Theoretical and Experimental Analysis on Thermal Properties of Flexible Thermal Insulation Composite Fabric

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Abstract: In this paper, the theoretical heat transfer of flexible thermal insulation composite fabric has been analyzed and the designing method has been discussed in systematically. Heat transfer analysis of flexible thermal insulation composite fabric is sometimes too complex to be used in practical design application. So, it is necessary to have simpler methods to evaluate the heat transfer flux through multilayer thermal insulation. The paper presented experimental and theoretical studies on the determination of the effective thermal conductivities of the flexible thermal insulation composite fabric. A mathematical model has been developed to describe the heat flux through the composite fabric, where the heat transfer consists of thermal radiation, solid spacer and residual gas conduction. The three distinct heat transfer modes are treated as parallel thermal resistances, and the multilayer thermal insulation behaviour considering a layer-to-layer approach and is based on an electrical analogy. Then, thermal performances of flexible thermal insulation composite fabric are presented, selecting different materials, different layers and different spacers. Finally, the prime structure of the flexible thermal insulation composite fabric is obtained through the theoretical and experimental analysis.

Keywords: flexible, composite fabric, mathematical model, thermal properties

1. Introduction

Thermal insulation has been the subject of great interest and importance to thermal engineers and to develop heat transfer technologies[1].From cryogenic temperatures to high temperatures, developments in heat transfer and use of thermal insulations in emerging technologies have extended the range of application during the last decades, such as temperature protection in spacecrafts, polar environments, volcano adventure and so on.

Evacuated flexible thermal insulation composite fabric consists of outer fabric, inner fabric and middle multilayer insulations. To reduce the heat transfer, the outer and inner fabrics are coated with PTFE or Kapton which can increase the obturation and heat reflectivity and has low emission. The middle multilayer insulations consist of a large number of highly reflecting shields, usually between 6 and 12 um insulation thickness, separated from each other by thin nonconducting spacers[2]. The shields are generally made out of plastic (Mylar or Kapton) films (typically 6 to 12 um), which have a high mechanical strength and a low thermal conductivity. For reflecting, the shields are coated with vacuum-deposited aluminium (Al) or gold (with a thickness between 0.03 to 0.05 um). The common materials for spacer are polyester or nylon netting or silk.

The heat transfer mechanism of the multilayer thermal insulation system can be extremely complex[3]. Presence of the anisotropic solid spacer conductivity, coupled residual gas conduction and thermal radiation heat transfer, three-dimensional temperature profile, complex geometries of the insulated system, temperature dependent physical properties, etc. can make the heat transfer analysis in multilayer insulation quite difficult[4]. Hence, it is necessary to have simple methods to evaluate the heat transfer and thermal properties of the multilayer thermal insulation systems.

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2. Heat Transfer Model for Thermal Insulation Composite Fabric

Different heat transfer modes of the multilayer thermal network are shown in Figure 1 Exemplary boundary temperatures are T_{20} (refers to hot boundary) and T_{10} (cold boundary) [5].

Different heat transfer modes of the multilayer thermal network are shown in Figure1. Exemplary

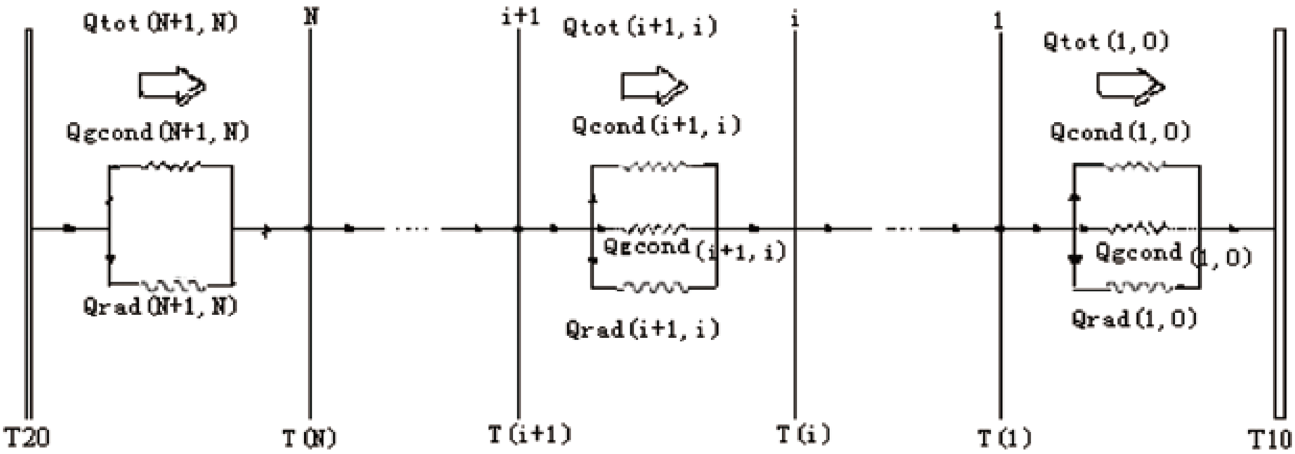

Figure1 Model structure, input and output parameters of thermal network

From T(N) to T_{10}, heat transfer through the system consists of thermal radiation (Q_{rad}), solid conduction which consists of reflectors and spacers conduction (Q_{cond}), and residual gas conduction (Q_{gcond}) . From T_{20} to T(N), the heat transfer consists of thermal radiation (Q_{rad}) and residual gas conduction (Q_{gcond}) .

In a basic steady-state condition, the total heat transfer (Q_{tot}) from layer to layer remains constant and a set of (i+1) equations can be written (compare Figure1)

$$Qtot_{i+1\to i}=Qrad_{i+1\to i}+Qcond_{i+1\to i} \quad (1)$$

2.1 Thermal Radiation Heat Transfer (Q_{rad})[7]

The corresponding calculation of radiative heat transfer diagram was drawn to calculate the radiation heat transfer, as shown in Figure 2

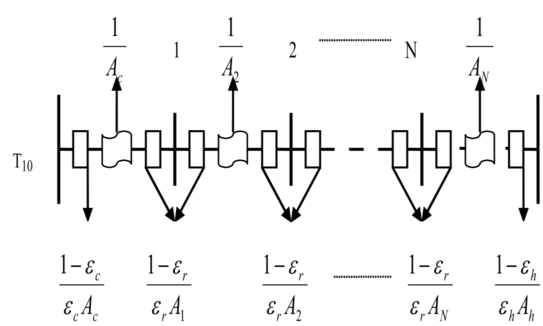

Figure 2 Radiative heat transfer diagram

Where, $(1-\varepsilon_h)/(\varepsilon_h A_h)$ as the surface radiative resistance of T_{20}, $(1-\varepsilon_r)/(\varepsilon_r A_i)$ as the surface radiative resistance of T(i), $(1-\varepsilon_c)/(\varepsilon_c A_c)$ as the surface radiative resistance of T_{10}, $1/A_i$ as the space radiative resistance between the adjacent heat transfer surface, εas the emissivity and Ai as the area of each reflecting shield.