Static and Dynamic Yield Stress Analysis

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Objective of the Experiment

1. To find **Dynamic Yield Stress** (shear rate ramp down) at different Electric field at 1mm gap

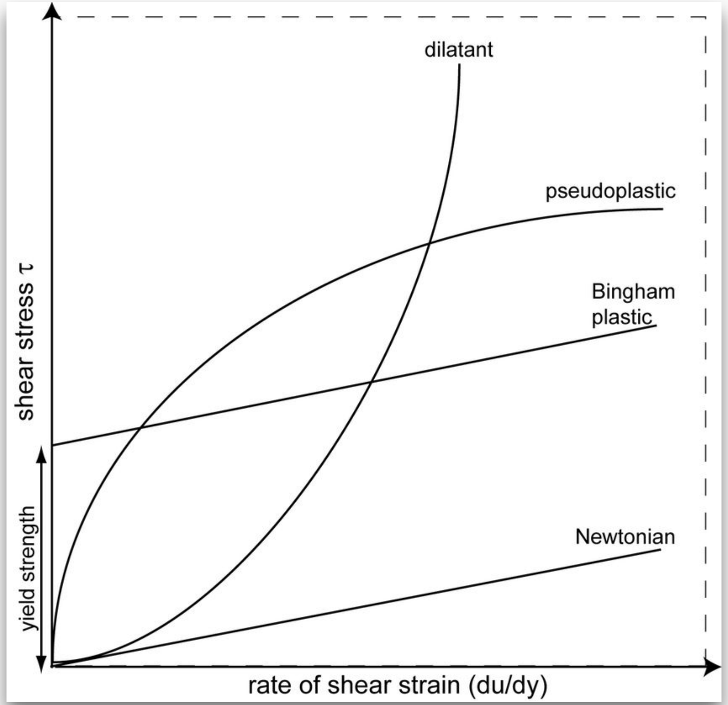
2. To find **Static Yield Stress** (shear rate ramp up) at different Electric field at 1mm gap

Theoretical Background – Yield Stress

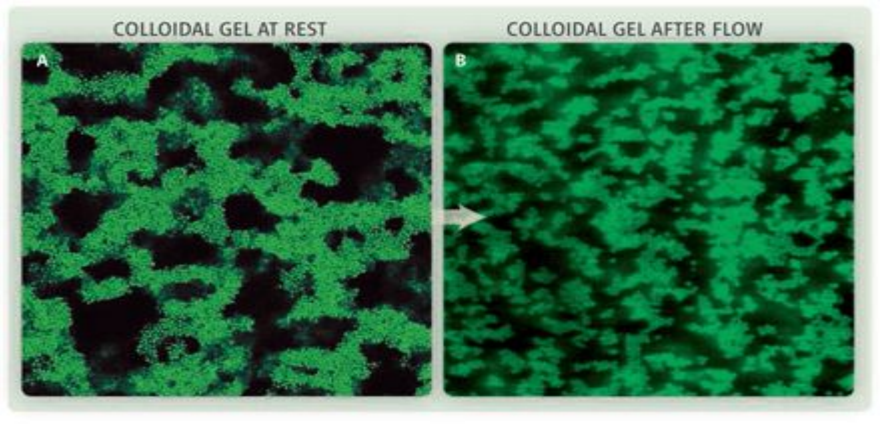
Yield Stress represents the minimum stress required for a material to undergo a transition from a solid-like behavior to a more fluid-like behavior (exhibit significant deformation or flow)

For **Newtonian fluids,** there is no yield stress because the viscosity of these material does not depend on the shear rate.

For **Non-Newtonian fluids** like Dilatant (Shear Thickening) or Pseudoplastic (Shear Thinning)**,** can have yield stress after which the transition occurs.



At Microscopic Level:



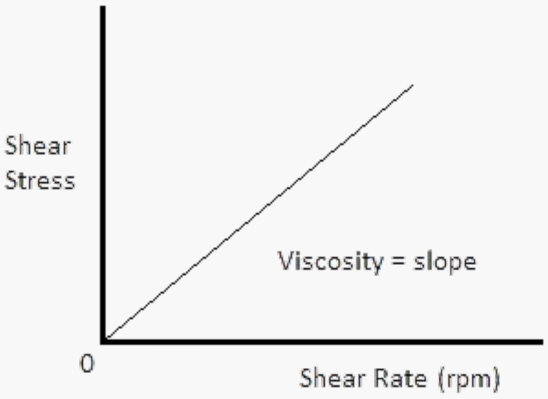
Theoretical Background – Different Models

Newtonian Model

Relationship between stress and strain rate in a material is linear and proportional.

