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EFFECT OF COAL BENEFICIATION PROCESS ON RHEOLOGY/ATOMIZATION OF COAL WATER SLURRIES.

Quarterly Progress Report
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OVERALL OBJECTIVE:

The overall objective of this project is to perform experiments to understand the effect of coal beneficiation processes and high shear rheological properties on the atomization of coal-water slurries (CWS). In the atomization studies, the mean drop size of the CWS sprays will be determined at various air-to CWS. A correlation between the high shear rheological properties, particle size distributions and the atomization will be made in order to determine the influence of these parameters on the atomization of CWS.

PROJECT STATUS:

Rheological properties of the CWS samples were determined after a six month storage period and the properties compared to freshly prepared samples. The rheological evaluations made include:

(A) Flow characteristics under low shear rates

(B) Flow Characteristics under high shear rates

(C) Viscoelastic behavior under low frequency of oscillation

All the three CWS samples formed a hard pack solid at the end of the six month storage period, and had to be redispersed. The flotation cleaned coal and the heavy-media cleaned coal however, had the tendency to settle much faster than the uncleaned coal. Each of them remained completely dispersed during the duration of the testing period.

RESULTS

Viscoelastic Behavior

Oscillatory measurements were made and the storage modulus, G', values were compared to previously obtained data. Viscoelastic properties can be exhibited in systems which have internal structure. These properties could affect the stability and fuel breakup of ligaments upon exiting a nozzle or orifice [1]. The linear viscoelasticity can be measured by subjecting the sample through a small amplitude oscillatory test. For a system where the strain varies sinusoidally with time, t, The strain amplitude can be given by:

$$\gamma(t) = \gamma_{max} Sin\omega t \qquad (1)$$

where τ is the maximum strain amplitude and ω is the angular frequency of oscillation [2]. The corresponding stress is given by

$$\tau(t) = \tau_{max} Sin(\omega + \delta)t \qquad (2)$$

where δ is the phase shift between stress and strain.

The above equation, (2), can be re-written as:

$$\tau(t) = \gamma_{max}(G' \sin\omega t + G'' Cos\omega t) \qquad (3)$$

The storage modulus, G' and the loss modulus, G" are defined in terms of the phase angles as:

$$G' = \frac{\tau_{max} Cos\delta}{\tau_{max}} \qquad (4)$$

$$G'' = \frac{\tau_{max} Sin\delta}{\tau_{max}} \qquad (5)$$

The storage modulus G' represents the "stored' or elastic component of the stress and is in phase with the strain. The loss modulus, G", represents the viscous component and it is the out of phase component. For a fluid that is purely viscous, G' is zero and the phase is 90° and for a purely elastic material where energy is stored but not dissipated, G"is zero and the phase is 0° [3].

Figure 1 compares the storage modulus of the three samples: Uncleaned coal slurry, Heavy media Cleaned slurry and the Floatation cleaned slurry . The plot shows that the uncleaned coal slurry has a much more elastic component than the rest of the samples examined. This observation is consistent with previously obtained data for the freshly prepared samples (Figure 2). This observation indicates that the cleaning process minimizes the elastic component of the slurries and that, the length of storage has no significant effect on the elastic properties of the slurries.

High Shear Rheology

In a capillary flow, CWS rheology can be adequately described by a power law model:

$$\tau = k\gamma^n \qquad (6)$$

where τ= shear stress

γ= shear rate

K = consistency index

n = power law index

n = 1 for Newtonian

n > 1 dilatant fluids

n < 1 for pseudoplastic fluids

HVA-6 Capillary Viscometer was used to determine the high shear rheological properties. The HVA 6 automated high shear capillary viscometer permits measurements from medium up to high shear rates ($D=10^2$ to 10^6 S^{-1}). Capillary tubes of 0.8mm, 1.5mm and 3.0mm in diameters and of length 100 mm were used in these measurements. The sample to be measured is forced through a capillary at definite pre-adjusted pressure and pressed into a burette where volume measurement takes

place. Figure 3 shows a high shear flow behavior of 61% CWS uncleaned, floatation, and heavy media cleaned slurries. Each of these slurries contain xantham gum as a stabilizer. The coal content of the exit slurry through the capillary tubes at each applied pressure, were collected and the solids content determined.

