CP301
Development Engineering Project

Design and development of Setup for Weissenberg Effect (Rod Climbing Effect)

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Title of the Project:

Weissenberg Effect (Rod Climbing Effect) Experimental Study and Setup

Aim:

The primary objectives of this project are:

- To construct a reliable experimental setup for demonstrating the Weissenberg Effect.
- To study the variation in fluid climbing behavior based on different viscoelastic fluids and rotation speeds.

Introduction:

Fluids with complex structures, such as macromolecular solutions and polymer melts, exhibit behaviours that cannot be described by Newton's law of viscosity. One of the most intriguing phenomena in this category is the Weissenberg effect, where a viscoelastic fluid climbs up a rotating rod, defying centrifugal and gravitational forces. This effect arises due to the inequality of normal stresses in shear flow, which results in a force that pulls the fluid inward and upward. Understanding this phenomenon is critical in the field of rheology, as it helps in predicting the behaviour of non-Newtonian fluids in industrial and natural applications. Several experimental, analytical, and numerical studies have been conducted to explain the mechanism behind this effect and its implications in fluid dynamics.

Background and Literature Review:

Non-Newtonian Fluid

Unlike Newtonian fluids, where viscosity remains constant irrespective of applied stress, nonNewtonian fluids exhibit complex flow behaviors. These fluids can be classified into:

- **Shear-thinning fluids**: Viscosity decreases with increasing shear rate (e.g., paint, blood, ketchup).
- **Shear-thickening fluids**: Viscosity increases with shear rate (e.g., cornstarch in water, wet sand).
- **Viscoelastic fluids**: Exhibit both viscous and elastic properties (e.g., slime, glue with borax).

Depiction of Weissenberg effect with Non-newtonian fluid vs non Newtonian fluid :

Non Newtonian fluid Newtonian fluid

Mechanism of the Weissenberg Effect

The Weissenberg effect occurs due to the development of **normal stress differences** in a shear flow, leading to rod climbing. Unlike Newtonian fluids, which experience only shear stress, viscoelastic fluids also develop a normal stress component that pushes the fluid toward regions of higher shear stress. This results in the unexpected climbing behaviour when a rotating rod is immersed in such a fluid.

When a viscoelastic fluid is sheared around a rotating rod, it climbs up instead of being flung outward. This happens due to normal stress differences in the fluid:

1. **Primary Normal Stress Difference** ($N_1 = \sigma_1 - \sigma_2$) ○ σ_1 (Tangential Normal Stress) > σ_2

(Radial Normal Stress) ○ This imbalance pulls the fluid inward toward the rod instead of moving outward.

2. **Secondary Normal Stress Difference** ($N_2 = \sigma_2 - \sigma_3$) ○ σ_2 (Radial Normal Stress) > σ_3 (Axial Normal Stress) ○ This causes the fluid to be squeezed upward, leading to climbing.

Applications in Engineering

Industrial Mixing and Processing

Application: Food, pharmaceutical, and polymer industries often deal with thick, viscoelastic fluids (e.g., dough, gels, pastes).

- **Why the Weissenberg Effect Matters:** In mixing tanks, instead of being thrown outward (like water), viscoelastic fluids can climb stirrers or behave unpredictably. Engineers can design better mixing systems by considering this effect to ensure uniform blending and prevent unwanted fluid buildup.
- In polymer processing, understanding normal stress differences helps in controlling extrusion and molding processes.

Biological Systems

Application: Bodily fluids like blood, mucus, and synovial fluid (joint lubrication) exhibit viscoelastic behavior.

Why the Weissenberg Effect Matters:

- Blood flow in arteries is not purely Newtonian; it exhibits normal stress differences. Understanding this helps in designing better medical devices (e.g., artificial heart valves, blood pumps).
- In mucus-related treatments, its climbing behavior affects how drugs spread within the respiratory tract, influencing inhaler designs and respiratory therapies.

Material Science & Engineering

Application: Creating advanced non-Newtonian fluids for 3D printing, coatings, adhesives, and lubricants.

Why the Weissenberg Effect Matters:

- In 3D printing, controlling the normal stress differences helps ensure precise extrusion of viscoelastic inks (e.g., bio-inks, polymer-based materials).
- In coatings and adhesives, climbing behaviour influences how materials spread and adhere to surfaces, improving application techniques.

- In lubrication, Weissenberg effects help design better synthetic lubricants that resist splashing and provide stable layers under rotation.

Experimental Setup :

The experimental setup consists of the following elements:

- A **base frame** that holds the entire setup stable.
- Two **threaded rods** attached to the base, supporting the stepper motor and ensuring rigidity.
- A **stepper motor** mounted at the top, which rotates the **rod** submerged in a beaker containing viscoelastic fluid.
- The **Arduino microcontroller** connected to the stepper motor, allowing precise control over rotation speed.
- A **potentiometer** for manual speed adjustments.
- A **beaker** placed at the center, containing the test fluid.
- A **high-speed camera** for data collection and analysis.

The setup is designed to allow smooth operation, with adjustable motor speed and firm structural support to minimize external disturbances. The rod's motion will induce the Weissenberg Effect, which we will analyze in subsequent experiments.

Objective

- To assemble a setup for experimental validation of the Weissenberg Effect.
- To study how different rotational speeds influence the climbing height.
- To analyze the effect of fluid rheological properties on the phenomenon.

- To compare experimental results with theoretical predictions

Requirements :

1. **Arduino**: The Arduino microcontroller is used to control and regulate the rotational speed of the stepper motor. It allows precise speed adjustments and automates the experiment, ensuring consistent results.

