JOURNAL OF MULTIDISCIPLINARY SCIENCES AND INNOVATIONS

VOLUME 5, ISSUE 05
MONTHLY JOURNALS

GERMAN INTERNATIONAL JOURNALS

ISSN NUMBER: 2751-4390
IMPACT FACTOR: 9,08

RHEOLOGICAL CHARACTERISTICS OF SUSPENSION FLOW AND THEIR INFLUENCE ON THE HYDRAULIC TRANSPORT PROCESS

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https://doi.org/10.5281/zenodo.20276080

ABSTRACT: The rheological characteristics of suspension flow play a significant role in determining the efficiency and stability of hydraulic transport systems used in mining, chemical, metallurgical, and construction industries. Suspensions containing solid particles exhibit complex flow behavior that differs considerably from conventional Newtonian fluids due to the interaction between solid and liquid phases. This study investigates the rheological properties of suspension flows and analyzes their influence on the hydraulic transport process in pipeline systems. Special attention is given to the effects of particle concentration, particle size, viscosity, and yield stress on flow behavior, pressure losses, and energy consumption. The study examines the transition between laminar and turbulent flow regimes and evaluates how non-Newtonian characteristics affect slurry transportation efficiency. Rheological models, including the Bingham plastic model, are applied to describe suspension behavior under different operating conditions. The research also discusses the impact of rheological parameters on sedimentation, pipeline blockage, and pump performance. In addition, Computational Fluid Dynamics (CFD) methods are considered for analyzing velocity distribution, pressure gradients, and particle movement in hydraulic transport systems. The results indicate that rheological properties strongly influence hydraulic resistance and transport stability. Proper evaluation of suspension rheology is essential for optimizing pipeline operation, reducing energy losses, and improving the reliability of hydraulic transport processes.

Keywords: suspension flow, rheology, hydraulic transport, non-Newtonian fluid, viscosity, yield stress, slurry flow, CFD analysis.

INTRODUCTION

Hydraulic transport of suspensions is widely used in modern industrial systems, especially in mining, metallurgy, chemical engineering, thermal power plants, and construction material production. In these industries, solid particles are transported through pipelines by means of a carrier liquid, usually water. This method of transport is considered economically efficient, environmentally safer, and technologically convenient for moving large volumes of solid materials over long distances. The effectiveness of hydraulic transport systems largely depends on the rheological characteristics of suspension flow. Suspensions are heterogeneous mixtures consisting of solid particles dispersed in a liquid phase, and their flow behavior is considerably more complex than that of conventional Newtonian fluids. The interaction between solid particles and the liquid medium significantly affects viscosity, flow resistance, turbulence, and energy consumption during transportation.

One of the key factors influencing suspension flow is the concentration of solid particles. As the concentration increases, the rheological behavior of the suspension changes from Newtonian to non-Newtonian. In highly concentrated suspensions, yield stress and plastic viscosity become important parameters that determine flow stability and hydraulic performance. These rheological properties directly influence pressure losses, pump efficiency, and the risk of particle sedimentation inside pipelines. The analysis of rheological characteristics is essential for understanding flow regimes in hydraulic transport systems. Depending on operating conditions such as flow velocity, particle size, and viscosity, suspension flow may occur in laminar, transitional, or turbulent regimes. Improper flow conditions can lead to excessive hydraulic losses, pipeline blockage, equipment wear, and increased operational costs.

In recent years, experimental studies and Computational Fluid Dynamics (CFD) methods have been widely applied to investigate suspension flow behavior and optimize hydraulic transport processes. These approaches provide valuable information about velocity distribution, pressure gradients, and particle movement in pipeline systems.

This study focuses on the rheological characteristics of suspension flow and their influence on the hydraulic transport process. The research investigates the effects of viscosity, particle concentration, and non-Newtonian behavior on flow stability, hydraulic resistance, and transport efficiency in pipeline systems.

