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Double-layer optical fiber coating analysis in MHD flow of an elastico-viscous fluid using wet-on-wet coating process

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ABSTRACT

Modern optical fibers require a double-layer coating on the glass fiber in order to provide protection from signal attenuation and mechanical damage. The most important plastic resins used in wires and optical fibers are plastic polyvinyl chloride (PVC) and low and high density polyethylene (LDPE/HDPE), nylon and Polysulfone. One of the most important things which affect the final product after processing is the design of the coating die. In the present study, double-layer optical fiber coating is performed using melt polymer satisfying Oldroyd 8-constant fluid model in a pressure type die with the effect of magneto-hydrodynamic (MHD). Wet-on-wet coating process is applied for double-layer optical fiber coating. The coating process in the coating die is modeled as a simple two-layer Couette flow of two immiscible fluids in an annulus with an assigned pressure gradient. Based on the assumptions of fully developed laminar and MHD flow, the Oldroyd 8-constant model of non-Newtonian fluid of two immiscible resin layers is modeled. The governing nonlinear equations are solved analytically by the new technique of Optimal Homotopy Asymptotic Method (OHAM). The convergence of the series solution is established. The results are also verified by the Adomian Decomposition Method (ADM). The effect of important parameters such as magnetic parameter M_i, the dilatant constant α, the Pseodoplastic constant β, the radii ratio δ, the pressure gradient Ω, the speed of fiber optics V, and the viscosity ratio κ on the velocity profiles, thickness of coated fiber optics, volume flow rate, and shear stress on the fiber optics are investigated. At the end the result of the present work is also compared with the experimental results already available in the literature by taking non-Newtonian parameters tends to zero.

Introduction

Investigating the behavior of the boundary layer of a viscoelastic fluid, on a continuous surface stretching, is important for the analysis of polymer extrusion, drawing of plastic films, fiber optics and wires. The significance in industrial process applications has led to a deep interest by researchers for the study of viscoelastic fluid flow and heat transfer in fiber and wire coating process. The optical fiber coating is an industrial process for provision of insulation, environmental safety, mechanical damage and guard against signal attenuation. The simple and suitable process for wire coating is the coaxial extrusion process that operates at the maximum pressure, temperature and wire drawing speed. This coating of the continuum velocity and melt-polymer produces high pressure in a particular region which results into strong bonding and fast coating. Many researches such as Han and Rao [1], Nayal [2], Caswell [3] and Ticker [4] studied the co-extrusion process in which either the polymer is extruded on axially moving belt or the fiber (wire) is dragged inside a die filled with molten polymer.

The manufacturing of optical fibers is a series of automated inline process such as the drawing of glass fiber from a softened Silica preform in draw furnace, the coaling of freshly drawn glass fiber in helium injected Coaling System, and the double layer coating of polymers on glass fibers. Then, the optical fiber manufacturing becomes complete as the liquid fiber coatings are cured by Ultraviolet (UV) Lamps.

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The coatings are necessary to provide mechanical protection and to prevent the ingress of moisture into microscopic flaws on the fiber surface. The optical fibers today in general are characterized by a double-layer coating structure: an inner layer (called a primary coating layer) made of soft coating material and an outer layer (called a secondary coating layer) made of hard coating material. The role of the Primary layer is to minimize attenuation due to micro bending, while the secondary layer protects the primary coating against mechanical damage. The widespread industrial success of optical fibers as a practical alternative to copper wiring could be attributed to these UV-curable coatings.

Two types of coating process are used for double-layer optical fiber coating, while being pulled at high speed namely: wet-on-dry (WOD) and wet-on-wet (WOW) process. In wet-on-dry coating process, the glass fiber passes through a primary coating applicator which is immediately cured by UV lamps, and then the fiber enters a secondary coating applicator, again followed by UV lamps. However, in the WOW coating process, the glass fiber passes through both the primary and secondary coating applicators and then both these coatings are cured by UV lamps. In the past, the majority of optical fiber drawing systems used the wet-on-dry process, but recently the wet-on-wet coating process has gained significant popularity in optical fiber manufacturing industry. Here, in this study, we also applied the wet-on-wet coating process for optical fiber coating as shown in Fig. 1.

In fiber coating, the fiber drawing velocity and the quality of material are more important. And after leaving the die, the temperature of the coating material is also important.

Different types of fluids are used for wire and fiber optics coating, which depends upon the geometry of die, fluid viscosity, temperature of the wire or fiber optics and the molten polymer. Most relevant work on the wire and fiber optics coating are thus summarized in the following.

The power law fluid model was used by Akter and Hashmi [5,6] for wire coating. Siddiqui et al. [7] used third grade fluid for wire extrusion in a pressurized die. Fenner and Williams [8] investigated the flow in the tapering section of a pressurized die. Unsteady second grade fluid with oscillating boundary condition inside the wire coating die was investigated by Shah et al. [9]. Exact solution was obtained for unsteady second grad fluid in wire coating analysis [10]. Shah et al. [11] studied third grade fluid with heat transfer in the wire coating analysis.