2. **Potentiometer**: A potentiometer is included to manually adjust the speed of the stepper motor. By varying the resistance, it enables fine-tuning of rotational speed, which helps in analyzing the effect of different rotation rates on fluid climbing behavior.

3. **Stepper Motor**: The stepper motor drives the rotating rod, ensuring controlled and stable rotation. Its stepwise motion allows precise adjustments to rotational speed, which is crucial for observing variations in the Weissenberg Effect.

4. **Rod**: The rod is connected to the stepper motor and is partially submerged in the viscoelastic fluid. When rotated, it induces normal stress differences in the fluid, leading to the climbing phenomenon.

5. **Beaker**: The beaker serves as the primary container for the viscoelastic fluid. It provides a stable and transparent environment for conducting the experiment, ensuring clear observation and measurement of the climbing effect.

6. **Base**: The base of the setup provides structural stability and support to the entire experimental assembly. It ensures that all components, including the motor and rotating rod, remain fixed in place, reducing unwanted vibrations and disturbances.

7. **Two Threaded Rods**: The threaded rods serve as vertical supports for the setup, holding the motor and rotating rod assembly in position. They provide adjustability in height and secure the system against lateral movement, ensuring accurate experimental results.

8. **High-speed camera** for capturing the climbing motion.

Experimental Procedure:

1. **Preparation of Fluid Sample:**
    - Select and prepare the viscoelastic fluid.
    - Ensure uniform mixing to maintain consistent fluid properties.
    - Pour the fluid into the beaker.

2. **Setup Configuration:**
    - Secure the beaker on the experimental base.
    - Attach the rotating rod to the stepper motor.
    - Ensure the rod is correctly positioned at the center of the fluid sample.
    - Connect the Arduino and potentiometer for speed control.

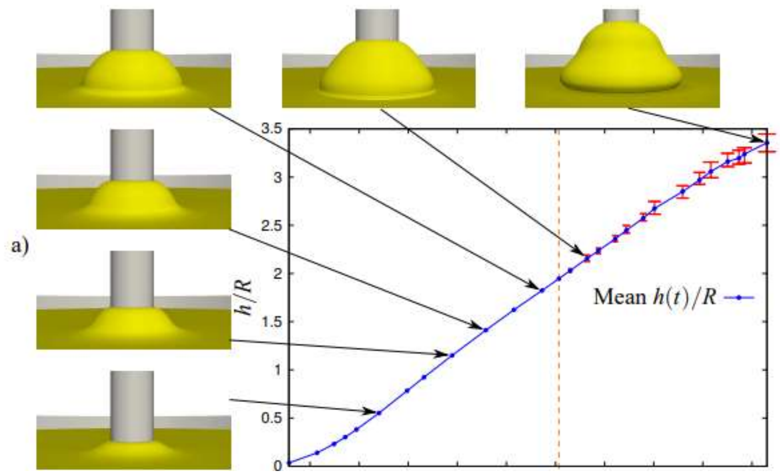
3. **Conducting the Experiment:**
    - Start the stepper motor at a low speed.
    - Gradually increase the speed using the potentiometer.
    - Observe and record the fluid climbing behavior.
    - Capture high-speed footage for further analysis.

4. **Measurement and Data Collection:**
    - Record the height of fluid climbing at different speeds.
    - Measure the rotational speed corresponding to significant climbing.
    - Compare results with theoretical predictions.

5. **Analysis and Interpretation:**

- Plot graphs of climbing height versus speed.
- Analyze deviations from expected behavior.
- Discuss possible improvements to the setup.

Plot of of h/R vs Wi (Weissenberg number) :



In the plot, h/R is the ratio of climbing height of fluid to the radius of rod and Wi refers to the **Weissenberg number**, a dimensionless number used in viscoelastic fluid dynamics. The Weissenberg number is defined as:

$$Wi = \lambda \dot{\gamma}$$

where:

- λ is the relaxation time of the fluid,
- $\dot{\gamma}$ is the shear rate.

Result and Discussion (To Be Completed After Experimentation)

- Comparison of experimental results with predicted theoretical behavior.
- Influence of rotational speed and fluid properties on climbing height.
- Identification of experimental uncertainties and possible refinements.

Conclusion (To Be Finalized After Experimentation)

- Summary of findings from the conducted experiments.
- Practical implications of the Weissenberg Effect in real-world applications.
- Recommendations for further study and potential improvements to the setup.

Further work to be done

As of now, we have completed the following steps:

- Studied theoretical concepts and literature on the Weissenberg Effect.
- Identified and procured required mechanical and electronic components.
- Planned the setup assembly and experimental procedure.

And Following work is remaining-

1. **Assembling the Experimental Setup:**
    - Mounting the stepper motor and connecting the rod.
    - Fixing the base and attaching the threaded support rods.
    - Ensuring structural stability and alignment of all components.

2. **Setup Calibration:**
    - Ensuring proper alignment of the rotating rod.
    - Testing different speed settings to achieve controlled variations.

3. **Experiment Execution:**
    - Introducing viscoelastic fluids into the setup. o Observing and documenting fluid behaviour at different rotational speeds.
    - Recording the climbing height and deformation patterns.

4. **Data Collection and Analysis:**
    - Capturing video footage for detailed motion analysis. o Measuring and plotting climbing height versus rotation speed.
    - Analysing deviations from theoretical models and discussing potential influencing factors.

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