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Estimation of Radiant Heat Resistance of Cotton Fabrics Treated with Bio-Based Flame Retardant ⋆

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Abstract

Modern technologies and developments have a major impact and contributions to a massive increase in the various types of hazards to which human beings are exposed. The protection from flame, fire, heat radiation sources, etc., is a principal requisite for both civil and defense applications. Textile fabrics constructed from natural fibers have been used traditionally for ordinary protection. Hence, the focal objective of the present research work was to scrutinize the improvement in thermal resistance/insulation performance of the flame retardant cotton fabrics treated with milk casein, a biomacromolecule-based flame retardant. Milk casein (a phosphorous-containing protein) was applied, as a green flame retardant finishing material, on the cotton fabrics through aqueous solutions by using an industrially applicable method. In order to evaluate the thermal protective performance, single-layer casein treated cotton fabric samples were exposed to a radiant heat source at a specific radiant heat flux density (Q_o) as per ISO 6942-B standard test method. The transmitted heat flux density (Q_c) and heat transmission factor (TFQ_o) were discerned to shift towards the lower values for the casein treated cotton fabric samples as compared to untreated cotton fabric indicating the enhanced thermal protection phenomenon.

Keywords: Cotton Fabric; Milk Casein; Green Flame Retardant; Thermal Resistance; Heat Flux Density

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1 Introduction

The resistance offered by flame retardant textile fabrics and clothing against thermal exposure is a vital requirement in order to protect the structure and ultimately to ensure human beings' survivability. In various industrial settings, several workers, firefighters, aircrewmen, and military personnel are routinely experienced a potential exposure to different levels of radiation heat flux but are only accidentally in contact with flames. That may cause skin burns even on wearing flame retardant fabrics and/or clothing. Therefore, the consideration of the thermal performance of flame retardant fabrics is important and indisputable [1]. The thermal resistance behavior of textiles provides protection from the thermal hazards that involve exposure to high-temperature radiant sources, flame impingement, hot gases and liquids, molten substances, and hot solids and surfaces [2]. The heat transfer from a thermal hazard can be ensued by different phenomena such as radiation, convection or conduction, and/or a combination. Therefore, from the total heat energy that reaches a fabric, some may be absorbed, some reflected and the remaining one either transmitted or conducted through the fabric. Approximately 95% of the incident heat energy that reaches the skin is absorbed by it and conducted to the inner and/or deeper layers, consequently fissuring and causing severe burn injuries to the skin [3]. Skin burns occur when the human tissue temperature is raised from a normal blood temperature of 36.5 °C to 44.0 °C at a rate that depends on the level of raised temperature [4-6]. In the previous literature, the thermal protective performance of single- and/or multilayered fabrics was evaluated under radiant heat exposures of different intensity levels according to the standardized or customized test methods [2, 7-11]. Thermal resistance textiles should, provide insulation against heat, not ignite, remain intact, not shrink and melt, not form the brittle char residues that may rupture and expose the wearer [7]. Indeed, due to availability in large quantities and plentiful diverse advantages such as good mechanical properties, hydrophilicity, physiological comfort, biodegradability, absence of static charge problems, etc., cotton, a cellulosic fiber, is one of the most important biopolymers in the world [12]. However, the ease of thermal degradation, ignition, and burning of cotton textile fibers and fabrics [13], restricted many of their specific applications in transportation, automotive, protective garments, military, furniture upholstery, bed linen, and nightwear. Thus the demands for flame retardant cotton textiles possessing good radiant heat resistance have become an urgent exigency and have had steady growth for the past decades. Nowadays, the textile sector strives to develop innovative technologies or to combine different techniques and materials to obtain a new material of different or better properties while considering environmental issues. From this perspective, the application of casein as an environment-friendly flame retardant provided an attractive solution for the valorization of the dairy industry by utilization of its by-product/waste. Biopolymer such as casein product (a family of proteins synthesized in the mammary gland composed of α_{S1}, α_{S2}, β, and k-caseins, according to the nomenclature developed for the bovine caseins) is the major milk protein (80%) and is obtained as a co-product from the cheese and milk industry during the production of skim milk. The casein macromolecules can be considered as polyamino acids bearing several phosphate groups in their micellae structure [14], which decompose similarly to the ammonium polyphosphate salt. In addition, their moisture adsorption features could partially dissipate the heat evolved during the combustion of the fabric, and dilute the produced combustible volatile species. It is evidenced, from the data results of our previous work that the casein treatments on cotton fabrics promoted an increase in total burning time, thus exhibiting their ability for the delayed burning and partial flame protection [15]. Furthermore, the casein treated cotton fabric samples burnt at a slower rate and resulted in stronger