Jan Giełżecki, Robert Marcin Wolański

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TECHNOLOGY RESEARCH OF TACTICAL PERSONAL PROTECTION CLOTHING BASED ON FIREFIGHTERS - RESCUERS

dr inż. Jan Giełżecki[1],
bryg. dr inż. Robert Marcin Wolański[2]
[1,2] Szkoła Aspirantów Państwowej Straży Pożarnej w Krakowie

ABSTRACT

The paper presents examples of protective clothing technology research in the context of maintaining an optimal level of safety of firefighters under the influence of the thermal environment. Attention was drawn to the essence of measurement parameters determining the effectiveness of protection. The article includes diagrams, photos and explanations of the methods covered by the copyright measurement technologies accomplished by a number of centers around the world. It has been shown the ability to evaluate the material and constructive personal protection adopted in developing safety technologies regardless of normative systems in force in different parts of the world.

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Security technologies, thermographic measurement, personal protection, aramid fabrics, special clothes.

INTRODUCTION

Today's activity field of virtually all uniformed formations is rich in complex of environmental risk factors model impacts. The importance of a sense of security and all operational abilities plays a key role in achieving any goals. Scientific and development achievements beginning of the XXI century allow only a partial recognition of the full danger in the present moment. This situation is promoted by uncontrollable and often unpredictable nature of the course of individual components of the event or purpose. Definitely destructive and to date relatively recognizable course of thermal phenomena in the fire environment allows one to research and analyze security solutions .

The previous discussion on reducing the impact of thermal processes on the body rescuer indicates the possibility of a broad and more comprehensive approach to the knowledge of the ability of the protection and the potential to improve their effectiveness. The model commonly adopted in many countries is considered as sufficient evaluation of materials or entire protective structures sets used if it fulfills standards. The results of the research conducted in the assessment of capability with standard show only the fulfillment of a sample of the defined conditions image. The knowledge of the behavior of materials and ready-made protective structures in situations deemed critical interactions, is not possible to be fully known.

The functioning of the model testing for wider knowledge is crucial in the development and modeling new construction.

Exploring extreme material parameters allows not only the creation of safe operating procedures but significantly managing of operational action.

The study focused on issues of direct action model of heat flux on the surface of the body officer protected by the set of protective clothing.

The basic model [6]

The basic model of heat conduction in firefighter protective clothing is used with assumptions:

– protective textiles are dry (e.g. no moisture from sweat),
– fabrics are treated by temperature below the thermal degradation (e.g. melting or charring).

A lot of firefighter burns occur even when there is no thermal degradation of protective clothing.

The flat geometry of the fabric layers of protective clothing lets assume one-dimensional heat flow (Fig. 1). Heat radiation is subjected to a fabric sample from both the front and the inner layer. The accuracy of the model is verified by comparing the time to obtain a certain temperature, both within and on the surface of typical fabric, with temperatures obtained experimentally – the fixing of the thermocouple measurement is shown in Fig. 1. The tests stands of the experimental research are shown in Figure 2. and 5., 6. The location of the thermocouple and its attachment are presented by Figure 3. and 4.The model well simulates the flow of heat especially in the interior of protective clothing, where the temperature difference between experiment and simulation is approx. 5 °C. Expected temperatures on the outer side of the garment differs most from the experimental values (approx. 24 °C). Presumably it takes place due to the lack of optical properties (transmission, reflection) of fabrics used in the model.