METHODS

In this study, theoretical, analytical, and computational methods were used to investigate the rheological characteristics of suspension flow and their influence on the hydraulic transport process. The research focused on analyzing the behavior of solid–liquid suspensions in pipeline systems under different operating conditions. Theoretical analysis was carried out using the basic principles of fluid mechanics and hydraulic transport theory. Reynolds number analysis was used to determine the flow regime and evaluate the transition between laminar and turbulent flow conditions. The influence of flow velocity, suspension density, and viscosity on flow behavior was also investigated. Since concentrated suspensions often exhibit non-Newtonian behavior, rheological modeling was applied to describe the relationship between shear stress and flow deformation. The Bingham plastic model was used to characterize suspension flow properties such as yield stress and plastic viscosity. This approach helped analyze the effect of rheological parameters on flow stability and hydraulic resistance.

Hydraulic calculations were performed to determine pressure losses and energy consumption during the transport process. The analysis considered the influence of particle concentration, viscosity, and pipeline geometry on hydraulic performance. Special attention was given to the conditions that may cause particle sedimentation and pipeline blockage. In addition, Computational Fluid Dynamics (CFD) methods were used to simulate suspension flow inside the pipeline. Numerical simulations allowed the evaluation of velocity distribution, pressure gradients, turbulence intensity, and particle movement under different transport conditions. The obtained results were analyzed to assess the efficiency and operational reliability of the hydraulic transport system.

RESULTS

The results of the study showed that the rheological characteristics of suspension flow have a significant influence on the hydraulic transport process. It was observed that increasing the concentration of solid particles caused a noticeable rise in suspension viscosity and density, which directly affected flow stability and hydraulic resistance inside the pipeline. The analysis indicated that low flow velocities promoted laminar flow conditions and increased the possibility of particle sedimentation. Under these conditions, solid particles tended to accumulate near the lower part of the pipeline, reducing transport efficiency and increasing the risk of blockage formation. As the flow velocity increased, the suspension flow gradually transitioned to turbulent conditions, improving particle suspension and providing more stable transportation. The rheological investigation confirmed that concentrated suspensions exhibited non-Newtonian behavior. The presence of yield stress significantly influenced the velocity profile and pressure distribution in the pipeline system. Higher values of plastic viscosity and yield stress required greater pumping power to maintain continuous flow.