$$\sigma = \mu \dot{\gamma}$$

μ = Viscosity



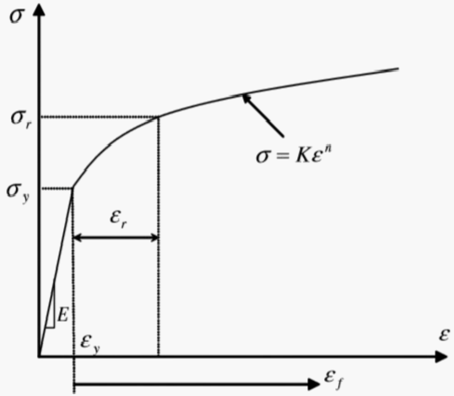
Power Law

Used to describe the non-Newtonian behavior, where shear stress is proportional to nth power of shear rate.

$$\sigma = K \dot{\gamma}^{n}$$

K = **Consistency index** (measure of the material's resistance to flow or deformation)

n = **Flow behaviour index** (characterizes the nature of the non-Newtonian behavior.)



Theoretical Background – Different Models

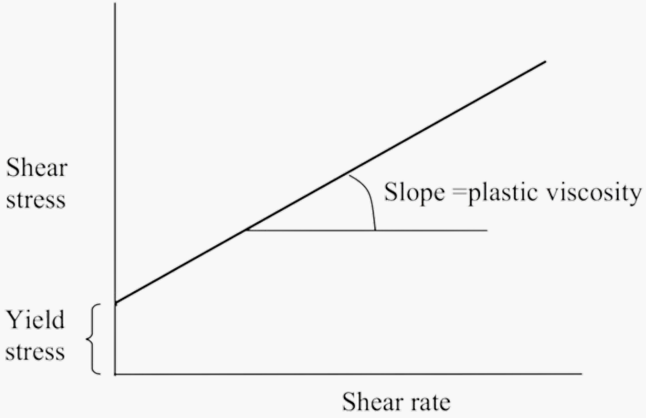
Bingham Model

Useful for materials that do not flow until a certain yield stress is exceeded.

$$\tau = \tau_0 + \mu \dot{\gamma}$$

μ = Viscosity

τ_0 = Yield stress



Herschel Bulkley Model

Used to describe non-Newtonian fluids with both a yield stress and shear-thinning or shear-thickening behavior.

$$\tau = \tau_0 + K \dot{\gamma}^n$$

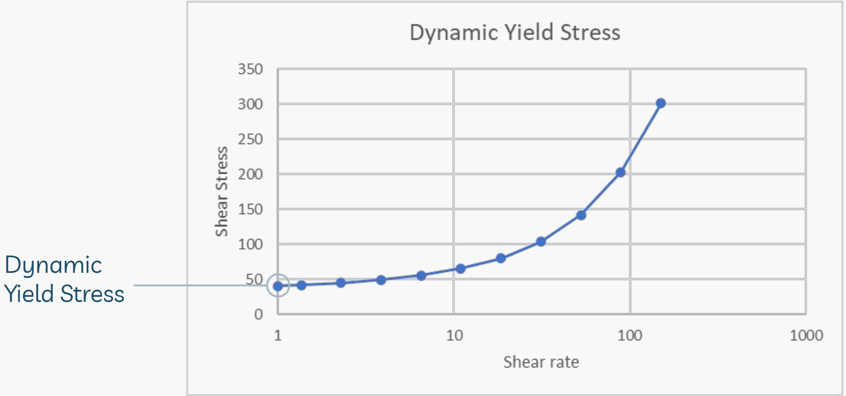
K = **Consistency index** (measure of the material's resistance to flow or deformation)

n = **Flow behaviour index** (characterizes the nature of the non-Newtonian behavior.)

Dynamic vs Static Yield Stress

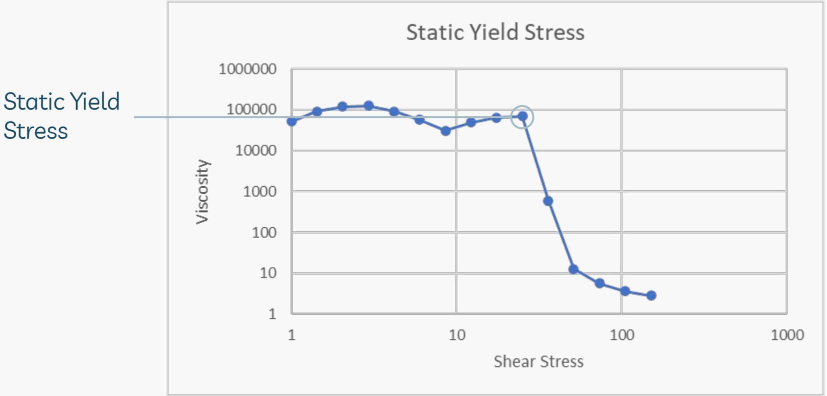
Dynamic Yield Stress

1. We get Dynamic Yield stress by extrapolating the curve of Shear stress vs Shear rate, starting from high shear rate to low shear rate.
2. Dynamic yield stress is related to rapidly changing or oscillatory stress conditions.
3. Application: dynamic yield stress is crucial in understanding the behavior of materials under oscillatory shear forces.



