EXPERIMENTAL STUDY ON MOISTURE TRANSFER THROUGH FIREFIGHTERS' PROTECTIVE FABRICS IN RADIANT HEAT EXPOSURES

by

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The effects of absorbed moisture on thermal protective performance of firefighters' clothing materials under radiant heat flux conditions were analyzed in this paper. A thermal protective performance tester and temperature sensor were used to measure the temperature variations for the facecloth side of four kinds of commonly used flame retardant fabrics in several radiant heat exposures, which varied in moisture content. Experimental results showed that, all of the temperature profiles of these four kinds of moistened fabrics under different radiant heat flux conditions presented the same variation trend. The addition of moisture had a positive influence on the thermal protective performance during the constant temperature period when heat radiation time was more than 60 seconds. As the heat radiation time increased beyond 500 seconds, the thermal protective performance of moistened fabrics became worse than that of dried fabrics in general.

Key words: *flame retardant fabrics, thermal protective performance, moisture content, radiant heat flux*

Introduction

Firefighters usually have to be exposed to heat radiation produced by fire or hot air while firefighting and thermal protective clothing is crucial to work and for survival for firefighters in extreme environments. The scene of firefighting is not a dry environment, in which some moisture would exist, such as fire water, perspiration produced by sweating firefighters or rains. After these moistures being absorbed by firefighters' clothing materials, it will play an important role on the thermal protective performance (TPP) of the materials [1]. Chen [2] tested the temperature of simulated skin under wet and dry fabric layer exposed to radiant heat flux. It was found that the temperature of simulated skin under wet fabric layer was higher than that under dry fabric layer, but the opposite trend appeared with time extending. Perkins [3] tested the distribution of temperature on the surface of protective fabrics exposed to a radiant heat flux of 16.8 kW/m^2. The results showed that the TPP of wet fabrics was better than dry fabrics. Barker *et al.* [4] measured TPP of turnout system exposed to a heat flux of 6.3 kW/m^2 and pointed out that the addition of moisture negatively impacts the predicted

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burn protection to the greatest degree when the moisture is added at a comparatively low level of approximately 15% of turnout composite weight. Wang *et al.* [5] analyzed the influence of outer fabric of firefighters' uniform under wetting condition on its TPP. It was observed that the thermal protection performance (TPP) value of the outer fabric tends to increase as its wetting degree increasing. Li [6] tested the TPP value of fabrics in different wet state exposed to a heat flux of 82.21 kW/m^2. It was revealed that moisture contributes to improve the TPP of single layer fabric. Fu *et al.* [7] conducted thermal manikin experiments with two kinds of multi-layer protective garments in hot environment, which varied in different sweating rates of manikin and ambient humidity ranges. It demonstrated that the internal and external moisture difference influenced the time needed to form the micro-environment, which impact the TPP greatly. This research was conducted to investigate the impacts of absorbed moisture on the ability of firefighters' clothing materials to protect against heat exposures by evaluating the temperature variations for the facecloth side of four kinds of commonly used flame retardant fabrics having different moisture content exposed to heat radiation.

Materials and methods

Materials

Four kinds of commonly used flame retardant fabrics were selected and their basic parameters were shown in tab. 1.

Table 1. The basic parameters of four kinds of flame retardant fabrics

Fabric samples	Composition	Texture	Thickness [mm]	Weight [gm^{-2}]
Fab. 1	50% nomex + 50% viscose	twill	0.41	190
Fab. 2	100% nomex	interlock	0.95	210
Fab. 3	93% nomex + 5% kevlar + 2% static wire	twill	0.49	200
Fab. 4	100% cotton	plain stitch	0.57	210

Methods

The experiments were conducted with these four kinds of fabrics exposed to radiant heat flux of 5, 20, and 40 kW/m^2. Motis TPP tester was used to provide heat source and Testo temperature tester was applied to test the temperature for the facecloth side of sample fabrics. The moisture content gradients were set as 0, 15, 25, 50, 75, 100, 125, and 150%. Only the experiments of the first six kinds of moisture content were conducted with Fab. 3 due to its poor hygroscopicity. The fabric samples were cut into the size of 140 ×140 mm. Sufficient water was then sprayed onto the facecloth side of the dry specimen to increase its weight by the desired amount, which was calculated according to the following equation after precise weigh of dry weight:

$$M_{\mathrm{w}} = M_{\mathrm{d}}(1 + \phi) \tag{1}$$

where M_{d} and M_{w} are the dry weight and wet weight of the fabric sample, and ϕ is the moisture content.

