

HEAT INSULATOR FLOOR ANALYSIS IN FIREFIGHTERS' UNIFORM

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Abstract: This article provides a scientific analysis of the thermal insulation layer used in firefighter protective clothing. The thermal liner is the primary component that delays heat transfer to the human body under exposure to high temperatures and radiant heat. The structure and fiber chemistry of aramid, PBI, and Nomex-Nano materials are reviewed together with evaluation parameters such as Thermal Protective Performance (TPP) and Moisture Vapor Transmission Rate (MVTR).

Keywords: Thermal liner; aramid fibers; TPP; MVTR; fire protection; firefighter clothing; radiant heat; Nomex; PBI; NFPA 1971; moisture barrier; degradation; ventilation; air gaps.

One of the factors that threaten the lives of firefighters during the process of extinguishing fires is heat. By extinguishing the fire, the temperature of the side area can reach from 400°C to 900°C. It may also show higher temperatures than this in some cases. The skin of a human moth begins to injure the body for a long time at 55, 60°C, or at temperatures above 70°C. Therefore, protection of the body from heat is the main task from both technological and physiological aspects. Firefighting clothing consists of three main layers: from them the heat-insulating floor, which is located closest to the body. This layer reduces or slows down the passage of heat through invisible holes. Due to the fact that natural air is an insulator in clothing, air vents determine the effectiveness of the floor. The more air is stored, the slower the heat transition.

In the process of performing its function, the insulating layer of firefighters' clothing should ensure that its fibers do not dissolve, do not burn and do not lose shape under the influence of heat. Therefore, high temperature-resistant materials such as meta-aramid, para-aramid, PBI (Polybenzimidazole) are often used as its materials. The molecular bonding of the aramid fiber consists of strong aromatic rings, which late enter thermal degradation in heat. PBI, on the other hand, although very expensive, retains its properties even at temperatures above 500°C. Another state-of-the-art fabric, Nomex Nano, is a technology that stores air capsules through micro-cellular fibers, which conducts heat by 20–25% less and reduces the overall weight of clothing by 10–15%. Reduced weight increases firefighter's mobility and endurance, reducing the risk of heat stress.

The main criterion in evaluating the effectiveness of thermal insulation is TPP (Thermal Protective Performance). The higher the TPP score, the longer the burn prevention period. For example, firefighting clothing with TPP=40 will not allow 20-25 degrees of burns for 2 to 2 seconds at a dangerous temperature. At this time, it allows the firefighter to complete the task or get to a safe area. But the increase in temperature of the thermal insulator increases the thickness of the clothing, which reduces freedom of movement. Therefore, manufacturers are looking for a balance between heat, the insulating layer of firefighters' clothing, efficiency and ergonomics. In other words, they attach great importance to these two cases.



The table below shows the thermal and mechanical properties of clothing materials:
Table 1

No	Material	Average heat resistance (°C)	Tensile resistance	Weight	Narx darajasi
1	Meta-aramid (Nomex)	370–400	High	Average	Average
2	Para-aramid (Kevlar)	450	Extreme	Light	High
3	PBI fiber	500+	Extreme	O‘rtacha-yengil	Extreme
4	Nomex-Nano	390–410	Average	Too light	High

According to the chart above, while PBI material provides the highest protection, it is economically unsuitable for all services. The Nomex-Nano, on the other hand, is regarded as the most effective in providing heat protection at a light weight.

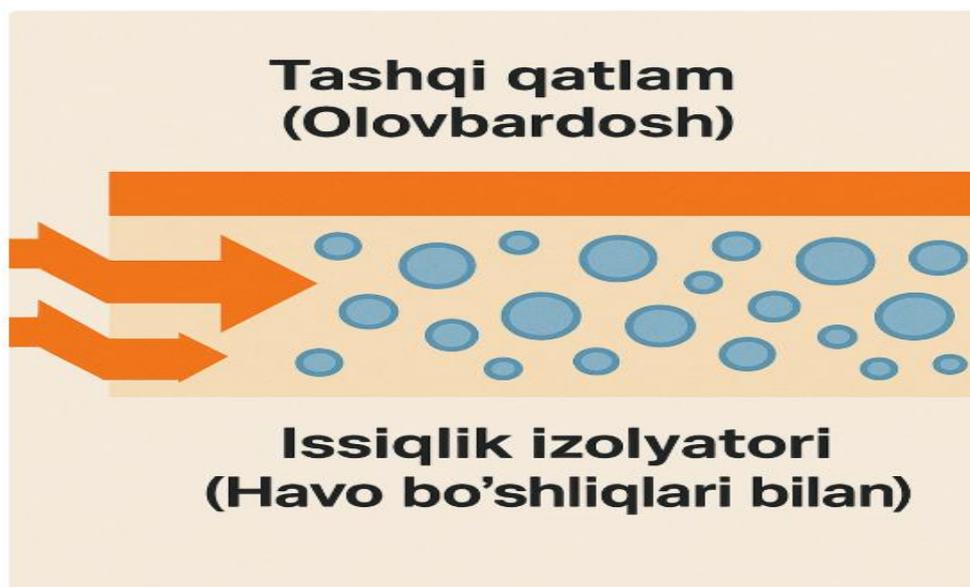


Figure 1: Layers of firefighters' clothing.