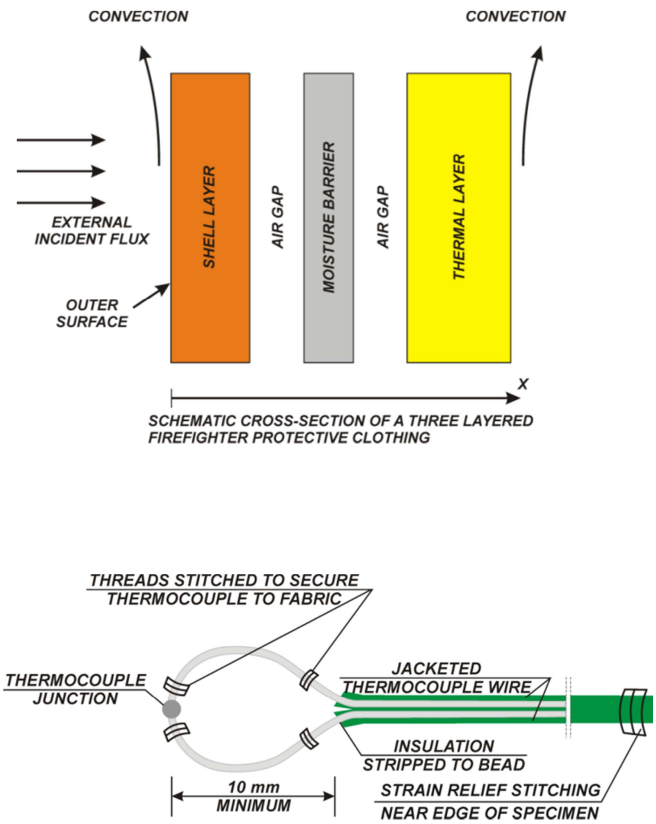


Fig. 1. The fixing of thermocouple to the fabric used for the construction of protective clothing [7, 8]

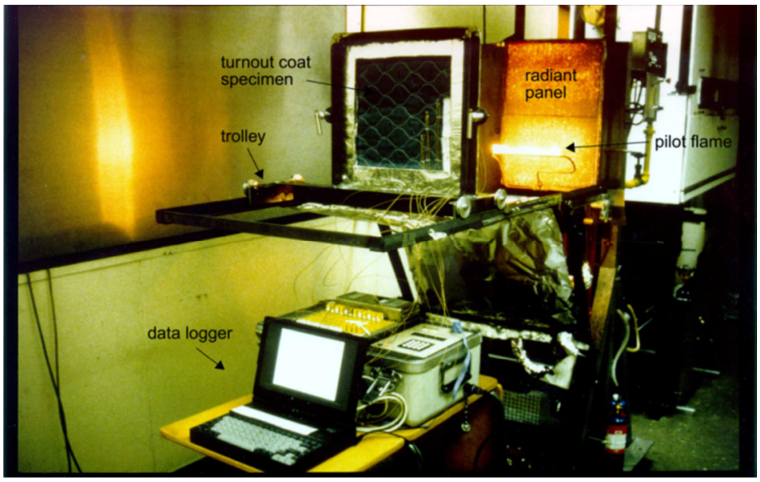


Fig. 2. The photography of measuring apparatus [2, 3, 6 ÷ 8]

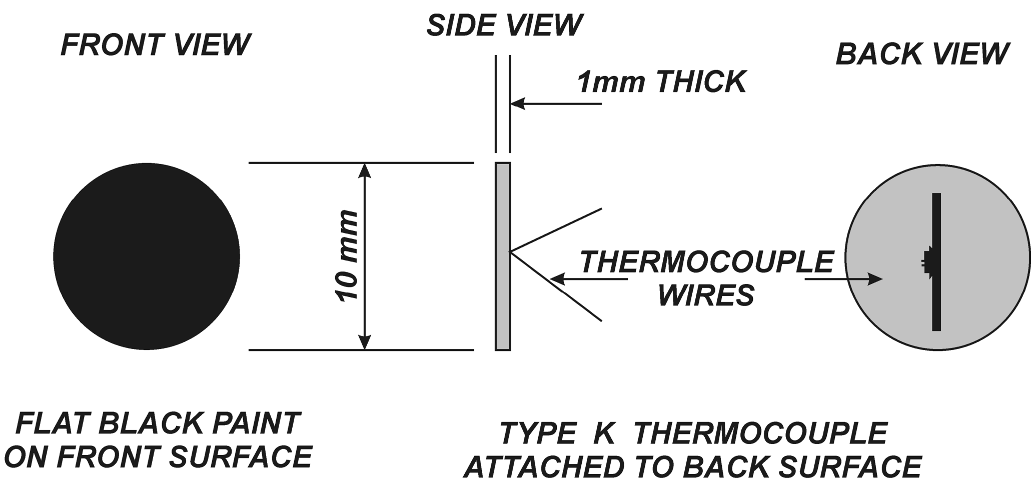


Fig. 3. The mounting of thermocouple to the measure of temperature of the mat [7]

