STUDY ON HEAT TRANSFER THROUGH WET TEXTILE EXPOSED TO RADIANT HEAT FLUX

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REZUMAT. In aceasta lucrare s-a studiat efectul umidităţii asupra transferului de caldura prin materialul textil, in cazul expunerii acestuia unui flux radiativ. S-a investigat transferul de caldura printr-un singur strat de material, cu continut de umiditate diferit. S-a constatat ca in timpul evaporarii umiditatii din materialul textil, temperatura inregistreaza un platou, aceasta ramanand constanta. Consumul de energie pentru schimbarea de faza a umiditatii din materialul textil este procesul care predomina, atata timp cat exista umiditate. Odata ce evaporarea s-a terminat, temperatura creste si se apropie de temperatura masurata in cazul materialului uscat. Umiditatea din stratul de material textil nu a condus la cresterea temperaturii, comparativ cu mostra uscata. Acest studiu confirma faptul ca umiditatea poate influenta pozitiv protectia termica a utilizatorului in cazul expunerii unui flux radiativ relativ scazut.

Cuvinte cheie: transfer de căldură, evaporare, confort termic.

ABSTRACT. In this study we analyzed the effect of moisture on the heat transfer through the textile material in case of exposure to radiant heat flux. We investigated the heat transfer through a single-layer fabric at different moisture content. It was found that during the evaporation of the moisture, a temperature plateau appeared during which temperatures were hardly rising. The energy consumption used for the phase change of moisture located in the textile dominated the heat transfer process as long as there was moisture present. As soon as all water has evaporated, the temperatures approached the temperatures measured for dry samples. The moisture within the mono-layer textile did not lead to increased temperatures compared to the measurements with dry samples. This research has confirmed that moisture can positively affect the thermal protection of the wearer in case of low radiant heat flux.

Keywords: Heat transfer, moisture evaporation, thermal comfort.

1. INTRODUCTION

The study of heat transfer is one of the most important fields of engineering science. Heat transfer problems are of great practical significance in textile engineering and have wide applications, such as for fire fighters, bakery workers, construction workers, miners, boiler room workers, metallurgy and glass industry workers, etc. Workers who are exposed to heat or work in hot environments indoors or outdoors may be at risk for heat stress. Exposure to heat can result in occupational illnesses caused by heat stress, including heat stroke, heat exhaustion, heat syncope, heat cramps, heat rashes, or even death [2].

Studies show that the maximum rate of sweat production by an average man is about 30 g/min (1.8 l/h) [1]. The sweat rate may even reach up to 4 l/m^2 for shorter duration [3]. *Schopper-Jochum et al.* found that 30-44% of the sweated amount of moisture is accumulated in the clothing system [6]. *Keiser C. and Rossi R.M.* found that under usual firefighting circumstances, about two thirds of this moisture may remain in the clothing system [4].

In this study we analyzed the effect of moisture on the heat transfer through the textile material exposed to radiant heat flux. We investigated the heat transfer through a single-layer fabric at different moisture content. Understanding mechanisms by which moisture in textiles affects heat transfer could lead to improvements in design of thermal protective clothing [5].

2. EXPERIMENTAL SETUP AND PROCEDURE

The scheme of the test apparatus for determining heat transfer under both steady and transient conditions through a single-layer when exposed to a low-level radiant heat flux is shown in Figure 1.

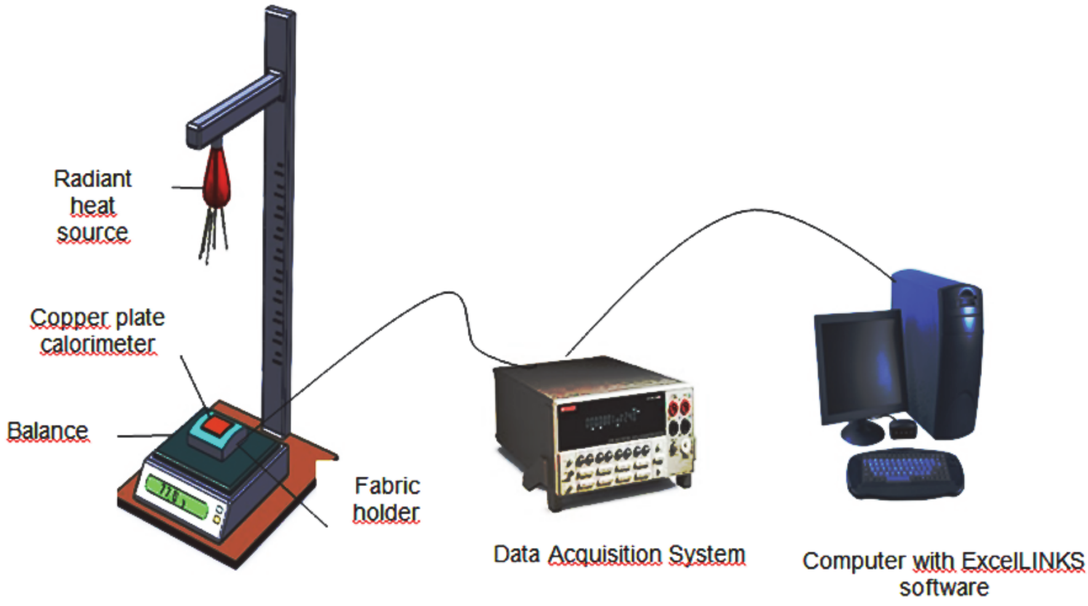

Fig. 1. Configuration of the test apparatus for determining heat and moisture transfer through fabrics exposed to a low-level radiant heat flux.