Static Yield Stress

1. Static yield stress is the stress at the point at which we witness a sharp dip in the viscosity, starting from low shear rate to high shear rate.
2. Static yield stress is associated with slowly applied or constant stress conditions.
3. Application: Static yield stress is relevant in situations where materials experience slow and gradual loading.



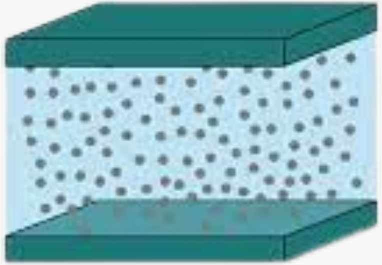
What do you think?

Can external factors influence the properties of a material?

Electrorheological Fluid

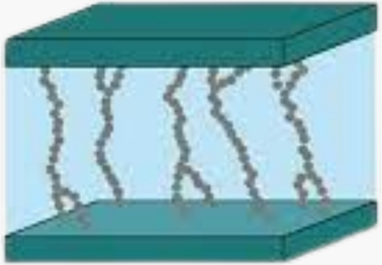
ER fluid, or electrorheological fluid, is a type of smart fluid that undergoes a reversible change in its rheological properties (flow behavior) when an electric field is applied.

Here, in this experiment, we have used **Corn-starch dispersion in Silicon oil (40wt%)** which exhibit electrorheological fluid behaviour.