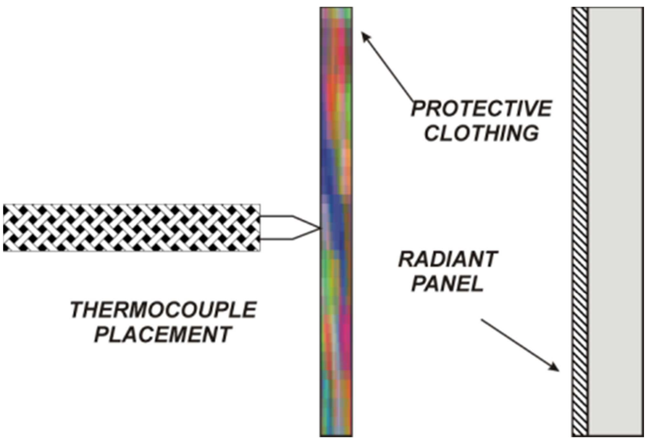


Fig. 4. The location of the thermocouple, the fiber and the radiator [7]

Fig. 5. Apparatus for testing the thermal conductivity - Rapid- k together with the computer system [9, 10]

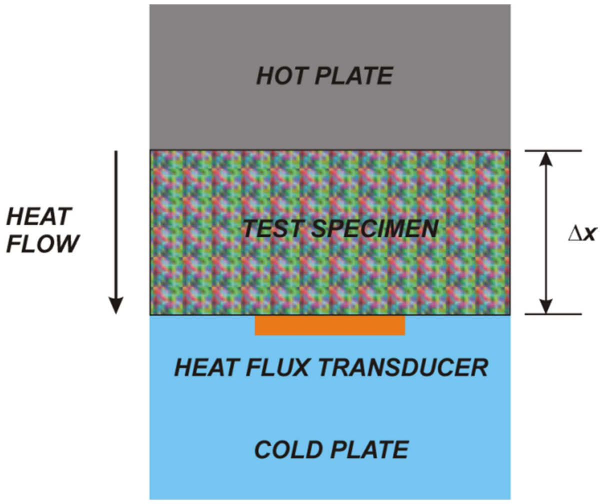


Fig. 6. The diagram shows the principle of the system Rapid - k [9, 10]

ADVANCED MODELS [11, 12]

During fires a firefighter is subjected to different thermal conditions such as: radiation, flame or contact with hot objects. The most common is being subjected to the exposure with low levels of heat radiation for a longer period of time. Firefighters working in these kind of conditions often sweat profusely which leads to accumulation of moisture in the material layers of clothing. Clothing can also become wet by contact with extinguishing water. The presence of moisture in the clothing can significantly alter its protective efficacy.

Wet clothes have higher heat transfer rate than dry ones. The evaporation and condensation of moisture and associated with this phenomenon's energy flow can affect on temperature changes at the skin surface. Firefighters body surface may get second degree burns while working in such conditions. Injuries can be the result of heating and evaporation of moisture in clothing. The development of the precise model of the mathematical testing of heat and moisture conduction trough multilayer fabrics with or without air layers between them may significantly affect the ability to reduce experimental studies. The flat geometry of the fabric layers of protective clothing (on experimental station) lets assume one-dimensional heat flow model.The model takes into account the thermodynamic changes of the textile and its properties due to the presence of moisture. In the numerical simulations of heat and mass transfer through wet thermal liners which were (used in firefighting protective clothing) treated with radiant heat flux results were comparable with those of the experimental measurements (using a radiant gas burner).

After heating up moisture in the fabric partially tends to re-condensate in the interior of the fabric. According to the observations of the experiment the temperature of the fabric layer and the heat flux on the skin surface is greatly related to the amount of moisture and its presence in the protective clothing. Simulations performed for different sets of multi-layer textiles (with different humidity) may be useful in designing the firefighters protective clothing.