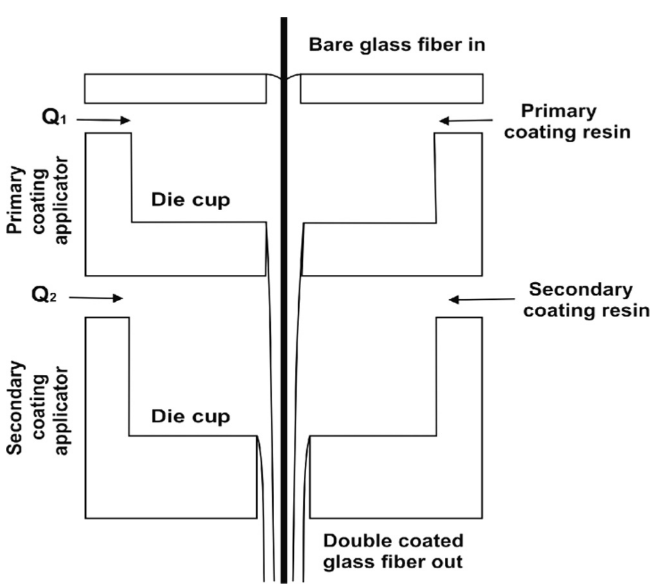

Fig. 1. Double-layer optical fiber coating in wet-on-wet coating process.

The interest in heat transfer problems involving non-Newtonian fluids have grown considerably as the application of non-Newtonian fluids perpetuates through various industries, including polymer processing and electronic packaging. Heat transfer analysis is very important for the advancement of science and technology, modern instruments such as micro-electro-mechanical systems (MEMS), laser coolant lines and compact heat exchangers are being used for many purposes. Laminar heating and cooling occur an increasing variety in such instruments. Consequently, the results for the flows and heat transfer of non-Newtonian fluids are needed. A complete survey of the literature is impractical. However, a few studies are listed here to provide starting points for a broader literature search. Shah et al. [12] studied the wire coating analysis with linearly varying temperature. Mitsoulis [13] studied the wire coating flow with heat transfer. The corresponding heat transfer problem of fully developed pipe and channel flows of PTT fluid was also investigated by Oliveira and Pinho [14].

Recently, a viscoelastic fluid model known as Phan-Thien-Tanner (PTT) model is widely used for wire and fiber coating [15]. It is a non-linear viscoelastic model which incorporates shear thinning, shear viscosity, normal stress difference and an elongation parameter which reproduces many of the characteristics of the rheology of polymer solutions and other non-Newtonian fluids. Many researchers studied the post-treatment analysis of wire coating with heat transfer [16]. Wagner and Mitsoulis [17] investigated the wire coating with the effect of die design. Numerical solution for wire coating analysis using a Newtonian fluid was investigated by Bagley and Storey [18]. Pinho and Oliveira [19] studied the problem of fully developed channel and pipe flows of PTT fluids and obtained an analytical expression for velocity fields and stress components in both geometries.

Many recent researchers have a significant interest in non-Newtonian fluid flow because of their extensive use in industrial and technological applications such as blood, soap solutions, cosmetics, paint thinners, crude oils, sludge, etc. Magneto-hydrodynamic (MHD) addresses the electrically conductive fluid flows in the presence of magnetic field. Researchers have devoted considerable attention to the study of MHD flow problems focusing on non-Newtonian fluids because of its broad applications in the fields of engineering and industrial manufacturing. Some examples of these areas are energy generators MHD, melting of metals by application of a magnetic field in an electric furnace, the cooling nuclear reactors, plasma studies, the use of non-metallic inclusions to the purification of molten metals, extractions of geothermal energy, etc. Abel et al. [20] studied the effects of radiation and thermal buoyancy force in MHD flow of viscoelastic fluid on a stretching area in continuous motion. Sarpakaya [21] was the pioneer who at first studied the non-Newtonian fluid flow when the magnetic field is present. Abel et al. [22] investigated the heat transfer analysis with effect of MHD to the Upper Convected Maxwell fluid examined the magnetohydrodynamic (MHD) effects the transfer of heat to the upper fluid convected Maxwell (UCM). Analytical solution was obtained of MHD flow of an Upper Conveted-Maxwell fluid by Hayat et al. [23]. Ali et al. [24] studied New Exact Solutions of Stokes' Second Problem for MHD Second Grade Fluid in a Porous. The unsteady magnetohydrodynamic oscillatory flow of viscoelastic fluids in a porous channel with heat and mass transfer investigated by Farhad et al. [25]. Khan et al. [26] investigated the exact solutions for the unsteady free convection flow of a Jeffrey fluid. Khan et al. [27] carried out an analysis for rotating MHD flow of a generalized burgers' fluid over an oscillating plate embedded in a porous medium. Energy transfer in mixed convection MHD flow of nanofluid containing different shapes of nanoparticles in a channel filled with saturated porous medium analizede by Aiza et al. [28]. Recently, Gul et al. [29] investigated the heat transfer in MHD mixed convection flow of a ferrofluid along a vertical channel.