No Electric Field

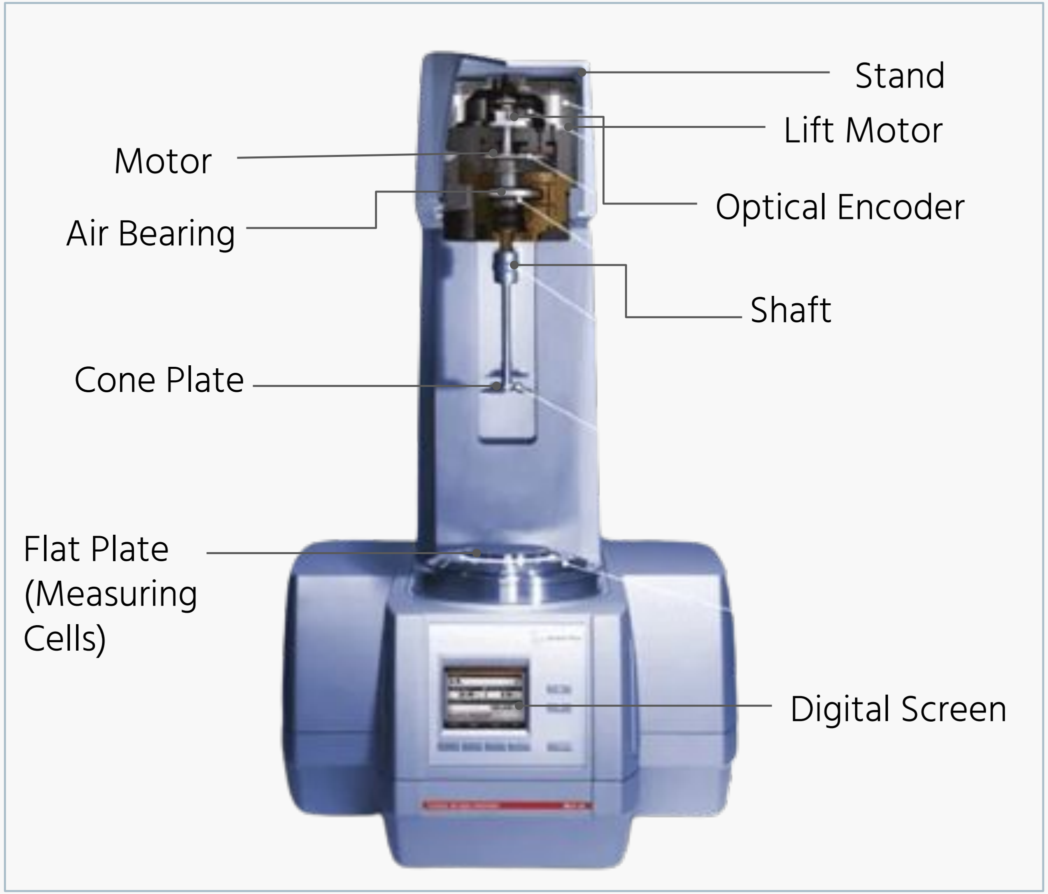
Fluid Like Behaviour

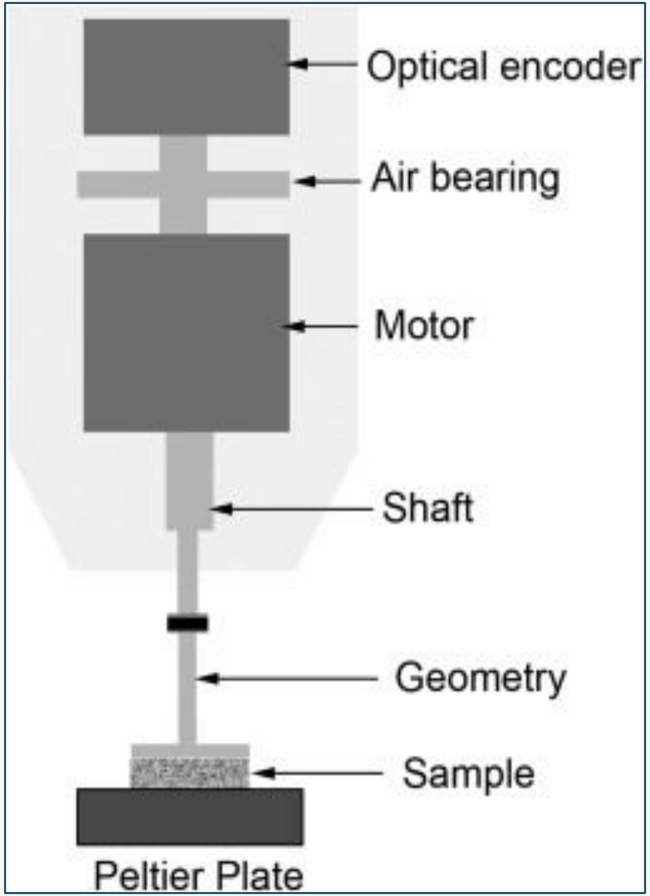


Electric Field

Solid Like Behaviour

Rheometer


Stand
Lift Motor
Motor
Optical Encoder
Air Bearing
Shaft
Cone Plate
Flat Plate (Measuring Cells)
Digital Screen

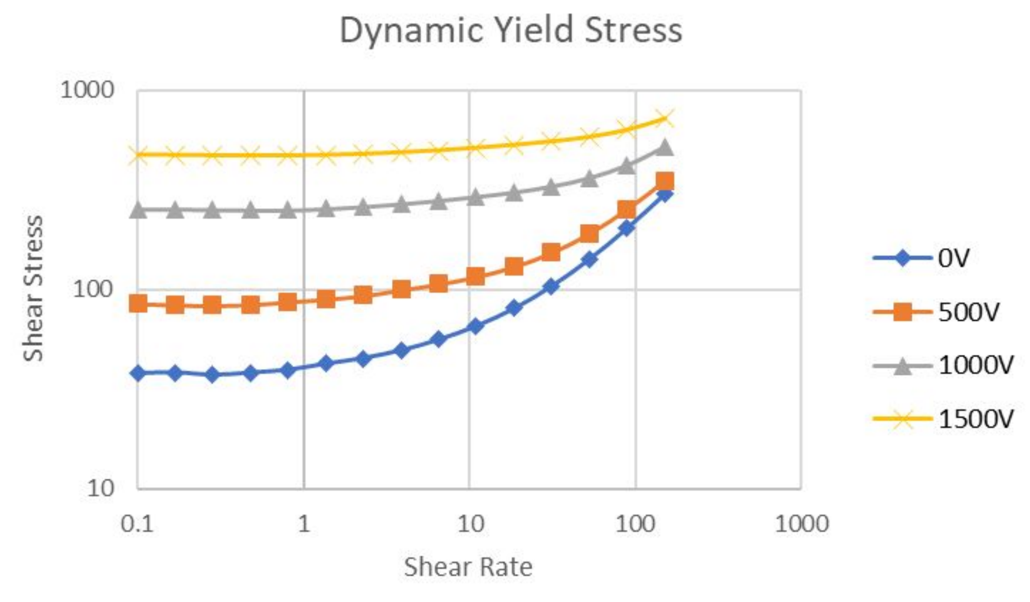

Optical encoder
Air bearing
Motor
Shaft
Geometry
Sample
Peltier Plate

Dynamic yield stress Input

Strength of Field	No of Data Points	Initial Shear Rate [1/s]	Final Shear Rate [1/s]
0 V/mm	15	150	0.1
500 V/mm	15	150	0.1
1000 V/mm	15	150	0.1
1500 V/mm	15	150	0.1

