Fire Safety Journal 71 (2015) 9–19

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

Study on visible–IR radiative properties of personal protective clothings for firefighting

A. Collin [a,b,*], A. Marchand [a,b], A. Kadi [a,b], Z. Acem [a,b], P. Boulet [a,b], J. Pageaux [a,b], S. Pinson [a,b], M. Lepelletier [c], Y. Van Waelfelghem [c], F. Magnolini [d], H. Charette [d]

[a] Université de Lorraine, LEMTA, UMR 7563, Vandœuvre-lès-Nancy, F-54500, France
[b] CNRS, LEMTA, UMR 7563, Vandœuvre-lès-Nancy, F-54500, France
[c] Service Départemental d'Incendie et de Secours de Vendée, SDIS 85, Les Oudairies, La Roche sur Yon, F-85017, France
[d] Service Départemental d'Incendie et de Secours de Meurthe et Moselle, SDIS 54, Groupement technique et logistique, Ludres, F-54710, France

ARTICLE INFO

Article history:
Received 14 April 2014
Received in revised form
11 September 2014
Accepted 23 November 2014
Available online 29 November 2014

Keywords:
Radiative transfer
Radiative absorptivity
Firefighter's clothing
Thermal protection

ABSTRACT

This work deals with the radiative properties of personal protective clothings worn during firefighting operations by firemen. Several intervention jackets are tested coming from different Fire and Rescue Services in France. The present study focuses on the spectral absorptivity of these equipments over visible–IR domains. The spectral absorptivity in the IR range is mainly responsible for the conversion of radiative transfer coming from the flame into heat flux through the protective jacket. This work shows that the mean absorptivities of different equipments are high, close to 90%, which penalizes the thermal protection. This study demonstrates that the colored textile has a weak effect on the radiative properties and then on the thermal protection. On the contrary, the dyeing mode can decrease the absorptivity, hence improving the thermal protection of jackets, a dyed jacket being more efficient in the present test than a jacket made of fibers dyed before weaving. Finally, this paper presents mean absorptivities based on Planck's averages for reference temperatures between 800 K and 1400 K, allowing to compare different personal protective clothings.

1. Introduction

Every year, many firefighters are victims of thermal injuries during fireground operations. For example, a recent survey provided by the National Fire Protection Association estimates that 43.5% of the 70 090 firefighter accidents occurred during fireground operations in 2011 [1] were due to thermal injuries. Despite the fact that firefighters' protective clothes are efficient and protect them better than ever before, their Personal Protective Equipment (PPE) now behaves as a performing thermal insulation which also has a negative impact regarding physiological strains. Indeed, PPE hinders heat transfer from inside to outside by radiation, convection and conduction which can induce a significant increase of the local temperature. This temperature can reach 50 °C or even more inside protective clothings such as fire resistant fabrics or helmets. A long exposure to these thermal conditions results in fatigue, overexertion and stress [1]. Consequences can be slips, trips, falls, burns and more dramatically, sudden cardiac events.

The heat flux responsible for this heat stress is generally produced by a fire (flames) and/or by the surrounding walls and is received by the firefighters on their protective clothings. The heat flux is in the range from few kW/m^2 for usual operations at a given distance from the fire to 200 kW/m^2 for a flashover or backdraft situation [2]. In order to define the thermal conditions encountered by firefighters, Duffle et al. [3] defined several configurations based on the incident radiative heat flux and the ambient temperature (involved in convective heat flux). This classification, recalled in Fig. 1, considers three typical conditions:

- *Routine* – conditions encountered during normal operations at some distance from the fire source.
- *Hazardous* – conditions encountered when the firefighters enter into a burning room.
- *Emergency* – conditions encountered within a flashover or backdraft situation.