Results and discussion

The TPP of these fabrics containing different amount of moisture could be observed through the trend of temperature variations in the same heat condition. Figure 1 illustrated the trend of temperature variations for the facecloth side of these fabrics exposed to a radiant heat flux of 5 kW/m^2 and fig. 2 showed the duration of keeping a constant temperature of these fabrics exposed to this radiant heat flux.

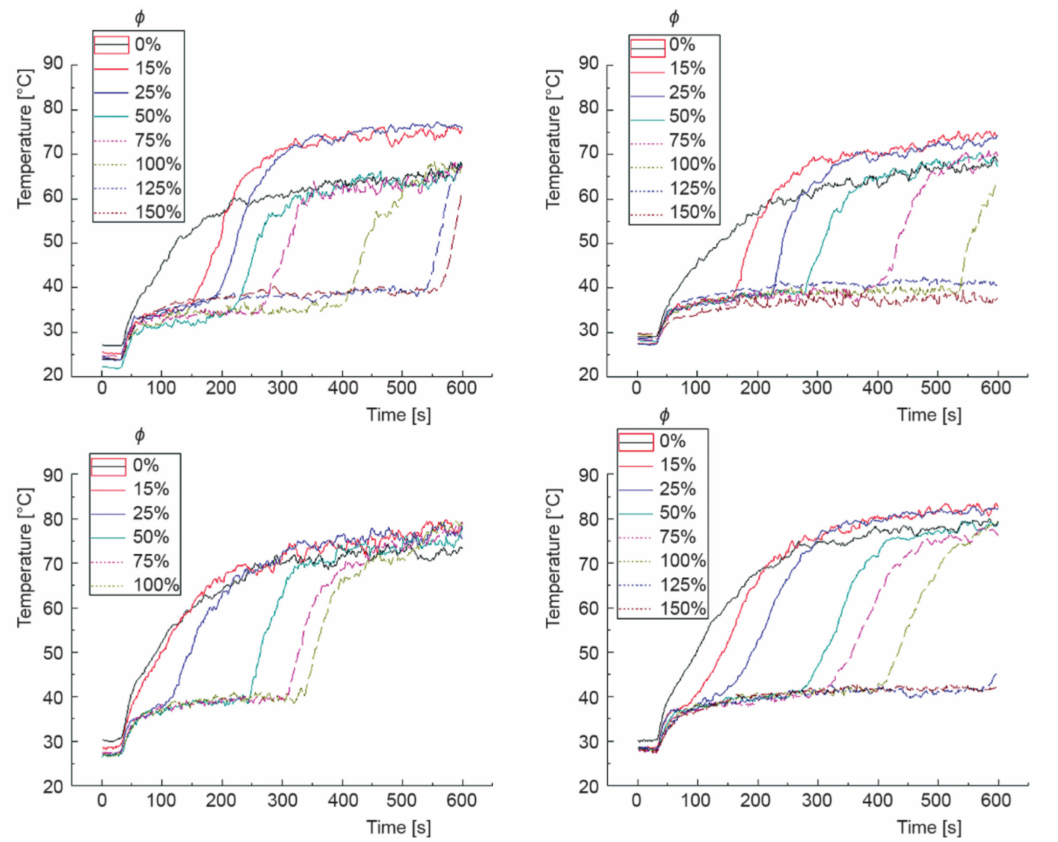

Figure 1. The trend of temperature variation of the four kinds of fabrics exposed to radiant heat flux of 5 kW/m^2

It could be seen from fig. 1 that all of the temperature profiles for the facecloth side of these four kinds of moistened fabrics presented same variation trend. As the heat source being turned on, the temperature rose rapidly. After a short period of time, the rising rate gradually slowed down then remained stable (between 35 and 40 °C) but began to rise again later. When the heat radiation time was beyond 500 seconds, the temperature showed slight change close to stable. Figure 2 revealed that the higher moisture content ϕ, the longer the temperature keeping constant at a relative low temperature. That means the existence of moisture increases the heat storage capacity of fabrics, which has a positive effect on TPP. The higher the moisture content, the better TPP of fabrics in this stage.