Numerical tools to study the transmission of moisture in the firefighter protective clothing thermally irradiated are crucial in preventing burns (as significant determinant) by designing new protective clothing. This tool provides information about the heat capacity of the firefighter protective clothing and its response to fire in different fire situations.

Detailed scientific analysis anticipating thermal properties of protective clothing must take into consideration the diversity of conditions in which firefighters lead actions. The main issue related to the phenomena occurring during the fire is heat and mass transfer through the structure of protection.

However, transport of heat and mass transfer in wet porous materials is a complex issue. The basic types of energy transmission mechanism in personal protection are conduction and convection in the liquid and gas phase. The model verification is carried out experimentally.

Examples of experimental methods:

- the method according to the ISO Standard 17492 TPP. The scheme of the test stand used in TPP method - a single fabric layer is shown in Fig. 7. and 8.
- permeation test method in the configuration used in the ATSM F903 shown in Fig. 9.,
- the method of measuring temperature and humidity Aminco -Aire Model J4s - 5460 is shown in Fig. 10.,
- sweating test method - temperature measurement, humidity and thermal properties of wet protective clothing subjected to dynamic pressure is shown in Fig. 11. and 12.

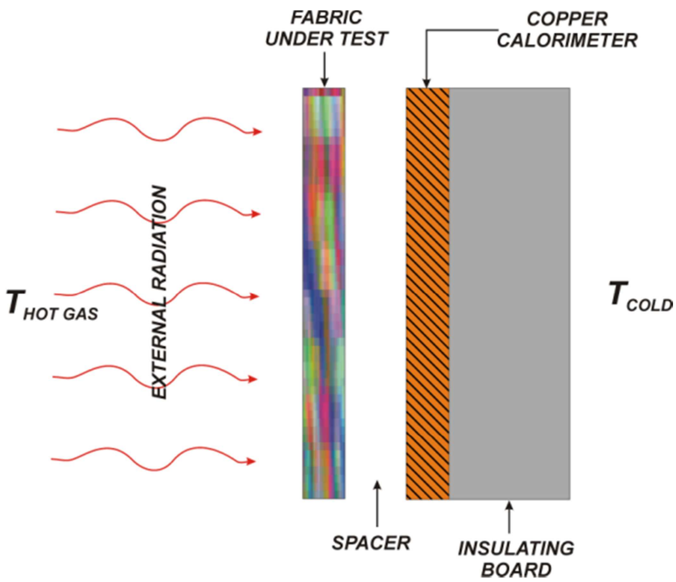


Fig. 7. The scheme of the method used in the TPP - a single layer of fabric (Model ISO Standard 17492 TPP) [11]