Results

The pressure drop in slurry flows is a key design parameter since it governs the pumping power required to move the slurry through the system. The change from laminar to turbulent flow results in a change in the flow resistance or friction loss. The prediction of the transition from laminar to turbulent flow can be inferred from the variation in the friction factor, which is dependent on the pipe diameter, the rate of flow, the length of the pipe, and the acceleration due to gravity.

In a horizontal flow, the actual deposition of the suspended particles is determined by the competing effects of gravity, particle-particle interaction and the rheological properties of the carrier fluid. As a result, either concentric or eccentric plug flow may result.

All the CWS used in the high shear capillary flow studies, followed either the Power law or the Hescheley- Buckley model (Figure 3). The power law and the Herschel- Buckley models can be represented by:

$\tau = k\gamma^n$ (Power Law Model) (7)

$\tau = \tau_o + k\gamma^n$ (H. Buckley Model) (8)

where k and n are rheological constants, and τ and γ are the shear stress and shear rate respectively.

For slurries whose properties are time independent, the dependence of the shear stress (τ) on the shear rate (γ) can be expressed as $\gamma = f(\tau)$. The distribution of velocity in the radiant direction and the relation between volumetric flow rate, Q and loss of pressure ΔP, can be easily obtained through Rabinowitsch's Equation [4].

$$\frac{Q}{\pi R^3} = \frac{1}{\tau_\omega^3}\int_0^{\tau_\omega} \tau^2 f(\tau) d\tau \qquad (9)$$

Where τ_ω is the wall stress.

Figure 4 compares the flow curves of the slurries studied, and Tables 1-5 list the experimental data obtained. The data show a transitional Reynolds number of 1500. The results indicate that the turbulence intensity is damped as the solids concentration increase.

The coal content in the exit slurry at each applied pressure did not differ significantly from the initial slurry concentration. This suggests a concentric flow through the capillary tubes.

Increasing the applied pressure increases the flow rate and thus, the kinetic energy. For slurry concentration greater than 25% solids, the effect of increasing the initial applied pressure had no significant effect on the Reynolds number. This effect is however, pronounced in slurries having solids concentration less than 20% solids.

The effect of increasing the capillary size, for the high solids concentration slurries, had no significant effect on the Reynolds Number.

References

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5. Winters, P.J., R. T. Bailey adn K. R. Olen, "The Effect of Fuel Formulation on the Atomization Characteristics of Coal-Water Mixtures", Proc. Seventh Int. Symp. on Coal Slurry Fuels Prep. and Util., U.S. Dept. of Energy, P.E.T.C., Pittsburgh, PA, pp. 430-439 (1985).

Table 1.

Flow Rate of 61% CWS Through 0.8mm Capillary Tube

P(bar)	Flow Rate(ml/s)	Reynolds Number	Coal Content in Exit Sample(%)
10.2	.56	6	62
12.2	.66	7	60
14.9	.81	8	60
18.1	1.0	10	59
20.6	1.1	12	59

Table 2.

Flow Rate of 61% CWS Through 1.5mm Capillary Tube

P(bar)	Flow Rate(ml/s)	Reynolds Number	Coal Content in Exit Sample(%)
4.0	.41	0	59
6.1	1.9	5	61
8.0	2.5	6	59
10.4	3.3	8	59
12.7	4.2	11	60
14.4	4.8	13	60

Table 3

Flow Rate of 61% CWS Through 3.0mm Capillary Tube

P(bar)	Flow Rate(ml/s)	Reynolds Number	Coal Content in Exit Sample(%)
1.2	0.47	0	55
1.7	1.7	0	60
3.2	3.5	1	59
5.1	5.6	2	60
6.4	8.7	3	59

Table 4.