Dynamic yield stress Output

0V			
Shear Rate	Shear Strain	Shear Stress	Viscosity
150	1.12E+03	300.98	2.007
88.9	2.17E+03	202.91	2.2812
52.8	2.78E+03	141.8	2.6876
31.3	3.15E+03	103.94	3.3212
18.6	3.37E+03	80.282	4.325
11	3.50E+03	65.452	5.9449
6.53	3.58E+03	55.957	8.5693
3.87	3.62E+03	49.405	12.756
2.3	3.65E+03	45.15	19.655
1.36	3.66E+03	42.295	31.027
0.81	3.67E+03	39.437	48.712
0.48	3.68E+03	38.145	79.464
0.284	3.68E+03	37.136	130.6
0.169	3.68E+03	38.206	226.59
0.1	3.69E+03	37.824	378.2



Dynamic yield stress output

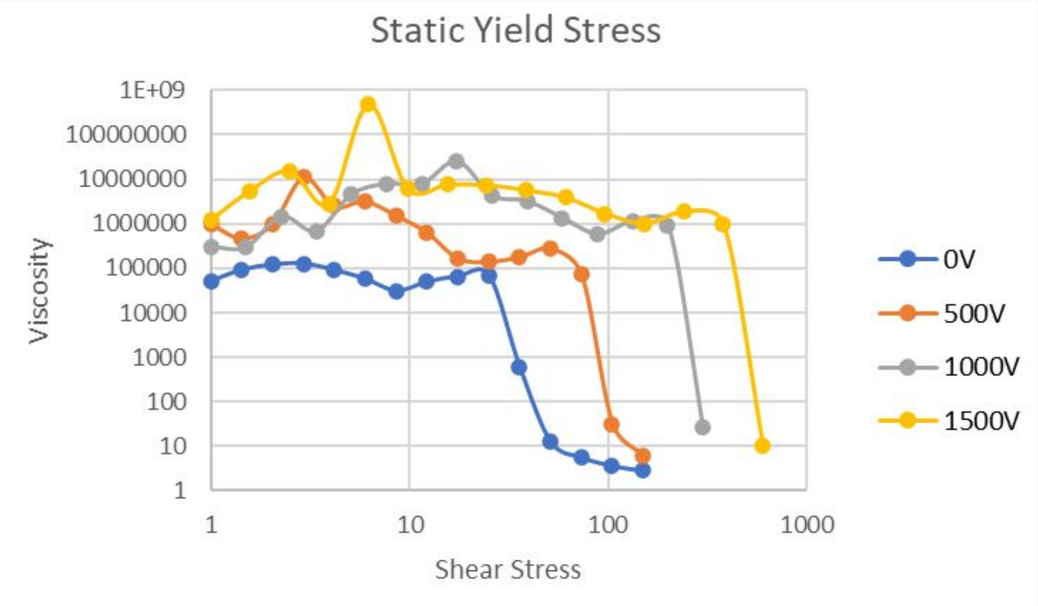
Strength of Field	Dynamic Yield Stress (Pa)
0 V/mm	37.824
500 V/mm	89.679
1000 V/mm	259.41
1500 V/mm	478.67

Static yield stress Input

Strength of Field	No of Data Points	Initial Shear Rate [1/s]	Final Shear Rate [1/s]
0 V/mm	15	1.96E-05	52.6
500 V/mm	15	9.96E-07	24.2
1000 V/mm	15	3.27E-06	11.4
1500 V/mm	15	8.25E-07	58.1

Static yield stress Output

0V			
Shear Rate	Shear Strain	Shear Stress	Viscosity
1.96E-05	0.000332	1	51022
1.57E-05	0.000459	1.4303	90958
1.70E-05	0.000603	2.0458	1.20E+05
2.33E-05	0.000806	2.9262	1.26E+05
4.64E-05	0.00116	4.1854	90283
0.000104	0.00196	5.9865	57341
0.000276	0.00486	8.5627	31047
0.000248	0.0138	12.247	49301
0.000269	0.0268	17.518	65146
0.000361	0.133	25.056	69360
0.0594	0.956	35.839	603.49
4	11.4	51.261	12.826
12.9	56.1	73.32	5.6755
28.8	164	104.87	3.6403
52.6	373	150	2.8499