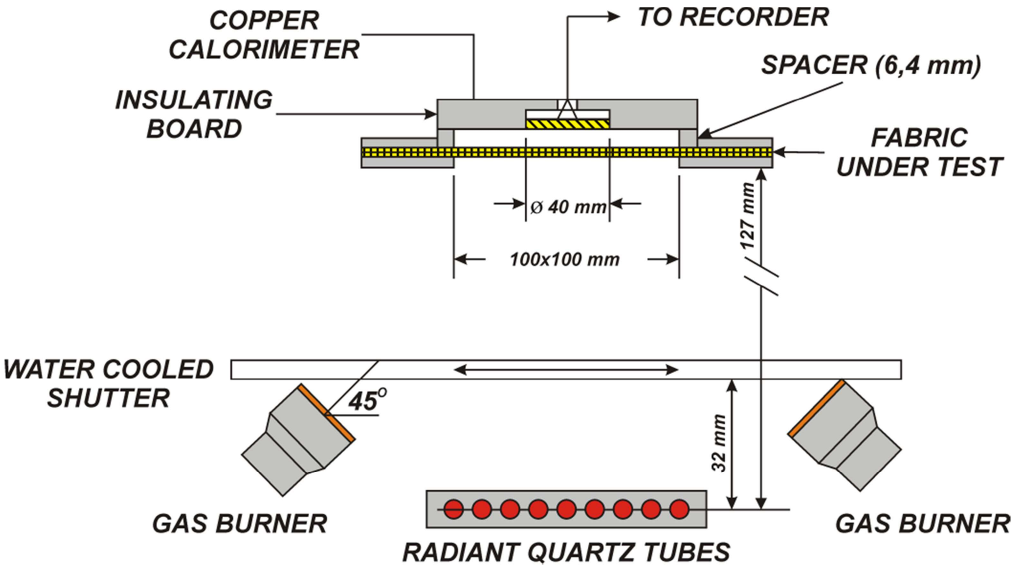


Fig. 8. Diagram of the device to determine the TPP - evaluation of monolayer [11]

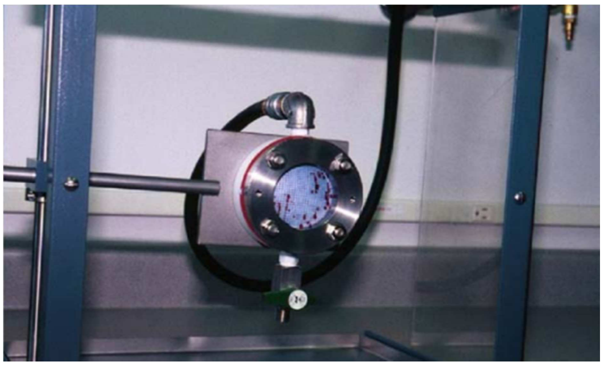


Fig. 9. The study of diffusion in the configuration used in the ATSM f903 [1]

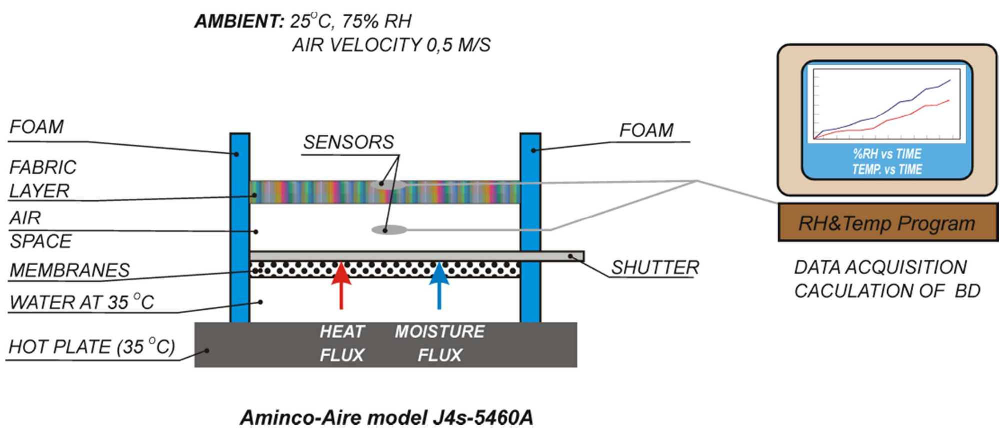


Fig. 10. Dynamic measurement of temperature and humidity [1]

Fig. 11. The test apparatus - hotplate in an environmental chamber [1]

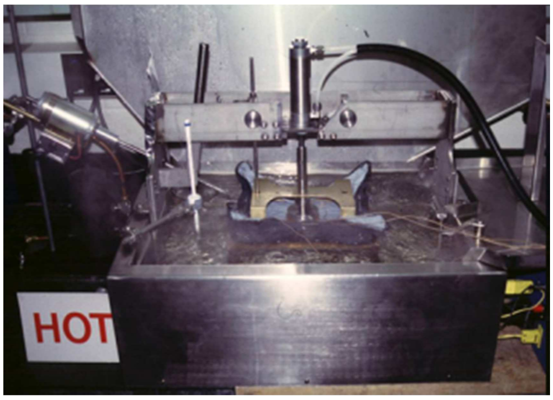


Fig. 12. Apparatus testing thermal properties of wet protective clothing subjected to dynamic pressure [7]

Firefighters exposure to external factors during fire and rescue operations concerns not only the thermal effect but also chemical and biological factors. The examples of these types of interactions are the permeation of chemical vapors or liquids and chemical molecules presented in Figures 13. and 14. The test of penetration the fire protective clothing by liquids is shown in Figure 15.

