Numerical Study on Time Dependent Visco-Inelastic Fluid Flow in Wire Coating Process

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Aim of the Research

This study investigates the wire coating process using an Eyring Powell fluid under a constant pressure gradient. The research focuses on the unsteady state with oscillating boundaries to develop the governing equations. The equations are subsequently transformed into a dimensionless format and resolved numerically via the Method of Lines. The findings are showcased through both 2D and 3D graphical representations.

Introduction

Various industrial materials, including polymers, food products, paints and cosmetics, show non-Newtonian characteristics. Grasping the flow properties of these substances is crucial for effective processing, production, and quality management. Additionally, polymers like PVC and polyethylene are vital in wire coating processes due to their excellent electrical properties, cost-effectiveness, and broad availability. These materials also offer significant resistance to moisture and chemicals. As a result, significant research has been focused on improving wire coating processes, spurred by the demand for wires that perform well under harsh conditions [1], [2]. Considering this, a significant portion of research has directed their attention towards studying the coating process for wires. These analyses have explored the behavior of non-Newtonian and Newtonian fluids, focusing on properties like rate of volume flow and the force needed for wire motion.

In later years, numerous researchers turned their attention to the wire coating process, with a specific focus on the behaviour of different non-Newtonian fluids. However, research addressing the mathematical aspects of wire coating in unsteady conditions is rarely conducted.

Wire coating is a critical process mainly in the manufacturing of electrical and electronic components, ensuring both the protection and functionality of the wires. Despite significant advancements in coating materials and application techniques, there remains a need for further exploration into optimizing these processes for better efficiency, cost-effectiveness, and environmental sustainability. The following research gap highlights the areas where current literature falls short and the potential for future innovation.

- Developing a mathematical formulation that governs the flow of EP model in a coating process. This framework aims to describe the flow characteristics of molten polymer solution by accounting for a constant pressure gradient along with oscillating boundaries. Also, the focus is on understanding these dynamics in an unsteady state.
- Analysing engineering parameters of interest including shear stress and volume flow rates using Method of lines technique.
- Investigating the sensitivity of the significant parameters like oscillating parameter, pressure gradient, and EP parameter corresponding to shear stress rate (S_{rz}) as response variable using Optimization technique.

Problem Formation

The fundamental equations that govern the system are presented in their dimensional form as follows:

$$div(\boldsymbol{v}) = 0 , \tag{1}$$

$$\rho_f \frac{Dv}{Dt} = div(\boldsymbol{C_{st}}). \tag{2}$$

$\boldsymbol{C_{st}}$ denotes the Cauchy stress tensor, and $\frac{D}{Dt} = \frac{\partial}{\partial t} + (\boldsymbol{v} \cdot \nabla)$ indicates the material time derivative.

The corresponding initial and boundary constraints are given by:

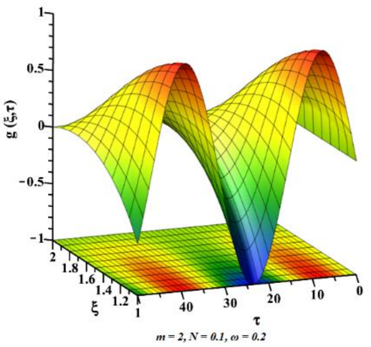
$$\text{At } t = 0, w = 0, 1 \leq r \leq \delta. \tag{3}$$

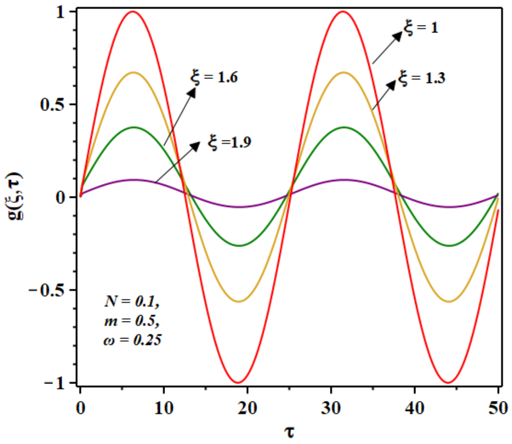
$$\left.\begin{array}{r} \text{At } r = R_w,\ w = U_w \sin(\tilde{\omega} t) \\ \text{At } r = R_d,\ w = 0 \end{array}\right\} \text{t} > 0.$$

Solution procedure

The Method of Lines (MOL) is a numerical technique used to solve partial differential equations (PDEs) by discretizing only the spatial variables, converting them into a system of ordinary differential equations (ODEs). The obtained system of ODEs is then solved numerically.

Results





Conclusions

- The fluid flow rate amplifies with an increase in the pressure gradient (m) i.e., rising m from 1 to 2 results in about 20.34 % increase in the flow rate (V) at $N = 0$ and around 10.88 % at $N = 1$.
- A 11.91% increase in the velocity profile occurs when the oscillating parameter (ω) is increased by 0.11 to 0.15.

Reference

1. Middleman S, *Fundamentals of Polymer Processing*. New York: McGraw-Hill, 1977.
2. J. N. Feil and J. E. Hrivnak, "Wire coating process," May 1986
3. McKelvey J M, *Polymer Processing*. New York: wiley, 1962.
4. Mitsoulis Evan, "Fluid flow and heat transfer in wire coating: A Review," *Advances in Polymer Technology*, vol. 6, pp. 467–487, 1986.
5. S. Hegde, N. Srikantha, and A. K. Hussein, "Optimisation of time-dependent Sisko flow in a wire coating process using response surface methodology," *Pramana*, vol. 98, no. 2, p. 71, May 2024, doi: 10.1007/s12043-024-02761-y.