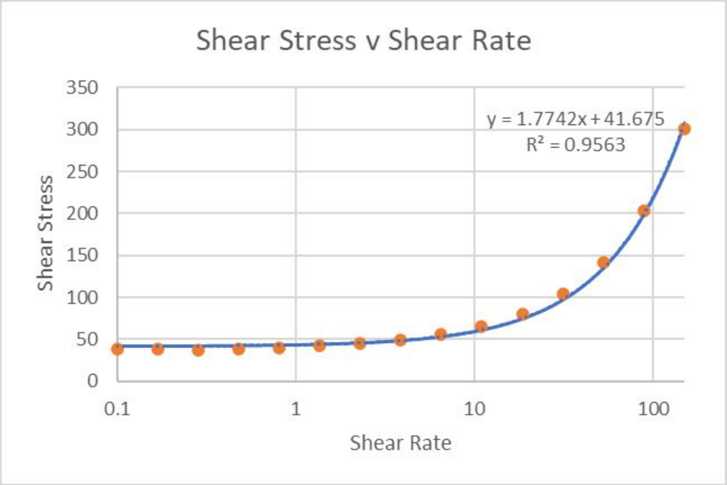


Static yield stress output

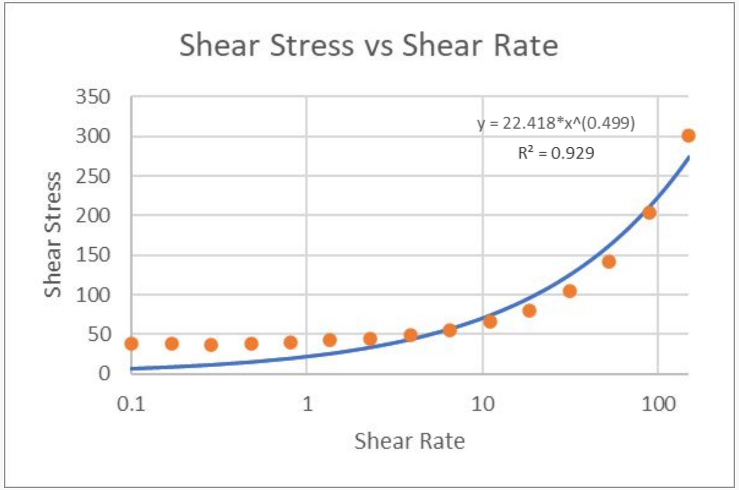
Strength of Field	Static Yield Stress (Pa)
0 V/mm	25.056
500 V/mm	51.261
1000 V/mm	199.61
1500 V/mm	379.94

Calculations – Nature of Fluid

Plotting Shear Stress against Shear Strain allows us to understand the nature of the fluid

