EXPLORING MATHEMATICAL APPLICATIONS OF NON-NEWTONIAN FLUID BEHAVIOR IN PIPELINE SYSTEMS

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Abstract

This work explores mathematical models and practical applications of non-Newtonian fluid characteristics, which may have implications for pipeline transport. Most fluid transport systems assume that fluids behave according to Newton's laws. There are, however, cases when non-Newtonian fluid characteristics, including shear-thinning or shear-thickening behavior, are necessary. Investigating and using these unique features may lead to more efficient pipeline systems.

In order to illustrate the flow behavior of non-Newtonian fluids, the mathematical models used in the study take rheological aspects and fluid parameters into consideration. Computer fluid dynamics (CFD) models are used to examine the energy requirements, pressure drops, and transport dynamics of non-Newtonian fluids in pipelines. In order to improve the efficiency, effectiveness, and reliability of fluid transfer in pipelines, this research aims to discover solutions that consider the fluid's rheological qualities.

The results could have far-reaching consequences as they provide suggestions for the administration and development of pipeline networks that might carry fluids that do not adhere to Newton's laws.

Keywords: *mathematical models, practical applications, non-Newtonian fluid, pipeline systems, Computer fluid dynamics (CFD).*

INTRODUCTION

Researchers in the medical field have shown a great deal of interest in computational fluid dynamics (CFD) during the last several decades as a tool for better understanding and processing patient data. In vivo flow velocities may be detected using 4D PC-MRI, a non-invasive magnetic resonance imaging technique. Some of this technology's issues, such its low signal-to-noise ratio, partial volume effects, and poor spatio-temporal resolution, may be solvable using CFD. Furthermore, in some pathologically limited portions of cardiovascular MRI scans, CFD could pinpoint the precise area of turbulent flow that is leading PC-MRI to make erroneous predictions of blood flow properties. In the context of a Newtonian fluid (water), this kind of measurement mistake has been investigated computationally and experimentally. Viscoelasticity, yield stress, deformation rate dependence, and other non-Newtonian features are known to occur in tiny blood vessels. The characteristics of platelets, red blood cells, and white blood cells become more noticeable when their size approaches that of the blood vessel's width. The values of parameters like relative residence time or wall shear stress are determined by non-Newtonian behaviour. It is often assumed, however, that blood acts like a Newtonian fluid in big arteries like the pulmonary artery or the aorta. In situations involving constricted arteries, there were found to be little changes between Newtonian and non-Newtonian models. Consequently, it is not immediately apparent if pathological flow, such turbulent flow through a stenotic valve or a constricted artery, does not exhibit some non-Newtonian property.

Optimal computational timeframes for PC-MRI data augmentation using computational fluid dynamics (CFD) methods should be similar to those of a standard clinical data post-processing procedure. Among these computational fluid dynamics (CFD) methods that perform well on GPGPUs is the lattice Boltzmann method (LBM). Since LBM only performs one non-local operation—the linear streaming of data to neighbouring lattice locations—it avoids solving the pressure Poisson equation, the most time-consuming step in numerical techniques, in contrast to traditional CFD methods.

LITERATURE REVIEW

Naga Pavani. [2023] The mass and heat transfer model is expressed as a system of partial differential equations (PDEs) including Joule heating, heat production, viscous dissipation, thermal radiation, chemical reactions, and Soret-Dufour. Using appropriate quantities, the PDEs are reduced to dimensionless PDEs. In order to resolve the simplified equations, the spectrum relaxation technique (SRM) is used. Soret and Dufour's effects on the flow are discovered to reversal each other. Graphical representations of the computational results for concentration, temperature, and velocity are provided for all flow parameters that are encountered. When comparing the current results to those of the past, a correlation is seen.

Rathish Kumar [2022]. By eliminating all unsolvable scales in relation to the coarse scale solution, the stabilised formulation was achieved, and the time dependence of both subscales was carefully considered. Here, we assume that the solute mass concentration is a function of the shear-rate dependent Casson viscosity coefficient, leading to a two-way connection. Obtaining the appropriate order of convergences relies heavily on the suggested formulations of the stabilisation parameters. A sufficiently regular precise solution has been meticulously assumed throughout the many theoretical derivations in order to carry out the estimates of the non-linear apparent viscosity coefficient. Using the lid driven cavity issue, we numerically verified the scheme's performance.

Wasim Jamshed [2021]. At the border of a porous flat surface, the non-Newtonian power-law scheme is taken into account for the nanofluid by means of partial slip restrictions. Assuming the nanofluid's viscosity and thermal conductivity vary linearly with temperature, a transverse magnetic field is applied to the stream. The controlling structure of partial differential formulae is transformed into the system of ordinary differential ones using the similarity conversion approach. The numerical resolution of the resulting ordinary differential formulae and partial slip restrictions is achieved via the use of the Keller box approach.