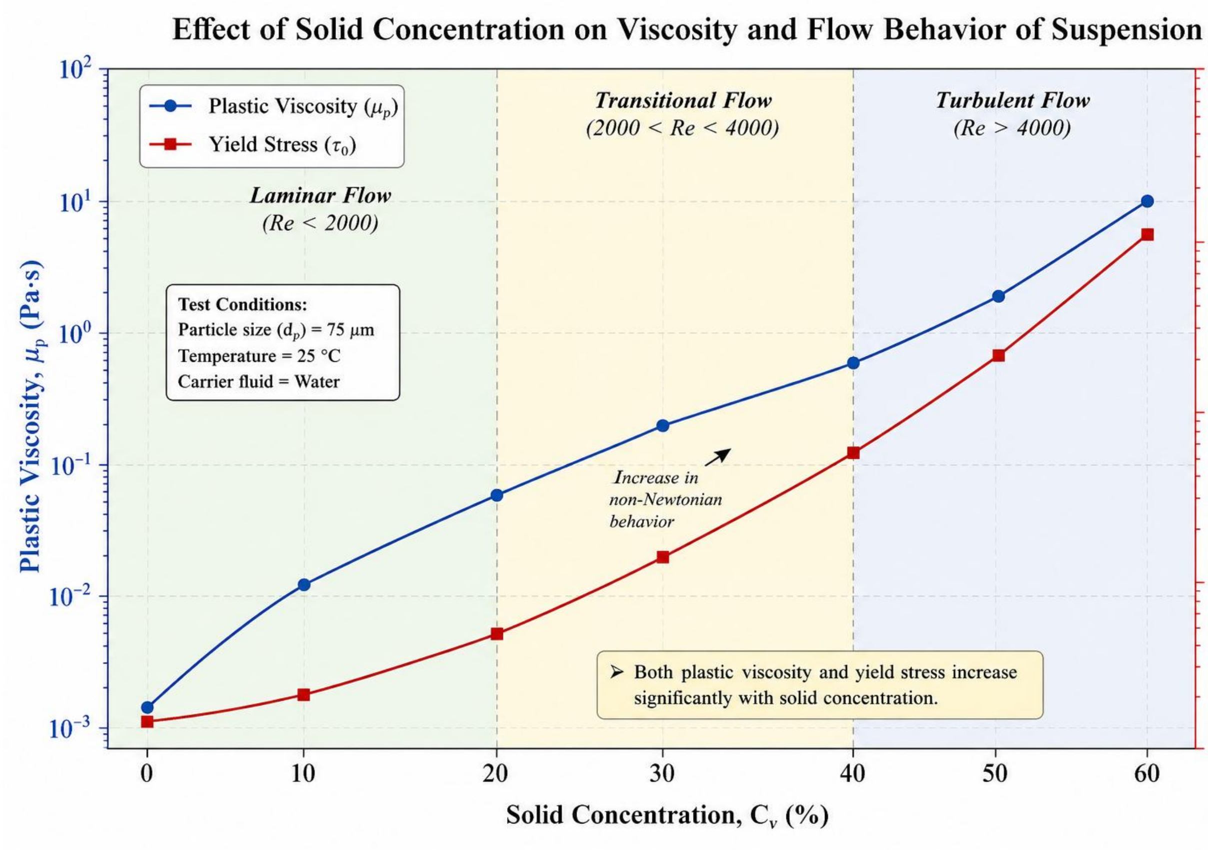

Figure 1. Effect of Solid Concentration on Viscosity and Flow Behavior of Suspension.

Hydraulic calculations demonstrated that pressure losses increased considerably with increasing suspension concentration and viscosity. The results also showed that smaller pipeline diameters generated higher friction losses due to stronger interaction between the suspension and the pipe wall. CFD simulations revealed that velocity distribution inside the pipeline became less uniform at high suspension concentrations. Numerical analysis identified low-velocity zones near pipeline bends and horizontal sections, where particle accumulation and sedimentation were more likely to occur. Turbulence intensity increased with flow velocity, improving particle mixing but also increasing energy consumption. Overall, the obtained results demonstrated that rheological properties strongly affect hydraulic transport performance, operational stability, and energy efficiency in suspension pipeline systems.

DISCUSSION

The results of this study demonstrate that the rheological characteristics of suspension flow play a crucial role in determining the efficiency and stability of hydraulic transport systems. The increase in solid particle concentration significantly changed the flow behavior of the suspension, leading to higher viscosity, increased hydraulic resistance, and greater energy consumption during transportation. One of the main findings of the study is the strong relationship between flow velocity and particle sedimentation. At low velocities, the suspension tended to flow under laminar conditions, which reduced the ability of the carrier liquid to keep particles suspended. As a result, particle accumulation occurred near the bottom of the pipeline, increasing the possibility

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of blockage formation and unstable transport conditions. In contrast, turbulent flow regimes improved particle suspension and enhanced transport stability.

However, the study also showed that turbulent flow conditions generated higher pressure losses and required greater pumping power. Therefore, although turbulence improves particle transport, excessive flow velocity may reduce the overall energy efficiency of the hydraulic transport system. This indicates that selecting an optimal operating velocity is essential for balancing transport reliability and energy consumption. The rheological analysis confirmed that concentrated suspensions exhibit non-Newtonian behavior characterized by yield stress and plastic viscosity. These properties significantly affect pressure distribution, velocity profiles, and flow resistance inside the pipeline. The Bingham plastic model used in this study