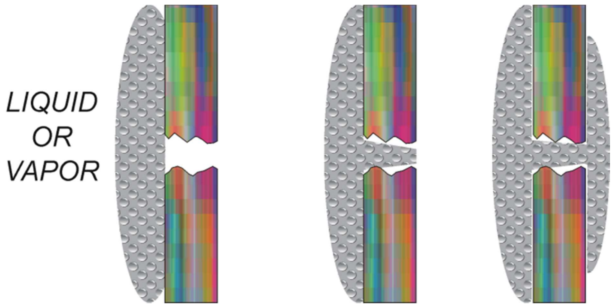


Fig. 13. Illustration of penetration chemical or liquids vapors through the material [1]

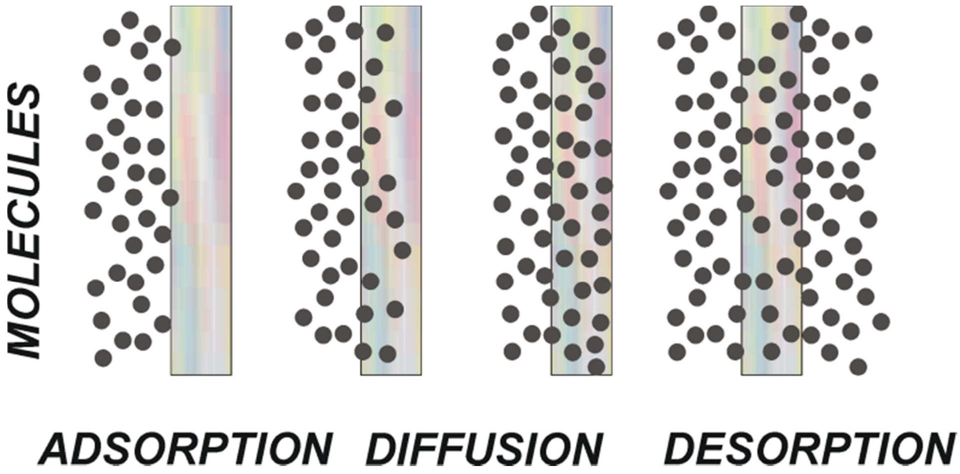


Fig. 14. Figure of permeation of molecules through the material [1]

Fig. 15. Test of penetration the fire protective clothing by liquids [1]

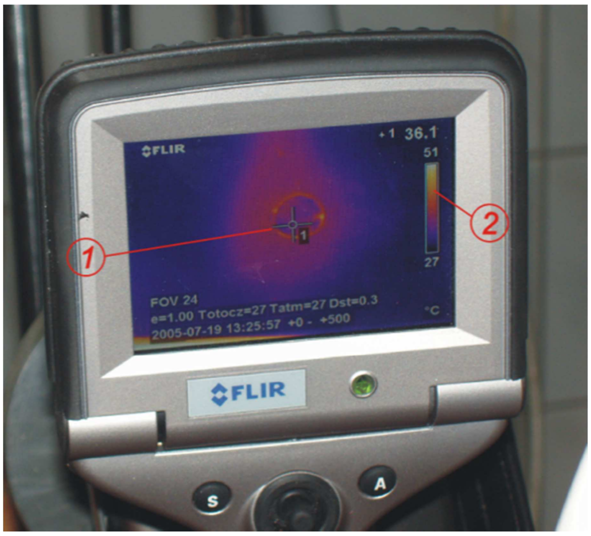
THERMOGRAPHIC TESTING METHOD OF EFFECTIVENESS OF PROTECTION AGAINST HEAT RADIATION (ACADEMY OF SCIENCE - TECHNOLOGY - DEPARTMENT OF THERMAL ENGINEERING AND ENVIRONMENT FACULTY OF METALS ENGINEERING AND INDUSTRIAL COMPUTER SCIENCE) [13 ÷ 21]

Studies conducted at the Department of Thermal Engineering and Environment Faculty of Metals Engineering and Industrial Computer Science AGH University of Science – Technology were to designate characteristics of the selected standard configuration used in personal protection. A thermal imaging camera was used in the method of measurement using. Nowadays thermal imaging camera is a standard tool in the non-contact temperature measurement.