An infrared lamp *(SICCA RED 150W 240V HG)* was used as radiant heat source in order to supply a constant radiant heat flux at the surface of the sample corresponding to the routine condition of the firefighting environment.

A fabric holder assembly was fabricated to hold and position a fabric sample rigidly against the hot air impinging flow. The heat transferred across the fabric is measured with a sensor assembly positioned on the fabric holder..

The sensor assembly is composed of a copper plate calorimeter 50x50 mm, 1.6 mm thick, an insulating board and a Chromega^{TM} - Constantan thermocouple silver welded on the copper plate. The calorimeter face is painted with a flat black paint having a coefficient of absorption greater than 0.9, so as to absorb radiant flux. The cooper plate is bent into an arc with a radius of 130 mm. The copper plate is accurately weighed before assembly. The curved copper plate is bonded to the mounting block around its edges using an adhesive resistant to high temperature.

The fabric holder assembly is placed on the precise balance in order to register the evaporation rate. The data are collected and stored with the LabX direct Balance 2.3 system on a PC.

A Data Acquisition System coupled to a computer with ExceLINKS software has been used to register the data.

Both dry and wet tests were performed. For the wet tests, at the beginning of the experiment the sample was wetted with a defined amount of water (1.08 g, 1.38 g and 1.74 g). This corresponds to the moisture content of 120%, 160% and 200%, respectively, relative to the conditioned weight (20 °C and 40 % RH). To moisten the sample, the following protocol was use: the specimen was first conditioned in the testing room prior the moisture application and testing. The sample was immersed in distilled water and then, placed between sheets of blotting paper, was rolled- over using a metal roller for removing the excess water until the needed amount of water was obtained.

The testing conditions were constant during the experiments: ambient temperature T_{amb} = 20 °C and air relative humidity RH= 40 %.

3. RESULTS AND DISCUSSION

Figure 2 shows the temperature variation for constant heat flux of 1100 W/m^2, for underwear with different moisture content. The temperature pattern for wetted fabrics can be divided into four different phases: an initial rising phase, a stagnation phase, a final rising phase and a final stagnation phase.

During the first phase energy was used mainly in heating up the fabric and moisture, and only a small quantity of moisture was evaporated.

During the second phase the temperature is constant (43.5 °C) regardless of the initial amount of water contained in the material. On the contrary, the amount of moisture has a significant influence on the second phase duration. Thus, for 120% moisture content the temperature plateau was registered for 1398 seconds, for 160% moisture content for 1608 seconds and for 200% moisture content for 1956 seconds. *Keiser C.* [3] found a linear correlation between the amount of water and the duration of the second phase. This linear correlation was confirmed by our results (see Figure 3).

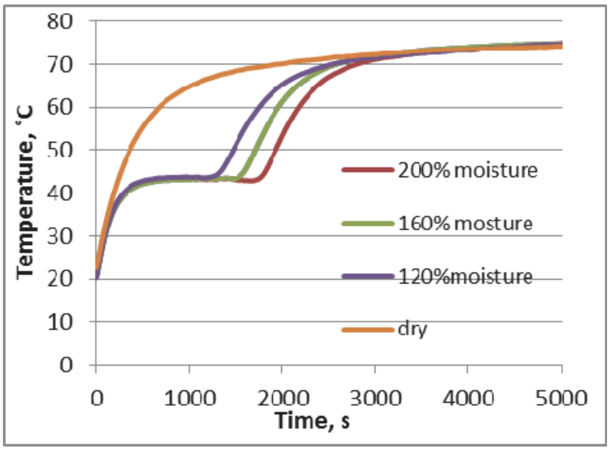

Fig. 2. The temperature variation for constant heat flux of 1100 W/m^2, for the textile with different moisture content .

In the third phase the temperature started rising again, and the fourth phase represented the equilibrium.

The temperature was lower during the evaporation of the moisture than during the measurement of the dry sample. The higher the initial moisture content the higher the difference during the evaporation. For all experiments, as soon as the moisture had evaporated, the temperature approached the temperatures measured for dry sample, 75°C.