The total heat flux received by firefighters combines a convective part (related to the ambient temperature) and a radiative part. These two heat transfer contributions are not easily separated. It is commonly assumed that the convective part is as important as the radiative one. The latter depends on radiations

* Corresponding author at: Université de Lorraine, LEMTA, UMR 7563, Vandœuvre-lès-Nancy, F-54500, France.
E-mail address: anthony.collin@univ-lorraine.fr (A. Collin).

http://dx.doi.org/10.1016/j.firesaf.2014.11.006
0379-7112/

Nomenclature

T	temperature (K)
I^o	blackbody emittance (W/m^2)

Greek symbols

α	absorptivity (–)
τ	transmissivity (–)
ρ	reflectivity (–)
φ	radiative heat flux (W)
λ	wavelength (m)

Subscripts, superscripts

ν	spectral dependence
inc	incident
r	reflected
t	transmitted
ref	reference
zero	offset

List of abbreviations

FTIR	Fourier transform infrared spectroscopy
MCT	mercury cadmium telluride
PPE	protective personal equipment
SEM	scanning electron microscopy

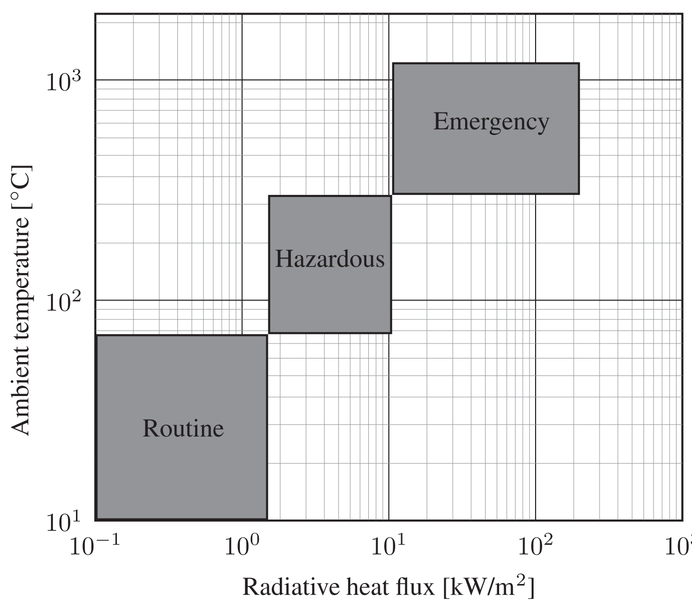

Fig. 1. Classification of firefigther exposure conditions according to Duffle et al. [3].

emitted by high temperature sources and on the radiative properties of firefighter PPE. When the optical thickness of the flame is large (i.e. sooty flame or flame with large dimensions) or when the wall temperature is high, radiative transfer may become the main heat transfer mode [4,5]. It is then important to well understand what is the radiative behaviour of the firefighter's clothing, evaluating its radiative properties and considering the influence of the textile involved in the PPE, which can vary from one fabric to another.

The PPE worn by firefighters has to keep them safe, providing enough protection, while still allowing flexibility and lightness in order to let them move quickly in emergency conditions. The protection involves a hood, a mask plus a helmet for the head, gloves, boots and a fire resistant suit. The present study focuses on the radiative properties of the fire resistant suits. Many years ago, leather was used in PPE, with problems related to its thermal retraction under the high temperature conditions. In France, dramatic events in Neuilly-sur-Seine (decease of 5 firefighters) and Loriol (4 deads and 1 missing) in 2002 led the national authorities to use synthetic fabrics, which now improve their visibility and the thermal protection (see the intervention jacket in Fig. 2(a) for example). Leather parts are now only used to increase the protection of some local areas on a protective clothing such as the knees, elbows and ankle.

Typical protective clothings are made of several layers as detailed in Fig. 2(b), from the left to the right:

- Outermost layer made of synthetic fibers (polymer) which are tightly woven. It provides a shield against flame and humidity. This fabric is a self-extinguishing material which means that it has no melting point, avoiding the flame propagation (fabric on the left hand side in Fig. 2(b)).
- Moisture barrier corresponding to the second layer in the protective clothing. This layer prevents from hot water and chemical compound transfer toward the firefighter skin.
- Innermost layer devoted to thermal insulation. It is generally made of one or two fabrics (the two last fabrics on the right hand side in Fig. 2(b)). Although the fibers used here are synthetic fibers just like for the outermost layer, they are not