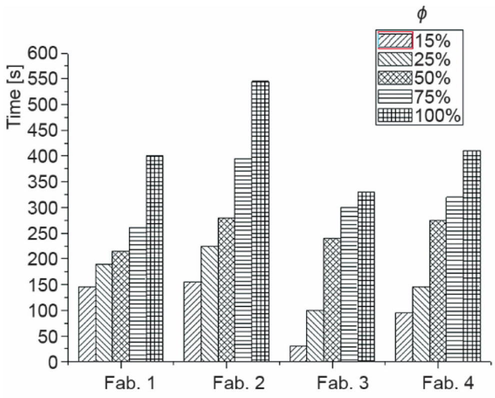

Figure 2. The duration of keeping a constant temperature of the four kinds of fabrics exposed to radiant heat flux of 5 kW/m^2

The trend of temperature variations for the facecloth side of the four kinds of fabrics exposed to radiant heat fluxes of 20 kW/m^2 and 40 kW/m^2 were illustrated in figs. 3 and 4. The duration of keeping a constant temperature of these fabrics exposed to the two radiant heat fluxes were presented in figs. 5 and 6. By contrasting figs. 1, 3, and 4, it can be found that the curves of temperature variations for the facecloth side of the four kinds of fabrics exposed to the three different radiant heat flux presented same variation trend. The temperature for the facecloth side of fabrics rose more quickly with the enhancement of radiant heat flux. Besides, the temperature after being stable at last was higher when exposed to a higher radiant heat flux. It can be observed in figs. 5 and 6 that the law that *the higher moisture content, the longer the temperature keeping constant at a relative low temperature* remained unchanged when

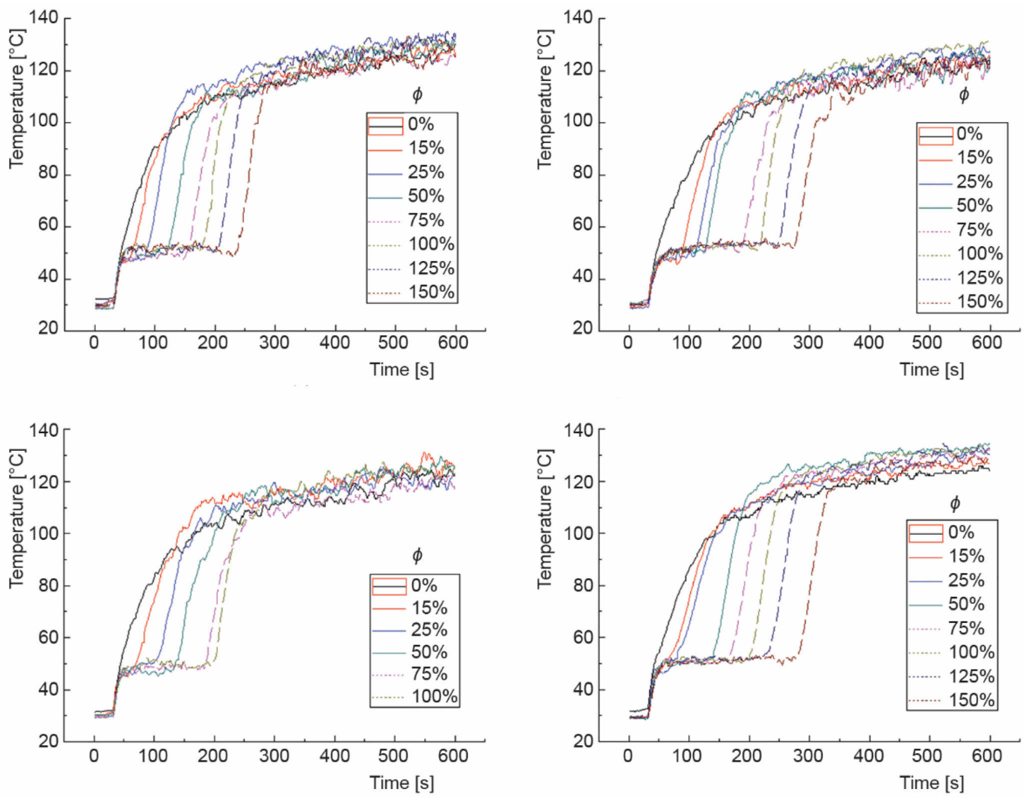

Figure 3. The trend of temperature variation of four kinds of fabrics exposed to radiant heat flux of 20 kW/m^2

