CONTROL OF RADIATION HEAT TRANSFER THROUGH A COMPOSITE WINDOW FEATURING ER FLUID: A CONCEPTUAL INVESTIGATION

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Radiation heat transfer control through the application of an electric field upon an Electrorheological (ER) fluid based composite material is an innovative new area of research. A conceptual experiment has been conducted to study radiation heat transfer through a composite window featuring an ER fluid. The composite window is composed of two thin glass plates with a layer of ER fluid contained between them. The glass walls were transparent except for a very thin coating of an electric-conductive film which enabled the inside of the glass surfaces to serve as electrodes. The ER fluid was contained between the glass surfaces and consisted of a suspension of micron sized crystalline zeolite particles in a silicon oil. This study has demonstrated the unique capability of ER fluids to regulate and control radiation heat transfer via transmittance measurements. A semi-empirical model is developed from the experimental data to correlate the dependence of radiation transmission through ER fluids based on several physical parameters ($f_v$, $V_*$, and $L$). This model agrees reasonably well with the measured data. The results obtained in this study are very important to those concerned with the development of a thermally smart material for heat transfer control.

INTRODUCTION

The stringent controls and demands of technologically-advanced industry have created a need for the thermally smart structure: a system or material which has built-in intrinsic sensors, actuators and control mechanisms. For this purpose high performance, compact and self-contained heat transfer control units are especially desirable. Recent studies have shown the potential capabilities of Electrorheological (ER) fluid in heat transfer control (Shul'man, 1982; Zhang and Lloyd, 1992).

ER fluids are suspensions of highly polarizable micron sized particles suspended in suitable carrier fluids. When an electric field of sufficient strength is applied (i.e., 1-3 kV/min), they give rise to a complex fibrous structure, electrically induced fibration (Winslow, 1947), composed of tightly formed particle-chains generally aligned with the applied electric field. The immediately obvious effect is that the viscosity of the fluid is increased, possibly even forming an elastic-plastic substance if the particle concentrations are high enough. This process is reversible. Upon removal of the field, these particle aggregates break up as the thermally induced motion overcomes the weak colloidal forces that hold them together. Such a unique feature of ER fluids suggests that it may be exploited to enable the control of heat and mass transfer.

For example, radiation through a composite window filled with ER fluid (see Fig. 1) should be controllable. ER fluids without an applied field can be treated as an absorbing, emitting and scattering medium. The process of radiative heat transfer through this type of medium has been the subject of considerable number of studies in heat transfer as reviewed by Buckius (1986). Upon application of an electric field, the entire particulate suspension transforms into a system of particle chains. Radiation is then transferred through a medium containing numerous cylindrical fibers which are controlled by the applied electric field. The interactions between electric field, particle

Random structure ($v_\perp = 0$)  

Fibrous structure ($v_\perp = 0.5$ kV/mm)

Fig. 1. Conceptual schematic of ER fluid.

movement and temperature creates a new control mechanism for radiant energy transfer. Thus, it is of primary importance to explore the use of this physical effect of electrically-induced fibration for the development of a new type of heat transfer control system.

Electrorheology is an interdisciplinary field. During its relatively short research history (less than 40 years) there has been very few studies concerning ER phenomena in heat transfer application. The fundamental mechanism has yet to be clarified. A recent numerical study by Klingenberg et al. (Klingenberg, Frank van Swol and Zukoski, 1989) shed light on the dynamic fibration process in which they suggested the particle motion at short times is characterized by the formation of small clusters, and at long times by the interactions between large and percolating clusters. Most of the previous applications of ER fluids have been primarily focused on flow control (Arguelles et al., 1973), power transmission and shock and vibration attenuation (Bullough et al., 1973; Duclos et al., 1987; Ushijima et al., 1988), largely because of the rheological characteristics, viscosity control by the field, of ER fluids. There was a study in Russia by Shul’man (1982) and Shul’man et al. (1986) who reported the enhancement of heat transfer in heat exchangers by utilizing ER fluids. At the same time, Cerda et al. (1981a; 1981b) studied electro-optical phenomena in fibrated suspensions, in which they qualitatively measured the transmittance through a dilute guanine and silvered erythrocyte suspension subjected to a 60-Hz electric field (strength: 15 V/mm to 50 V/mm).

The objective of this research is to address and explore an innovative concept for controlling radiation heat transfer through an ER fluid based composite window. A conceptual experiment was systematically conducted to investigate the potential capability of ER fluid in controlling radiation transfer. Also discussed here is the controlling mechanism for this peculiar phenomena in light of current findings and those theory postulated in the literature. The result of this work clearly demonstrated the unique character of ER fluids in their ability to alter and control radiation transfer, and it proposed a simple but realistic transmission model derived from experimental data and retains the essence of physical mechanism.

EXPERIMENTAL

As shown in Fig. 2, a He-Ne laser beam (polarized and with wavelength of 0.6328 $\mu$m) was directed normally at a small composite window. This rectangular composite window ($38 \times 19$ mm$^2$) was filled with a layer of ER fluid with pathlengths varying from 0.5 mm to 2 mm. The inner surfaces of window glass were coated with a thin film of electric conductive Indium Oxide to enable them to serve as electrodes. A high voltage (~6000 V) luminous gas tube transformer was used to apply the electric field across the ER fluid. The transmitted laser beam intensity was measured using an Oriel 77344 photomultiplier tube which was mounted on a demountable optical holder. The PMT signal was processed by an Oriel 7070 PMT readout instrument and fed to a Fluke 2625A data acquisition