process equipment that is able to distort thermal fields by reflection effect. The height of the industrial buildings and structures under consideration was assumed to be equal to $h = 10-14$ m.

As to premises with sources of mobile infrared radiation with a limited volume and the availability of additional equipment and structures, it is necessary to take into account the reflection of thermal energy and its redistribution in the workplace. Thus, it is necessary to use differentiated approach, which is considered by our methodology in physical simulation and the integration assessment of the picture of thermo-radiation load in workshop space.

At the next stage of research, it became necessary to establish the pattern of change in φ_1/φ_2 ratio depending on irradiation by means of mathematical analysis.

Light simulating equipment (Fig. 5) consists of a light camera (1); semitransparent screen (2); matrix ultra-bright LEDs (3).

The maximum size of semitransparent screen is 300 x 340 mm. Movable curtains (4) allow reduction in size of illuminating window up to 20 x 20 mm. Due to use of special opaque masks, it is possible to get a model of the radiating surface of a complex shape.

700 ultra-bright diodes that ensure brightness of 10-15 candelas are powered by a 4.5 volt source, which can be adjusted from 2.0 to 4.5 V. Consumed voltage is 35-40 A at maximum brightness.

The light camera is located on an optical face (5), which has distance scale and sensing head (6) which can move along rails. Figure 6 gives general view of the experimental equipment.

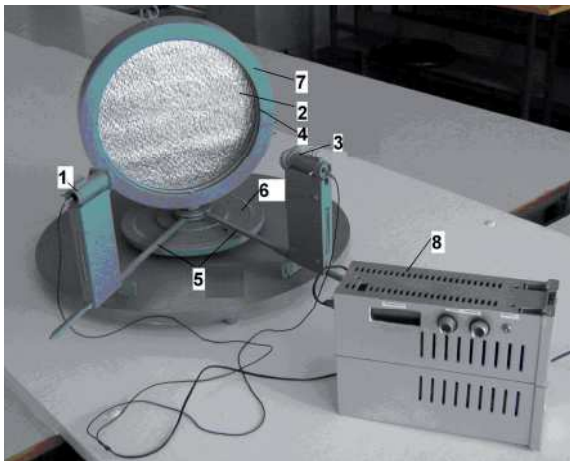


Fig. 6. General view of experimental equipment for the physical simulation of the thermal irradiation: 1 – infrared emitter; 2 – semitransparent screen; 3 – photodetector; 4 – rotary ring with graduation marks; 5 – bars; 6 – ring with a degree scale; 7 – matrix of LEDs; 8 – analog-digital registration unit

The examination of workplaces and measurements of thermal irradiance in a circular diagram or in a particular sector showed large measurement error due to backlighting, as well as the effect of illumination from other sources.

To reduce this effect, we used light shield [9] with mobile diaphragms since it was very often necessary to change head sight angle. Similar improvements are used in the special sensing head for measuring irradiation. In order to reduce interference from background illumination and

increase the accuracy of the measurement, we used reduced cross section of the spring in receiver, which made it equally tough along its entire length.

The device of the existing sensing head is shown in Figure 7 in the position of the maximum and minimum sight angle. The device consists of hollow body (1), flat cylinder spring (2), movable system (3) with installed receiver (4) – Fig. 7.

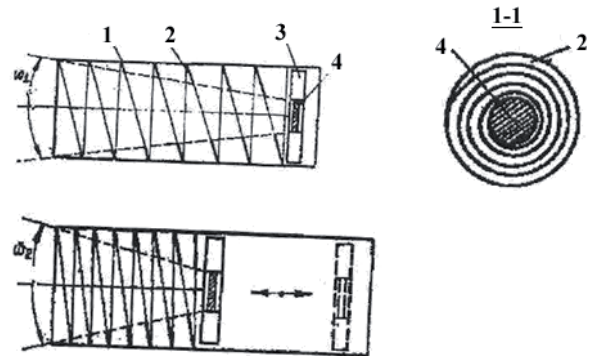


Fig. 7. Sensing head for measuring energy irradiation: 1 – body; 2 – movable diaphragm; 3 – floating block; 4 – receiver

The proposed design of sensing head for measuring radiant fluxes allows you to change the viewing angle from 50 to 140°, uses single casing and reduces the material capacity and adjustments by 10-15 times due to the fact that the distances between the coils of the spring (diaphragms) will be optimal.

Operation principle of the device is described below.

In position 1, sensing head has a minimum permissible sight angle φ_1 . To increase sight angle, the moving system 3 with the receiver 4 moves along the hollow body of the head 1, compressing coils of flat cylinder spring. The distance between the coils of the spring (diaphragms) decreases, maintaining an even distance between the coils. This distance reduces with the increase of sight angle φ_2 .

This device allows you to improve the accuracy of measurements in the devices. The measurement error does not exceed 3-4 %.

Although all positive results of measurements, we disclosed significant error in repeated measurements of high-intensity heat fluxes. During multiple measurements with small intervals between measurements, the frame of sensing head is heated up due to heating of movable diaphragms and becomes the secondary source of radiation. The authors have introduced certain improves in design of sensing head, which has a technical novelty and is declared as an invention. This improvement allowed significant

reduction in temperature of the body of sensing head and its maintenance at environment level (Fig. 8). This improvement was expressed in creation of special openings in the case, which has improved heat transfer conditions from excessive heating of the casing (Fig. 9).

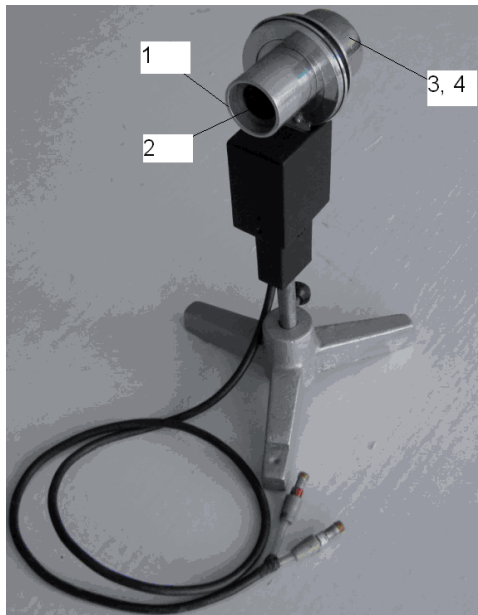


Fig. 8. General view of the improved sensing head: 1 – body; 2 – mobile movable diaphragm; 3 and 4 – mobile movable system with receiver

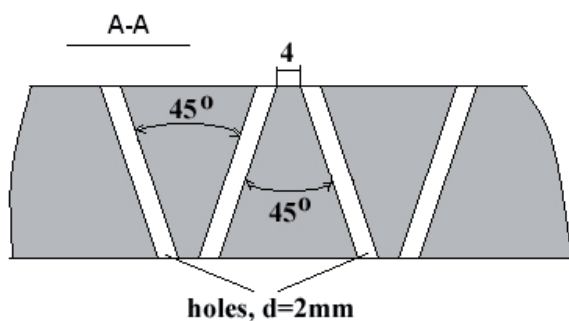


Fig. 9. Improved sensing head

The holes are located throughout the length of the body at the angle of 45° relative to each other, which ensures optimal conditions for cooling the case to the ambient temperature and most efficient receipt of incoming direct measured radiation.

This improvement allowed the authors to increase the accuracy and reliability of measurements of thermal radiation at the workplace.

4. Conclusions

Based on results of conducted research and optimization, we propose protective compositors that are nonflammable. This fact allows the increase in safety of facilities during operation and evacuation routes in emergency case due to high-temperature effects.

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