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Melting heat transfer effects on stagnation point flow of micropolar fluid with variable dynamic viscosity and thermal conductivity at constant vortex viscosity

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Abstract

The two dimensional boundary layer flow of micropolar fluid towards stagnation point formed on a horizontal linearly stretching surface is investigated. Melting heat transfer at the surface, temperature and exponentially space dependent internal heat generation within fluid domain are considered. It is assumed that dynamic viscosity and thermal conductivity are temperature dependent while micropolar vortex viscosity is constant. These assumptions are discussed. Classical temperature dependent viscosity and thermal conductivity models were modified to suit the case of melting heat transfer following all the necessary theories. Similarity transformations are used to convert the governing equations into non-linear boundary value problem and solved numerically. Effects of various parameters on the micropolar fluid flow and heat transfer are analyzed. The results reveal that one of the possible ways to increase transverse velocity of micropolar fluid flow over melting surface is to consider variable thermo-physical property of micropolar fluid at constant vortex viscosity with a decrease in melting parameter while velocity ratio increases. For correct analysis/investigation of micropolar fluid flow with variable properties over melting surface, the new thermo-physical models are to be considered. The velocity increases with the increase of velocity ratio under the new condition compare to classical condition (constant thermo-physical property) of micropolar fluid flow over melting surface.

Keywords: Constant vortex viscosity; Micro-polar fluid; Stagnation point flow; Variable viscosity and variable thermal conductivity

1. Introduction

In thermal Physics, heat transfer has been reported as the passage of thermal energy from a hot body to a cold body (i.e. fluid). This aspect in fluid mechanics is of particular interest in engineering and industrial processes due to its importance in the configuration and production of heat transfer equipment such as coolers and evaporators. The study of stagnation point flow was pioneered by Hiemenz [1]. A flow can be stagnated by a solid wall, a free

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stagnation point or a line can exist in the interior of the fluid domain Shateyi and Makinde [2]. Bhattacharyya et al. [3] analyzed the effects of partial slip on steady boundary layer stagnation-point flow of an incompressible fluid and heat transfer towards a shrinking sheet. The relevance of this study attracted Motsa et al. [4] to formulate mathematical equation governing Maxwell fluid for two-dimensional stagnation flow towards a shrinking sheet and analyzed the flow behaviour extensively using similarity variables together with successive linearization method. Stagnation point flow has also been investigated by Makinde and Charles [5], Nadeem et al. [6], Makinde [7], Mahapatra and Nandy [8]. All these intellectual properties and many related published articles has widened the knowledge of fluid flow with microstructure and heat transfer near stagnation regions. In recent years, the dynamics of fluid with microstructure has become a popular area of research. Micropolar fluid belongs to a class of fluids with non-symmetric stress tensor and consists of particles with spinning motion [9]. During the industrial production of polymer fluids, colloidal solutions and fluid containing small additives; a point where the local velocity of fluid with non-symmetric stress tensor is zero tends to exist. Stagnation-point flow appears in virtually all fields of science and engineering [2]. Micropolar fluids consist of rigid, randomly oriented (or spherical) particles which have own spins and micro-rotations suspended in a viscous medium [9–11]. Since static pressure is highest when the velocity is zero, static pressure is at its maximum value at stagnation point. Hence, Engineers in industry introduces internal heat generation to reduce drag and enhance easy flow of fluid around stagnation point where the velocity is zero. There are many ways where internal heat generation in a convective flow tends to occur. For instance, in the development of a metal waste form from spent nuclear fuel, phase change processes and thermal combustion processes, convection with internal heat generation plays an important role in the overall heat transfer process Olanrewaju et al. [12].

Internal energy generation can be explained as a scientific method of generating heat energy within a body by a chemical, electrical or nuclear process. Natural convection induced by internal heat generation is a common phenomenon in nature. Example include motion in the atmosphere where heat is generated by absorption of sunlight [13]. Crepeau and Clarksean [14] carried out a similarity solution for a fluid with an exponential decaying heat generation term and a constant temperature vertical plate under the assumption that the fluid under consideration has an internal volumetric heat generation. In many situations, there may be appreciable temperature difference between the surface and the ambient fluid. This necessitates the consideration of temperature dependent heat sources that may exert a strong influence on the heat transfer characteristics (see El-Aziz and Salem [15]). El-Aziz and Salem [16] further stated that exact modeling of internal heat generation or absorption is quite difficult and argued that some simple mathematical models can express its average behavior for most physical situations. Effect of this internally generated heat energy on the surface may lead to melting of solid surface and also weaken the intermolecular forces between the micropolar fluid layers as it flows towards stagnation point. From the knowledge of kinetic theory of matter, every solid melts if expose to a high temperature. In an earlier study, the effect of melting on heat transfer was studied by Tien and Yen [17] for the Leveque problem. The tangential velocity profile is assumed to be linear. It was further reported by Yen and Tien [18] that the approximation in [17] is valid if one deals with a high Prandtl number fluid so that the significant temperature change takes place only within a thin layer of fluid immediately adjacent to the solid boundary and consequently the velocity profile inside this thin layer can be approximated by a linear segment. The similarity between the melting problems and mass transfer or transpiration cooling problems was also noted in [18]. In addition, effect of melting on heat transfer between melting body and surrounding fluid qualitatively from the point of view of boundary layer theory was investigated. In recent years, many researchers have investigated and reported the effect of melting parameters [19–25].

In all of the above mentioned studies, fluid viscosity and thermal conductivity have been assumed to be constant function within the boundary layer. However, it is known that physical properties of the fluid may change significantly when expose to internal generated temperature. For lubricating fluids, heat generated by the internal friction and the corresponding rise in temperature affect the viscosity of the fluid and so the fluid viscosity can no longer be assumed constant. In a case of melting as reported by many researchers [19–25]; it is worth mentioning that temperature of fluid layers at free stream may also have significant effect on the intermolecular forces of the micropolar fluid. The increase of temperature may also leads to a local increase in the transport phenomena by reducing the viscosity across the momentum boundary layer and so the heat transfer rate at the wall may also be affected greatly. According to Anyakoha [26], Batchelor [27], Animasaun and Oyem [28] and Meyers et al. [29], it is a well-known fact that properties which are most sensitive to temperature rise are viscosity and thermal conductivity. Recently, Mukhopadhyay [30] considered this same fact in order to predict stagnation point flow behaviour on non-melting surface. Also, Salem and Fathy [31] presented the effect of variable viscosity and thermal conductivity on steady