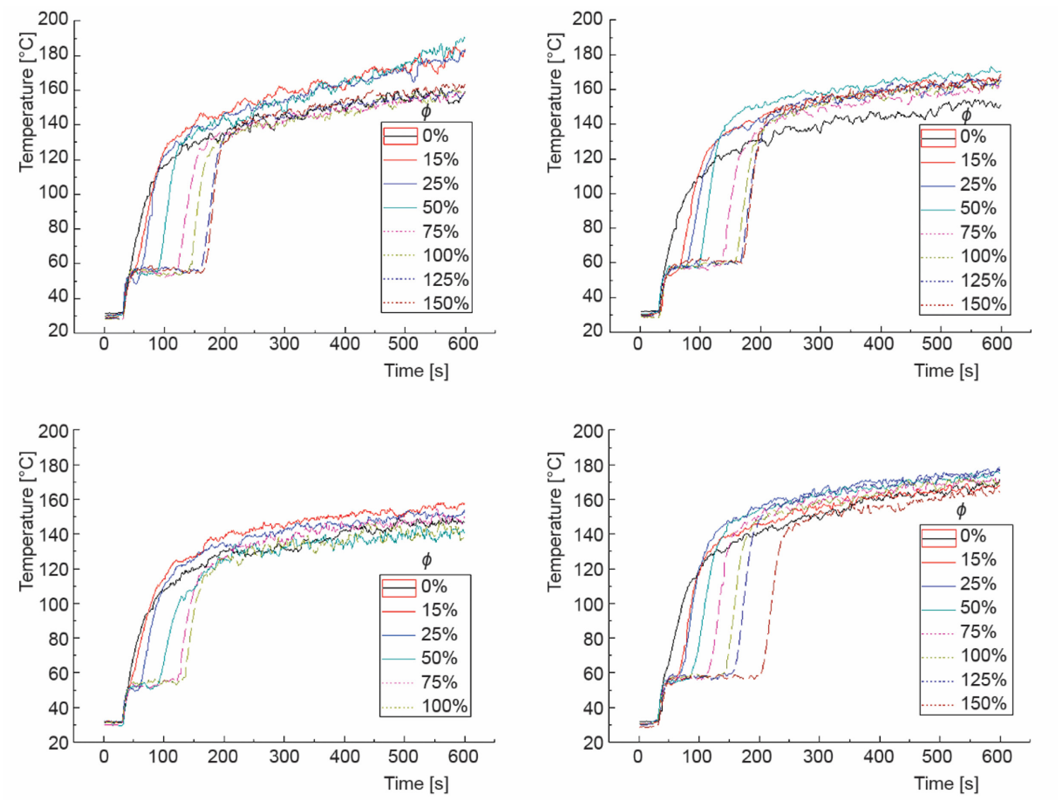

Figure 4. The **trend of temperature variation of four kinds of fabrics exposed to radiant heat flux of 20 kW/m^2**

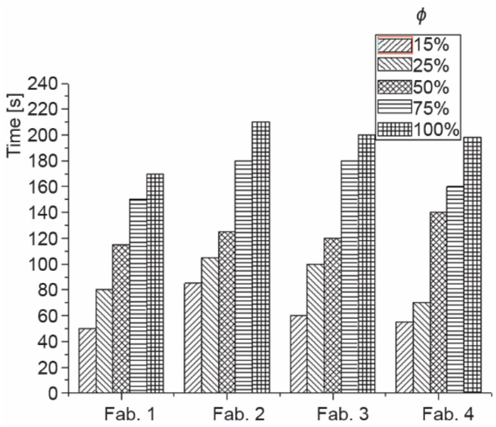

Figure 5. The duration of keeping a constant temperature of the four kinds of fabrics exposed to radiant heat flux of 20 kW/m^2

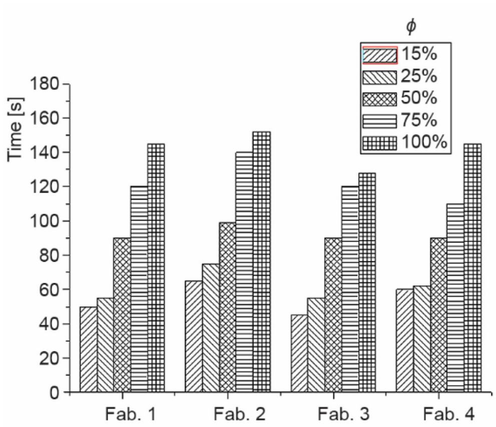

Figure 6. The duration of keeping a constant temperature of the four kinds of fabrics exposed to radiant heat flux of 40 kW/m^2

exposed to radiant heat flux of 20 kW/m^2 and 40 kW/m^2. By contrasting figs. 2, 5, and 6, it can be found that the duration of keeping a constant temperature shortened as the enhancement of radiant heat flux. So in conclusion, the situation when exposed to radiant heat flux of 20 kW/m^2 and 40 kW/m^2 were consistent with the situation in radiant heat flux of 5 kW/m^2 except that the temperature rose more quickly, the duration of keeping a constant temperature was shorter and the temperature after being stable was higher. Therefore, high radiant heat environment has a higher request for TPP of fabrics.