Another dangerous factor for firefighters is radiative heat. During firefighting, walls, metal structures, fuel and machinery fragments become highly heated and dissipate heat through radiation. Radiant heat does not touch the skin directly, but it absorbs very quickly. Therefore, the thermal insulator floor should reduce not only hot air, but also radiation energy. In some cases, for sewing firefighters' clothing, fibers with an aluminum coating are used in the clothing. But since this coating of metal reduces air exchange in clothing, it is recommended to use it only for special operations and areas with high radiation. Skin and blood circulation are also severely tested during or during firefighting. When heat stress occurs, the body tries to cool down by sweating. If there is no air exchange in the clothes during this procedure, the skin becomes moisturized, which accelerates the transfer of heat to the inside. For this reason, the insulating layer of the firefighter's clothing should have a breathing structure, that is, a structure that contributes to the release of steam. Some manufacturers and enterprises are choosing 3D fabrics



for the insulating layer of the interior with a 3D structure and with their help improve the quality of the way the sweat vapor escape. Our state, taking into account the climatic conditions of Uzbekistan, further increases the importance of choosing the right thermal insulation layer of clothing. The reason for this is that in summer the air can be above 40°C. At this time, even with thick insulation protecting from heat, body temperature increases rapidly. Therefore, in the warm season, it would be more expedient to use lighter composite materials and in winter - denser insulating floors.

In the manufacture of firefighters' clothing, great importance is paid to another aspect of clothing. The heat insulator floor will wear out over time. As a result of each fire, the molecular structure of the fibers is subjected to thermal stress. With each wash, special chemical treatments in the fibers can be lost. Also, there is a lot of friction at the armpits, knee and elbow joints. In these places, wear happens faster. Therefore, regular technical inspections are important:

- check the thickness of the layer
- tears and injuries are repaired with a patch
- membranes are checked for perforation-worn clothes are replaced.

Since the waterproof insulating layer of the garment is the main layer of the garment, several laboratory tests are used to evaluate its heat-protecting properties. One of the most important of these is the TPP test, in which a heat flux is directed to a certain extent to the clothing sample, and the amount of time when a grade 2 burn can occur on the skin is determined. A grade 2 burn is a serious injury, such as deep damage to skin tissue and fluid accumulation. The higher the TPP value, the longer it will be possible to serve in a hot environment without damage. There's also an RPP Radiant Protective Performance test. This test assesses the degree of protection of the garment in radiant heat. Metal structures, vessels full of flammable liquid, and generate intense thermal radiation caused by explosions. The RPP tests show just how effective the thermal insulation layer is in such situations.

Another important aspect is the design geometry. It is very important that the thermal insulation does not stick too much to the body. Because the air distance between the insulator layer and the skins will be the main protective factor from heat. If the air distance is lost, the heat passes directly into the body. Due to this, special "bubble" structures are created in the chest, shoulder and back zones. Salt in the skin, which occurs during most fires, is also a problem. Salt eats away at the fibers from the inside, breaking their density. Therefore, the insulator layer must be chemically inert — that is, it must not react with acids and salts in sweat.

Another real danger is steamburn. If moisture accumulates and the heat in the outer layer suddenly increases, the water instantly turns into vapor and hits the skin as an explosion. This condition is one of the most painful and dangerous manifestations of burns. This means that the heat insulator needs to manage not only heat, as mentioned above, but also humidity. That's where the quality of the barrier layer comes into play. If the moisture barrier is poor, then the heat insulator can not even do its job. The two are seen as an inseparable tandem. In modern production technologies, elements of a special ventilation duct are added to the layer of thermal insulation. These ducts provide air circulation at each step of the fire extinguisher and reduce the temperature inside it. As a result, heat stress is reduced, endurance increases, and the risk of fainting decreases.

Conclusion

The thermal insulation floor of the protective clothing of firefighters is considered the most important layer that protects the life of a person at risk of fire. The main task of this layer is to slow down the transition of convective and radiant heat flow of high temperatures into the body, prevent burns and reduce thermal stress. The effectiveness of thermal insulation is determined by



the chemical composition of its fibers, micro-air pores, thickness, structural elasticity and moisture control properties. Heat-resistant fibers such as Aramid, PBI, and Nomex Nano do not melt in heat and retain their shape, ensuring that the protection lasts continuously.

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