Dr. P. Kavitha [2020] in this paper. Utilising the indicator corrector conspiracies, the innovative method regains answers for the naturally observable conditions originally discovered in the cross-section Boltzmann condition via the Chapman-Enskog extension research. Incorporating local adjustments to the physical consistency and the corresponding unwinding parameter into the shorter force law model, this method revives non-Newtonian practices. The proposed approach, in contrast to the current non-Newtonian cross-section Boltzmann models, legitimately advances the naturally apparent factors instead of the circulation capabilities, thus overcoming intrinsic limitations like excessive virtual memory costs and problematic physical limit condition execution.

Non- Newtonian Fluid

We state that the fluid is non-Newtonian if the relationship between shear stress and shear strain rate is not straight. In this category, thick liquids are common. Paints, varnishes, pastes, jellies, oil-in-water emulsions, and particle suspensions are common examples. For non-Newtonian fluids, the rheological models that connect shear stress to shear rate usually work. Most non-Newtonian fluids fall into one of three categories: differential, integral, or rate. Non-Newtonian fluids are notoriously difficult to study due to the non-linearity of their constitutive equations. Analytical methods for fluids that defy the Newtonian model have been the subject of much study and development. Countless constitutive models have been developed due to the fact that non-Newtonian fluids encountered in real-world scenarios need a large number of constitutive equations. The only way non-Newtonian fluids like power-law and Bingham plastic can behave is viscously.

Modeling assumptions

Despite the fact that gas transport operations are characterised by fundamentally dynamic processes, we persist in operating under the premise of a steady-state situation. Hence, for pipeline systems that run for relatively long periods of time, the mathematical model provides answers.

Assuming the system is in steady-state, the flow variables are rendered time-independent. Because of this, we can use very simple algebraic equations to represent the flow of natural gas via our pipeline system. By tracking the factors of choice throughout time, a transient analysis might uncover their interrelationships. The speed, density, pressure, and temperature of a gas are some of its characteristics. This

Computational Fluid Dynamics (CFD)

There are a lot of different industries that employ complex-structured fluids in their production processes. Countless more sectors, not limited to the food, polymer, pharmaceutical, chemical, oil, mining, construction, water treatment, and energy generating industries, fall under this vast umbrella. Yogurt, mayonnaise, juice, and pureed fruits and vegetables are examples of organic suspensions, while paints, foams, and industrial oils are examples of inorganic suspensions

Pipelines

Pipelines are vital for the transfer of easily available fuels like natural gas and other commodities. Many people rely on them in the transportation sector. For example, many interesting pubs and the Veltins-Arena in Gelsenkirchen, Germany are connected to other beer distribution lines via a five-kilometer-long pipeline system. Demand variations throughout a football game should be less pronounced, in principle, with these distribution lines.

However, the largest and most important use of pipelines is transporting energy products, such as natural gas and oil.

Solution methods for gas pipeline systems

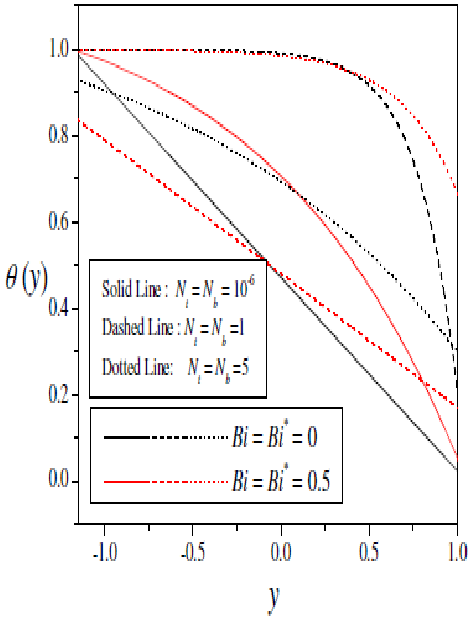
In gas pipeline systems, finding the optimal distribution network pressure settings and mass flow rate values is a common part of optimising the operation plan. Given the potential application of several complicated (inequality and equality) limits to a typical natural gas transportation problem, this is clearly not an easy undertaking. Common approaches to these kinds of problems include numerical simulation and mathematical optimisation.

