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Heat transfer analysis and flow of a slag-type fluid: Effects of variable thermal conductivity and viscosity

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ABSTRACT

In this paper we study the effects of variable viscosity and thermal conductivity on the heat transfer and flow of a slag-type non-Newtonian fluid between two horizontal flat plates. We solve the governing equations in their non-dimensional forms and perform a parametric study to see the effects of various dimensionless numbers on the velocity, volume fraction and temperature profiles. The different cases of shear- thinning and thickening, and the effect of the exponent in the Reynolds viscosity model, for the temperature variation in viscosity, are also considered.

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1. Introduction

Flowing mixtures consisting of solid particles entrained in a fluid are relevant to a variety of applications such as fluidized beds and pneumatic or hydraulic transport. The primary approach for describing and analyzing these processes has generally been accomplished through experimental studies where empirical correlations are used to describe the complex flows. Traditionally engineers have relied on experiments to study and design the various components in a power-plant resulting in empirical formulas and correlations. With recent advances in theoretical and computational modeling techniques, design engineers now have the predictive capability and the freedom to choose and change conditions leading to a better design of combustors with higher efficiency, optimum geometry, less pollution, etc. As a result, many computational fluids dynamics (CFD) codes have been developed; most of the physical models used in these codes are linear models.

Among the many areas of interest in energy related processes, such as power plants, atomization, alternative fuels, etc., one can name slurries, specifically coal–water or coal–oil slurries, as the primary fuel. Some studies indicate that the viscosity of these fluids depends not only on the volume fraction of solids, and the mean size, and the size distribution of the coal, but also on the shear rate (see [1,2]). Similarly, to improve the production efficiency of blast furnaces low slag volume is preferred by using high pulverized coal injection (PCI) operations. "Slagging" is defined, in general, as the deposition of ash in the radiative section of a boiler. For a slagging combustor, the temperatures are so high that much of the coal particles are melted and the molten layer, in turn, captures more particles as it flows. Many studies have indicated that the slag viscosity must be kept within a certain range of temperatures, for example, between 1300 °C and 1500 °C, for smooth operations where the viscosity is approximately 25 Pa s. As the operating temperature decreases, the slag cools and solid crystals begin to form. In such cases the slag should be regarded as a non-Newtonian suspension, consisting of liquid silicate and crystals [2]. In many cases, as Kang et al. [3] observed, the fluidity of blast furnace slag is controlled by changing the slag chemistry. Kang et al. [3] indicate that not only is the viscosity of slag important in these operations, but also coke/slag interactions, which could significantly impact the liquid permeability of the blast furnace In the continuous casting of steel, as the mold powder is added to the free surface of the liquid steel, it begins to melt and flow. The re-solidified mold powder, also called slag, forms a layer adjacent to the walls; there is an increase in its viscosity and it begins to act as a solid-like material (see [4,5]). Once the slag cools, a glassy layer is created. Heat conduction across the slag layer plays a major role in the operation; it is a function of the thickness of the slag and depends on the conductivity of the various layers and particles embedded in the slag. In the continuous casting of steel, the viscosity of the molten slag or flux varies with the composition of the various elements present and the temperature(see [6]). There is a great deal of similarity in the processes involving steel production and those of

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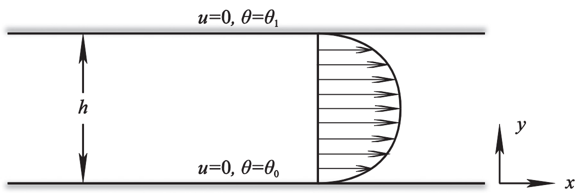

Fig. 1. Schematic representation of slurry flow in a channel.

slag in coal gasification or combustion processes. Another important area of research in the steel industry is the conversion to continuous casting from ingot casting, a process which is driven by improved efficiency, yield and higher quality steel (see [7]). The molten steel contained within the solidifying shell in the continuous casting process resembles the slag layer. Thomas et al. [8]) seem to be among the first researchers who attempted to develop a comprehensive mathematical model involving fluid flow, heat transfer, shrinkage, and stress generation in such a slab-casting

Table 1
Designated values of the dimensionless numbers and parameters.

m	M	B_1	B_2	B_4	R'_4
−0.6, 0, 0.4	0, 1, 1.5	−0.5, −1.5, −2	0, 0.01, 0.05	0.05, 0.1, 0.2	5, 10, 15
ω	C_1		C_2		
0, 1, 3, 7.6, 10	−1.5, 0, 1.2, 2.07121, 2.25		0.46244, 0, 0.41322, 1.35044, 2.16423		