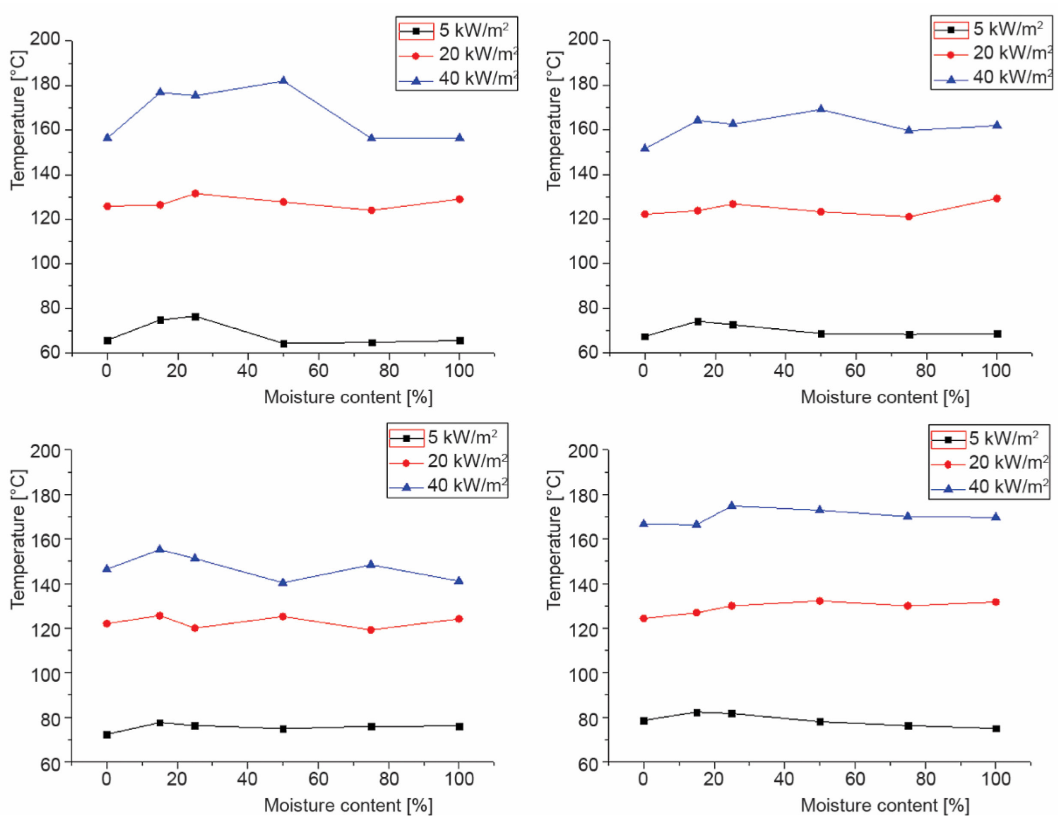

Figure 7. The influence laws of moisture content ϕ on TPP of fabrics

The average temperature for the facecloth side of fabrics during 500 to 600 seconds were took as reference data of their TPP to compare the influence laws in different radiant heat exposures. Figure 7 showed the influence laws of moisture content on TPP in different test conditions. It indicated that these influence laws were not the same when exposed to different radiant heat flux. The temperature for the facecloth side of moistened fabrics was higher than dried fabrics in each radiant heat exposures in general, namely the TPP of moistened fabrics was worse than dried fabrics.

Conclusion

All of the temperature profiles for the facecloth side of moistened flame retardant fabrics under different radiant heat flux conditions presented the same variation trend. The TPP enhanced with the increase of moisture content when the heat radiation time is more than

60 seconds. While when heat radiation time increased beyond 500 seconds, the TPP of moistened fabrics became worse than that of dried fabrics in general. Consequently, the absorbed moisture will execute different impacts on the TPP of flame resistant fabrics in different periods of heat radiation. Besides, the moisture will played different roles when exposed to different radiant heat flux.

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