METHODOLOGY

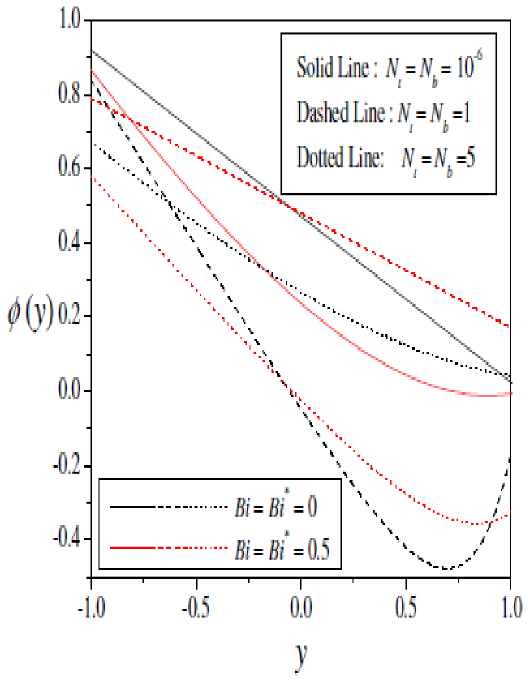
This research takes a look at two distinct kinds of multiphase systems, identified by the amount of phases they include. In the first scenario, the gas-solid system consists of an equation representing the continuous gas phase in an Eulerian form and a Lagrangian model reflecting the dispersed solid particles. In the alternative situation, a system with gas, liquid, and solid components is considered. Because it describes the two continuous phases using gas and liquid, the volume of fluids (VOF) model is applicable here. The same methodology applies for studying the dispersed phase (sand particles) using the Lagrangian method.

RESULTS

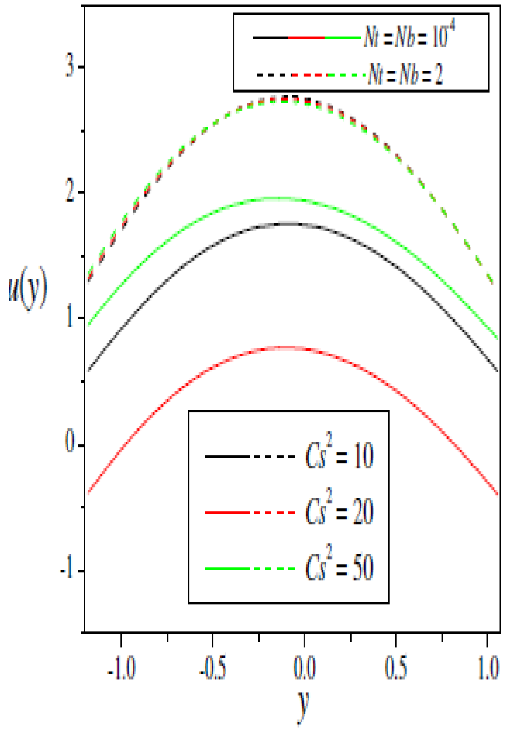
We review the key findings from the precise answers for the distribution of temperature, nanoparticles, and velocities, as well as the pressure increase over a wavelength. Since the lirerature accounts for the peristaltic flow impact, we will only cover the outcomes that correspond to the significant physical factors, such as the couple-stress parameter, Grashof numbers, Biot numbers, and slip parameters. In addition, the couple-stress and slip parameter only influence the distribution of velocities; they do not influence either the temperature or the concentration of nanoparticles because equations (5.20) through (5.24).



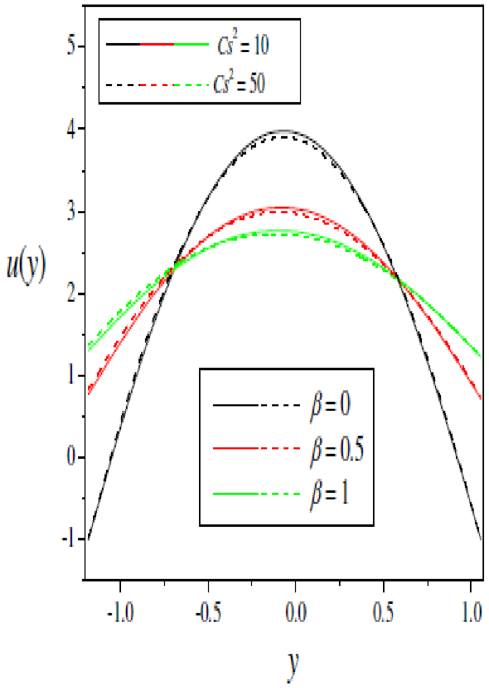
Graph 1. Biot number temperature distributions for various values



Graph 2. Dispersion of nanoparticles for a range of Biot numbers



Graph 3. Distinct couple-stress parameter values show distinct velocity patterns.



Graph 4. Various slip parameter values and their corresponding velocity distributions

CONCLUSION

The first thing you should do is provide a brief overview of the main points and outcomes of your mathematical applications regarding non-Newtonian properties in pipeline transit. Make sure to emphasise any major takeaways or themes that came out of your inquiry. Use the results of your research to back up or disprove your previous opinions and assumptions. Check the accuracy of the projections and look into any unforeseen results. Think about how your results could affect pipeline operations and design in the actual world before you release them. Think about the ways in which non-

Newtonian components may improve pipeline systems, reduce energy consumption, and increase performance in general. Learn about the characteristics and differences in pipe behaviour of Newtonian and non-Newtonian fluids. Outline the benefits and drawbacks in more depth, and explain why non-Newtonian characteristics are preferable to their Newtonian equivalents.

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