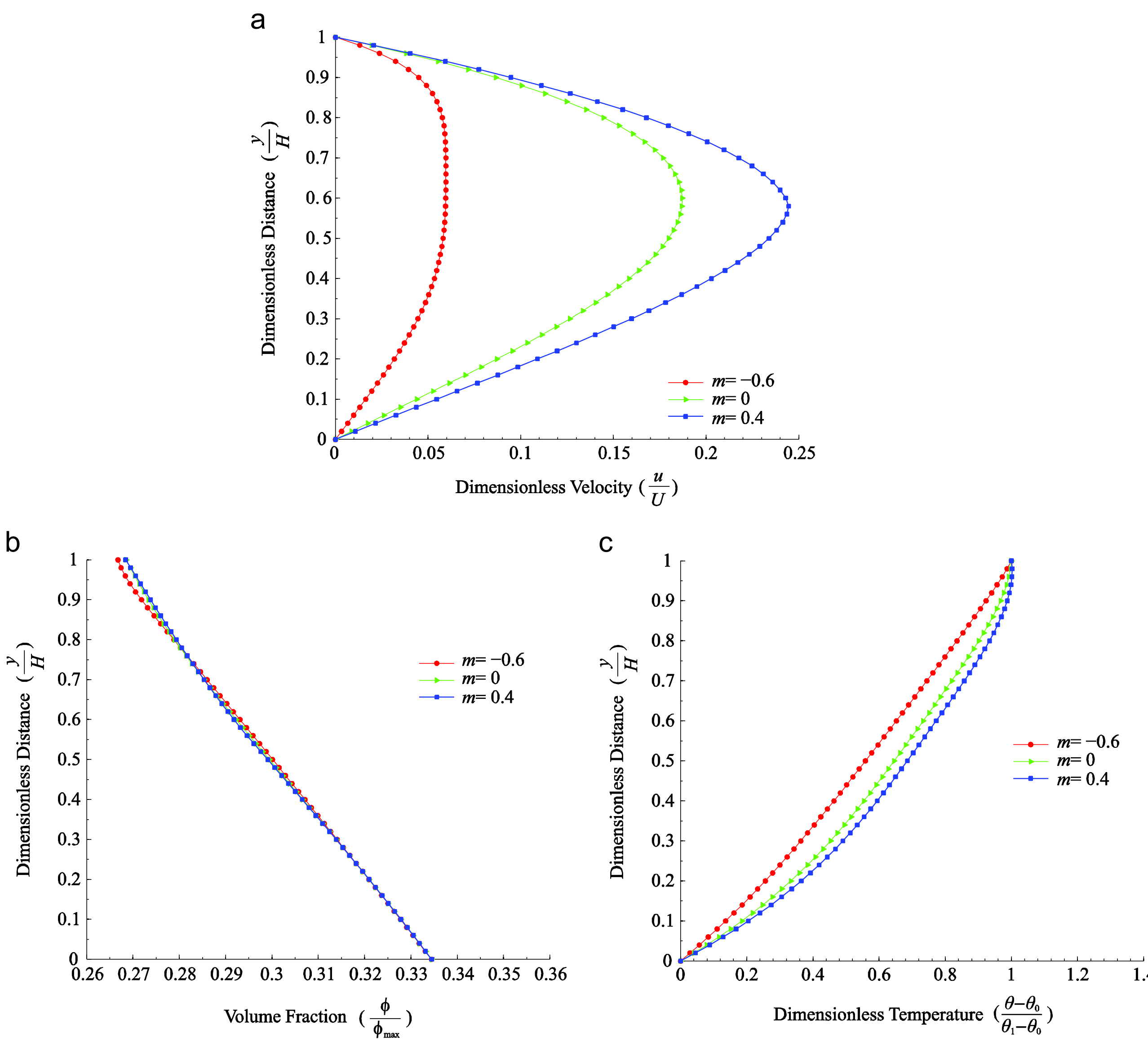

Fig. 2. (a) Effect of m on the dimensionless velocity distribution. (b) Effect of m on the volume fraction distribution. (c) Effect of m on the temperature distribution. .$M=1, B_1=-2, B_2=0.01, B_4=0.1, R'_4=5, \omega=0.1, T=1.5, N=0.3$.