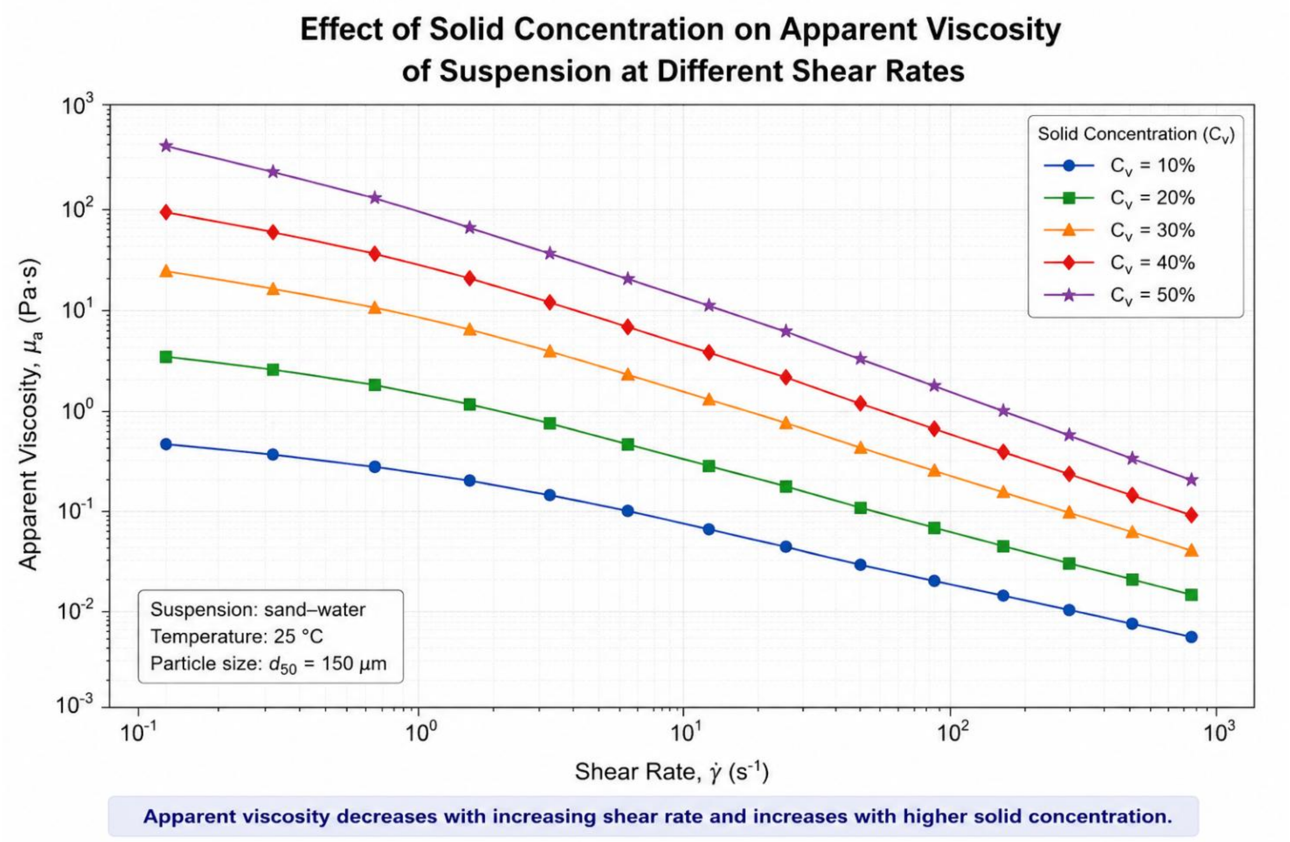

Figure 2. We experienced an error when generating images.

effectively described the rheological behavior of the suspension and provided a reliable basis for hydraulic analysis.

CFD simulations provided additional insight into local flow structures and particle movement. Numerical results revealed that low-velocity regions near pipeline bends and horizontal sections are the most critical areas for sedimentation and