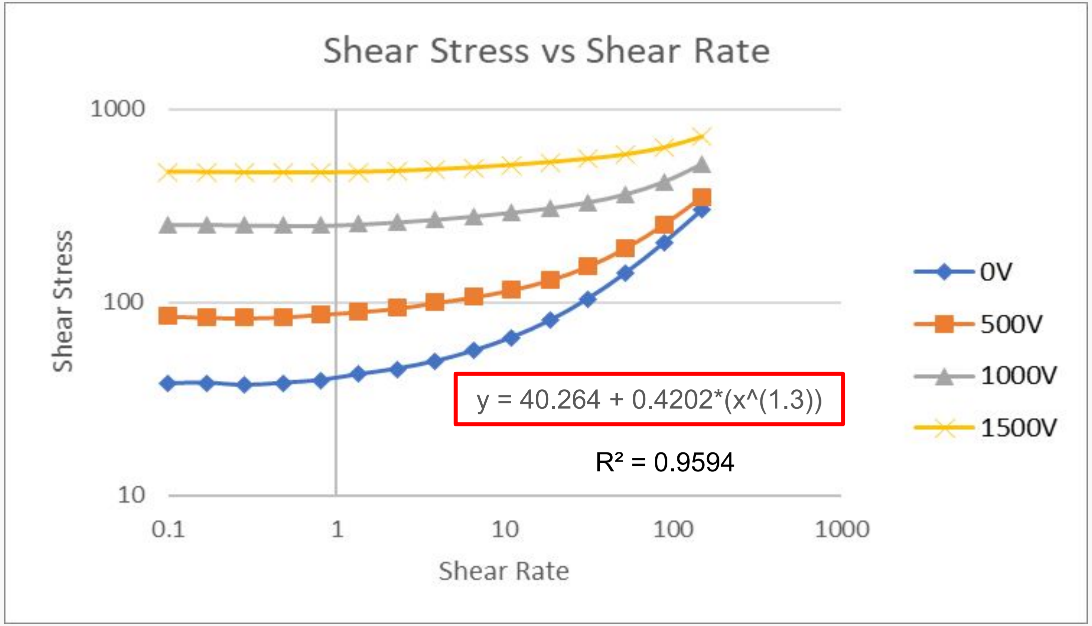


Bingham Fluid Model



Power Law Fluid Model

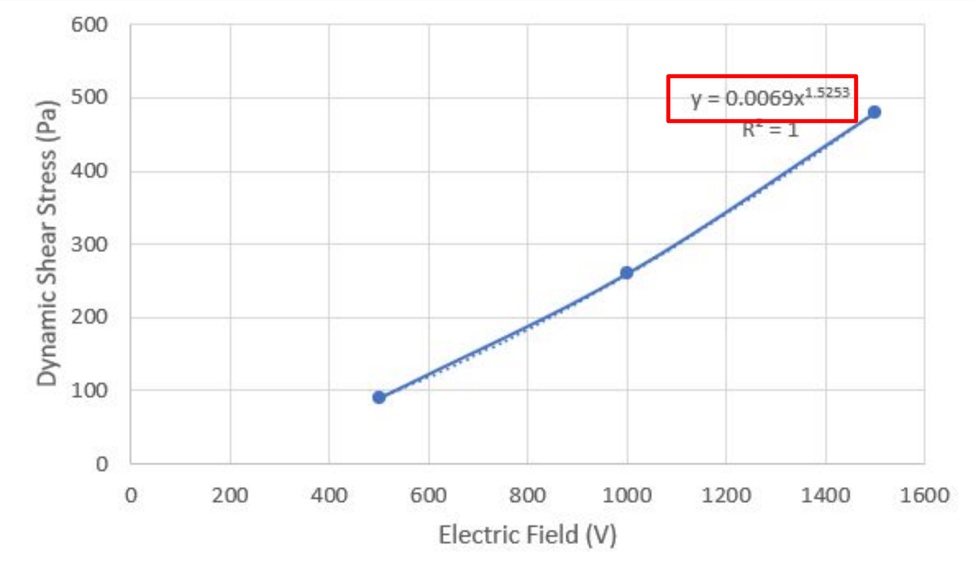
Calculations – Nature of Fluid



On fitting the data to $Y = A + B(X^n)$, we achieved the best fit.

Hence, the fluid is a **Herschel-Bulkley Fluid,** with n approximately equal to **1.3.**

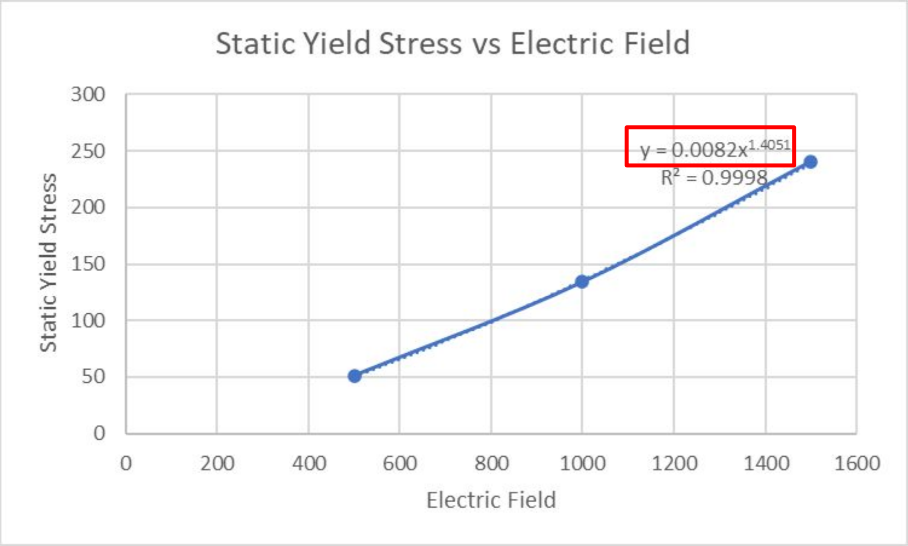
Calculations – Dynamic Yield Stress



On fitting the data of Dynamic Yield Stress vs Electric Field to **Y = A(X^n)**, we achieved the best fit.