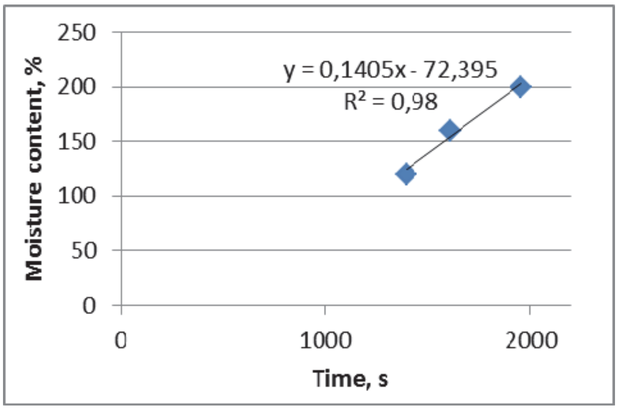

Fig. 3. Correlation of the amount of water and the evaporation phase duration

Figure 4 shows the decrease in the moisture contents. The moisture content stayed constant in the beginning for about 30-60 seconds and then decreased. The moisture decreased linearly with time. From these results the evaporation rates were calculated, by dividing the moisture content by the time it took to evaporate the amount of water. The evaporation rates were 0.981 x 10^{-3} g/s for 200% moisture content, 0.927 x 10^{-3} g/s for 160% moisture content and 0.841 x 10^{-3} g/s for 120% moisture content, respectively, that is, 0.297 g/m^2.s, 0.280 g/m^2.s and 0.255 g/m^2.s, respectively. Thus, for the same radiant heat flux, the rate of evaporation seemed to increase linearly with the moisture content (Figure 5).

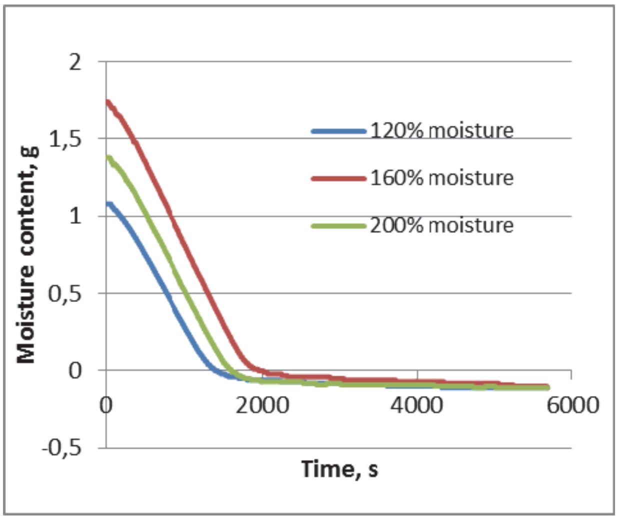

Fig. 4. Variation of moisture content.

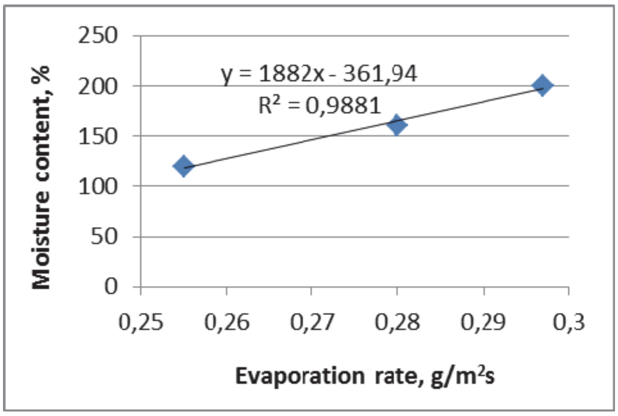

Fig. 5. Correlation of the evaporation rate and the amount of moisture.

At the end of the experiment, moisture content reached a negative value. As weight of the whole system was set to zero initially, a negative amount of water at the end of measurement indicates that this amount of water must be present within the textile layer at the beginning of the measurement. The samples were kept at room conditions prior to the tests, and therefore an initial amount of water corresponding to their moisture regain was present in the material. After radiation was cut off the same amount of water was absorbed back into the fabric from surrounding atmosphere. This amount represents 12.79% of the mass of perfectly dry material and corresponds to the moisture regain of fibers, that is, 12%.

4. CONCLUSIONS

During the evaporation of the moisture, a temperature plateau appeared during which temperatures were almost constant. The energy consumption used for the phase change of moisture located in the textile samples dominated the heat transfer process as long as there was moisture present. As soon as all water had evaporated, the temperatures approached the temperatures measured for dry samples.

Water has higher thermal conductivity relative to air and it has been assumed that heavily wet condition makes faster temperature increase. But, this research has confirmed that moisture can positively affect the thermal protection (heat transfer) in case of routine firefighting operation. The moisture within the textile samples did not lead to increased temperatures compared to the measurements with dry samples. The effect of the higher heat capacity and energy absorption through vaporizing overtook the effect of higher heat conductivity of the wet material.

Linear correlations were confirmed between the moisture content and both the evaporation time and the evaporation rate.

This study contributes to better understanding of the impact of moisture retained in the textile on the protective behavior, under the conditions of low-level radiant heat flux.

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