An Investigation of the Radiative Heat Transfer through Nonwoven Fibrous Materials

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ABSTRACT

In this study, the surface-to-surface radiation model of the Fluent CFD code is used to investigate the response of a fibrous material to the radiative heat transfer. The unsteady state heat transfer equation is solved for the temperature and heat flux in and around the fibers that constitute a nonwoven fibrous material. For a fixed fiber diameter, it was shown that the higher the fabric's Solid Volume Fraction (SVF), the slower is the material's average temperature rise. Our simulation results also indicate that for a fixed SVF, fiber diameter has a negligible influence on the unsteady transfer of heat through the media. Of particular interest in this paper is the effect of material's thickness on the heat penetration. It is shown that the transient heat transfer exponentially decreases by increasing the material's thickness for fixed SVFs and fiber diameters. The above finding is also in agreement with our experimental study.

INTRODUCTION

Radiative heat transfer through fibrous media has been an area of interest for many years due to the aggressive growth of such materials in thermal insulation applications. Nonwovens are fibrous materials that are manufactured in different weights and structures, and their widespread use is due to their cost-effective methods of manufacturing. Examples range from the low-cost fiber batting materials that are typically used for insulation in residential buildings to the more sophisticated and expensive composite materials used in aerospace.

Most fibrous insulation materials work by lowering the conduction and convection heat transfer, but because of their extensive available surface area, they are not as efficient in suppressing the radiative heat loss. Radiation can be a considerable mode of heat transfer through high-porosity fiber thermal insulations even at temperatures above a few hundred Kelvin.

The early radiation studies were based on semi-empirical approaches of curve fitting to experimental data, which therefore, have limited applicability in analyzing insulations of different compositions [1-14].

The objective of the current study is to examine a different approach to study radiative heat transfer in fibrous media. In this approach, we use the recently developed and implemented surface-to-surface radiation model of the Fluent CFD code to develop a better understanding of the role of fiber diameter, Solid Volume Fractions (SVF) and the material's thickness in suppressing the radiative heat transfer. This work is aimed at providing useful guidelines for product design and development. We outline the surface-to-surface radiation model of Fluent in the next section and present our simulation domain and boundary conditions in section 3. Section 4 describes our experimental setup. Simulation and experimental results are presented in section 5 followed by the conclusion in section 6.

MODELING RADIATIVE HEAT TRANSFER INSIDE FIBROUS MEDIA

Surface-to-surface model presents a method to obtain the intensity field of radiation exchange in an enclosure of gray-diffuse surfaces. The energy exchange between two surfaces depends on their size, separation distance, and orientation. These parameters are accounted for by the so-called view factor. The amount of incident energy upon a surface from another surface is a direct function of the surface-to-surface view factor, F_{jk}. The view factor, F_{jk} is the fraction of energy leaving surface k that is incident on surface j. The incident energy flux $q_{in,k}$