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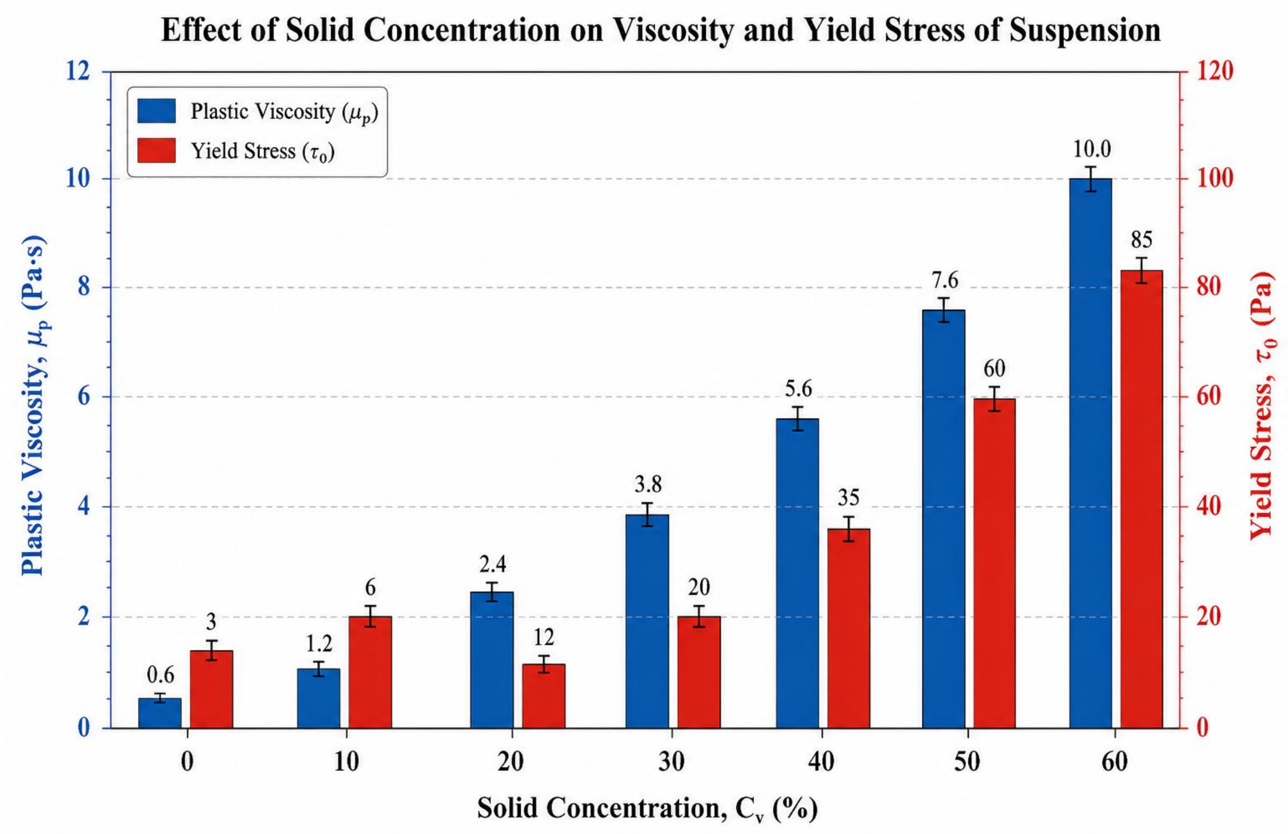

Figure 3. Effect of Solid Concentration on Viscosity and Yield Stress of Suspension.

particle accumulation. These findings emphasize the importance of proper pipeline design and flow control for preventing operational problems in hydraulic transport systems. Overall, the study highlights the necessity of accurate rheological analysis for improving the performance and reliability of suspension transport systems. Understanding the interaction between rheological properties and hydraulic conditions can contribute to reducing energy losses, minimizing equipment wear, and optimizing industrial slurry transportation processes.

CONCLUSION

This study investigated the rheological characteristics of suspension flow and their influence on the hydraulic transport process in pipeline systems. The results showed that the rheological properties of suspensions, including viscosity and yield stress, have a significant effect on flow behavior, hydraulic resistance, and transport stability. The analysis demonstrated that increasing the concentration of solid particles leads to higher viscosity and pressure losses, which increases energy consumption during hydraulic transport. Low flow velocities were found to promote particle sedimentation and blockage formation, while turbulent flow conditions improved particle suspension and transport reliability. However, turbulent regimes also caused greater hydraulic losses and required higher pumping power. The study confirmed that concentrated suspensions exhibit non-Newtonian behavior, and the Bingham plastic model effectively described the relationship between shear stress and flow characteristics. CFD simulations also showed that low-velocity zones near pipeline bends and horizontal sections are the most critical regions for particle accumulation. Overall, accurate evaluation of rheological properties is essential for optimizing hydraulic transport systems, improving operational efficiency, reducing energy losses, and preventing sedimentation problems in industrial pipeline transportation processes.

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