Fig. 16. shows the test stand position for measuring the temperature on the inner side of a set of protective layers irradiated by blackbody (thermographic method) and in Fig. 17. The thermal imaging camera monitor with visible thermal image of the sample surface. The most commonly used measurement is the range of wavelength from 0,5 μm– 20 μm.

1. Radiator
2. Sample
3. An infrared camera
4. The controller of the microprocessor controller
5. Thermal chamber to measure the surface emissivity of tested materials
6. Computer

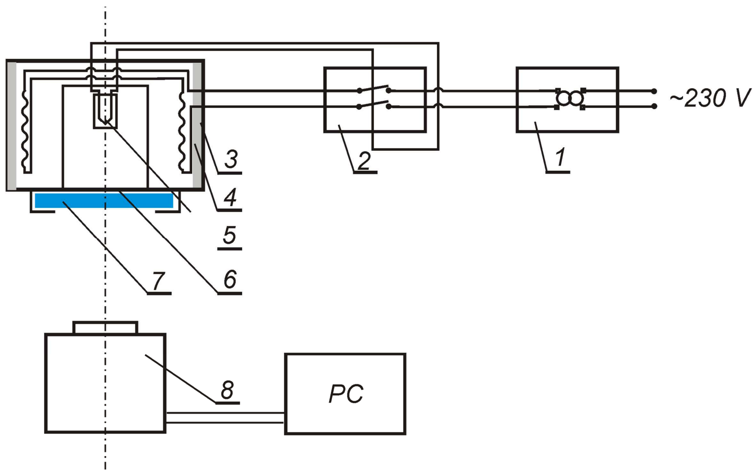
Fig. 16. The thermal measurement of the temperature of the sample irradiated by blackbody



1. Thermographic image of the scanned surface
2. The scale of temperature measurement range

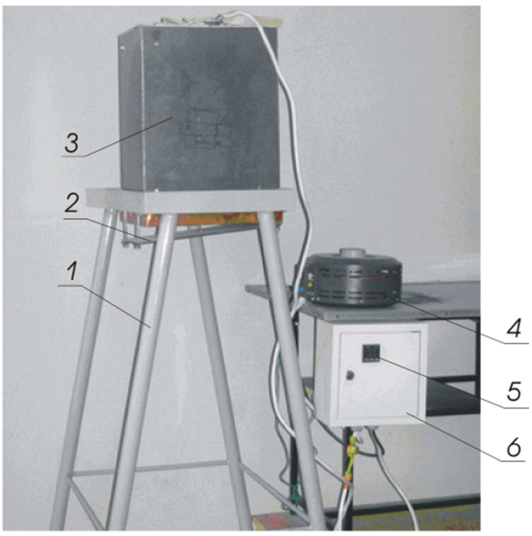
Fig. 17. The monitor of the thermal imager with a visible internal thermal image of the specimen

The test stand to study the effectiveness of thermal protection materials and sets of protective layers is shown by schematic diagram in Fig. 18.and the image in Figure 19.