Here, n was found to be approximately **1.52.**

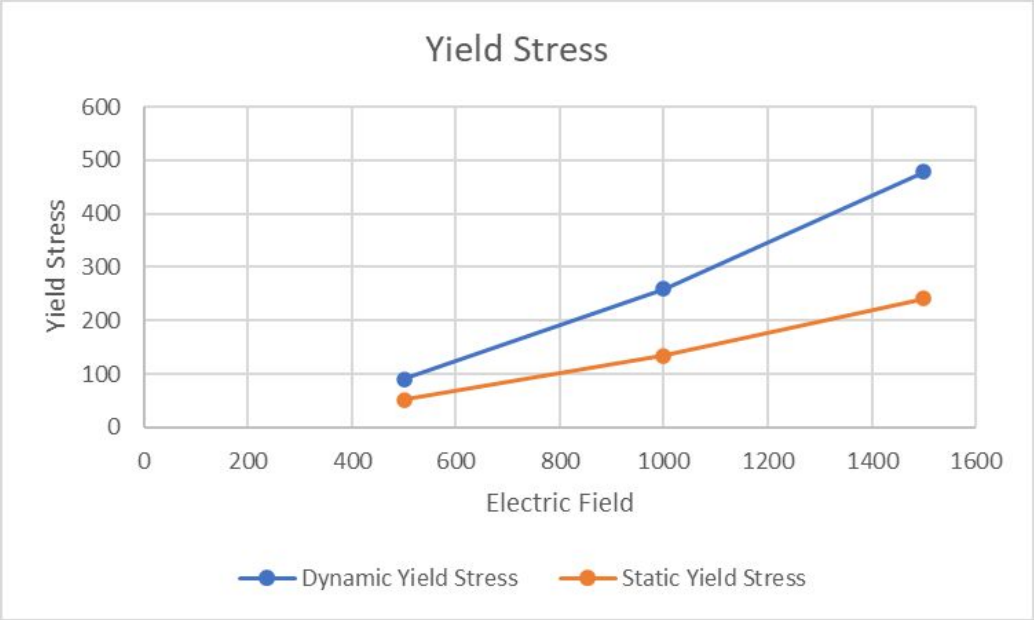
Calculations – Static Yield Stress



On fitting the data of Static Yield Stress vs Electric Field to **$Y = A(X^n)$**, we achieved the best fit.

Here, n was found to be approximately **1.4.**

Calculations – Yield Stress



On comparing the curves for Dynamic and Static Yield Stress, we can see that there is a difference - with the values for Static Yield Stress being **lower**.

Herschel-Bulkley Fluid

Herschel-Bulkley Fluid are non-Newtonian fluids which are depicted by the equation type:

$$\begin{aligned} \dot{\gamma} &= 0, && \text{if } \tau < \tau_0 \\ \tau &= \tau_0 + k\dot{\gamma}^n, && \text{if } \tau \geq \tau_0 \end{aligned}$$

- Three parameters define this fluid: consistency (k), flow index (n), yield stress (tau_0)
- Beneath the yield stress, the fluid acts as a rigid (non-deformable) solid
- The given solution is a **shear thickening** fluid, as n>1

The Herschel-Bulkley Fluid Model is a generalisation of the Bingham Fluid and Power Law Fluid Models, and is hence called the **Yield Power Law** or **Modified Power Law.**

Observations – Dynamic Yield Stress

Shear stress increases with increase in **electric field** intensity for same shear rate

The fluid exhibits **Non-Newtonian behaviour** and the shear stress reduces as we decrease the shear rate

The dynamic yield stress corresponding to 0 shear rate **rises higher for higher E**

The dynamic yield stress is **proportional to E^n** where n ranges from 1.5 to 2

Observations – Static Yield Stress

Viscosity increases with increase in electric field intensity: **particles get aligned** when subjected to E field

The static yield stress point **shifts to the right** (increases) as E goes higher

At high shear stress, the intermolecular forces holding the starch particles get disrupted, **viscosity drops sharply**

The dynamic yield stress of the solution is **higher** than static yield stress for same E

Conclusion

1 Change in Properties

The ER fluids can **change their rheological properties** when subjected to external electric field

2 Increase of Dynamic Yield Stress

Material stores shear stress even at 0 shear, which increases with an elevated electric field, **enhancing solid-like behavior**.

3 Increase of Static Yield Stress

The ER fluid exhibits solid-like behavior until it reaches its static yield stress, beyond which its viscosity rapidly decreases. **High E shifts it to right**.

Change in results due to Variations

Concentration

Increase in concentration leads to higher Yield Stress because of more solid-like behavior

Microstructure

Finer the grain size gets, there is an increase in solid-like behaviour

Temperature

An increase in temperature decreases viscosity, thus liquid-like behavior increases

Errors during the Experiment

Uneven viscosity graph due to breakage and buildup of the dipole structure

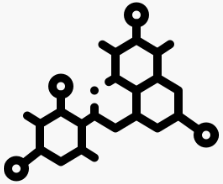
Error due to use of the **same sample** for multiple rounds of experiments

Reading error due to changes in **environmental conditions** like temperature, humidity, etc.

Applications

Geo-Engineering

Stability of soil, rock and earthquakes



Biomechanics

Mechanical properties of bio-tissues and medical devices

3D Printing

Optimal viscosity to ensure precise layer deposition

Pharmaceuticals

Flow behavior and stability of drugs

Thanks!