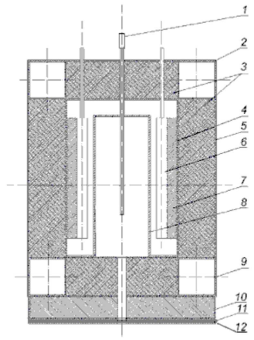
1. Transformer
2. Controller
3. Insulation
4. Heating coil
5. Thermocouple
6. Blackbody
7. Sample
8. Infrared camera

Fig. 18. The scheme of the measurement position



1. Basis radiator
2. Furnace
3. The sample holder
4. Autotransformer
5. Microprocessor-based controller
6. The security system

Fig. 19. The position of measurement for testing the effectiveness of personal protection



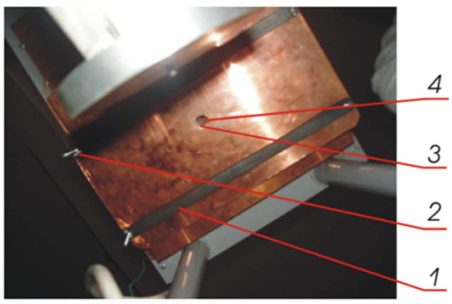
1. Thermocouple type K (NiCr – NiAl)
2. Cover
3. The insulating layer Al_2O_3
4. The inner wall of the housing
5. The outer housing wall
6. The heating element 1,75 kW
7. The contribution of insulation
8. Activities blackbody
9. The screw connection
10. The core of the handle
11. Joint
12. The hinged frame

Fig. 20. The furnace for simulating the blackbody

The simulator of a blackbody is a hole in the wall of the furnace shown in Fig. 21. The basic element is a cylindrical cavity (8) with an internal diameter of 100 mm. It is situated in the symmetry axis of the outer furnace body in a way that its axis coincides with the axis of the bore in the outer furnace body with a diameter of 16 mm. There is a ceramic sleeve with an inner diameter of 10 mm mounted in the bore.

The energy source is created by a set of two heating elements powered by electric current that is adjusted by an autotransformer which voltage is 0 – 260 V. The heating elements are embedded within the steel casing by a screw fastening and the insulating cartridge (7). Electric power supply from the autotransformer is regulated by a microprocessor controller RE16 – 1111000, made by Lumen company, operating on the basis of the thermocouple temperature measurement NiCr - NiAl (1). The thermocouple is located in such a way that measurement in the central point of the cavity is possible. The controller allows to check the current instrument reading of temperature on the display and to program the maximum temperature inside the cavity. This function enables to maintain constant temperature in the interior of furnace during making measurements.

Cover plates of interior and exterior walls, furnace base and cover are mounted with screw (9) fasteners. This solution provides for the reduction of thermal deformation during the test and increases the of the device. Internal spaces between the plates are filled with construction insulating wool Al_2O_3 (3). The lower part of the structure is equipped with a sample holder. The handle consists of a suspended on screws (11) hinged frame (12) with measuring bore that has got 16 mm internal diameter. A sample setting mechanism allows quick and precise setting of the material. In addition, tilting frame is blocked by two screw connectors. This solution shown in Fig. 21. is prepared for direct measurement of internal surface areas of personal protection made of aramid fibers.



1. Frame tilt
2. The locking screws
3. The test port
4. Sample

Fig. 21. Photography sample holder

The test of effectiveness of the thermal protection of samples can be achieved under thermical conditions with radiation of the blackbody at different temperatures ranging up to 800 °C and including (used in previous studies of temperature: 400 °C (673,15 K), 500 °C (773,15 K), 600 °C (873,15 K), 700 °C (973,15 K), 800 °C (1073.16 K).

The measurement of the temperature of the blackbody in a microprocessor control circuit, which regulates the power supply of the heating elements, is implemented by the thermocouple type K (NiCr - NiAl). The result of the study is a set of thermal images which (after processing) make it possible to determine the course of the temperature changes over time.

The first step after powering the heating chamber of the furnace is setting the certain temperature on the controller. The prepared sample is placed on the test stand after setting a thermal imaging camera and its launch.

The camera operates at a specified measurement range with emissivity characteristic to the tested material sample.

For personal protection samples made of polycarbonate and woven carbon fiber emissivity in the temperature range of 30 – 60 °C is $\varepsilon \approx 0.9$. Measurement frequency depends on the predicted temperature waveforms image that is 0,1 – 1 s. Thermograms recorded during the measurement are stored in computer memory. Further analysis is to read the average temperatures in the study area from thermogram sequences and to keep the records of them in a spreadsheet.

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