Flow Rate of 35% CWS Through 0.8mm Capillary Tube

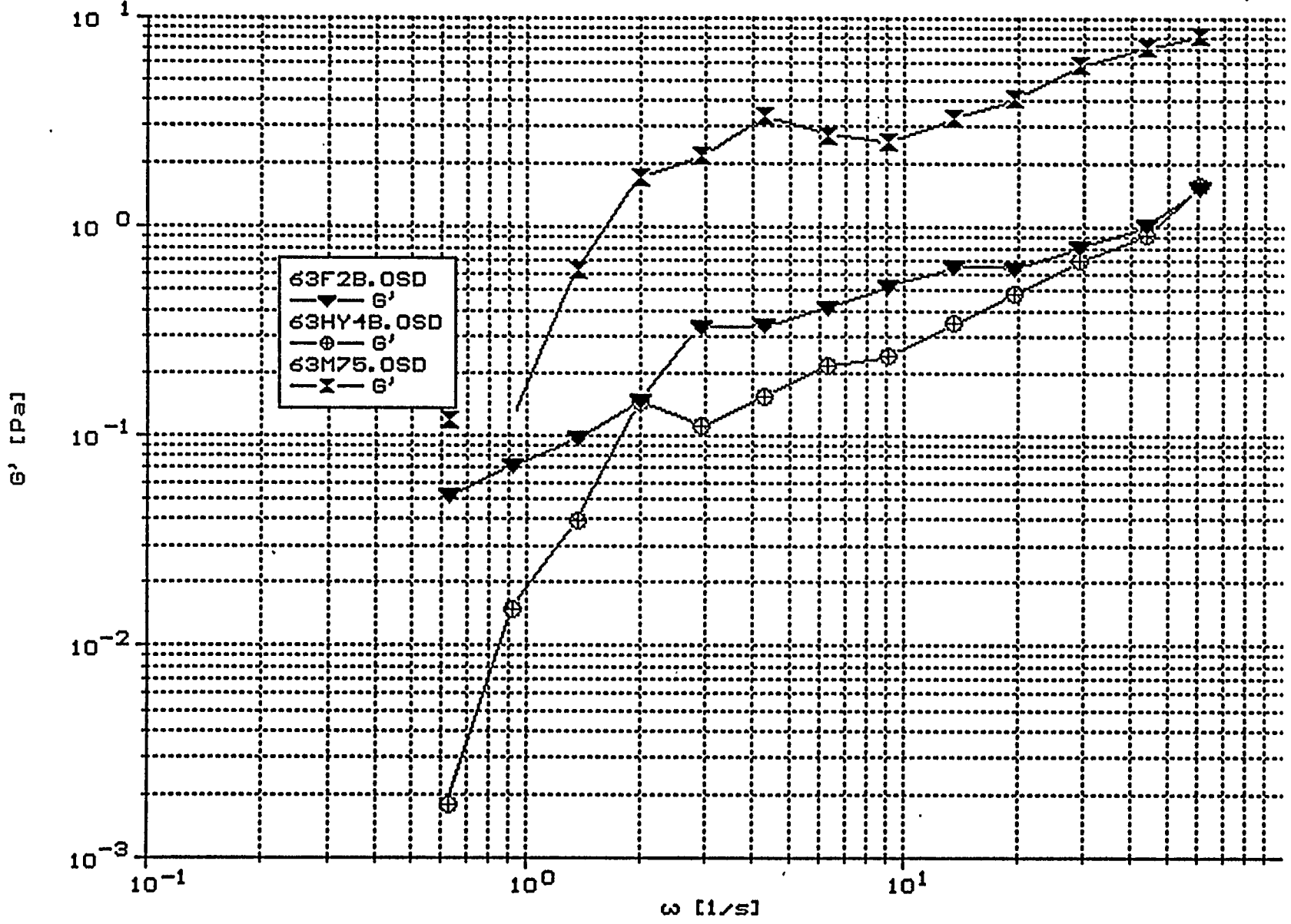
P(bar)	Flow Rate(ml/s)	Reynolds Number	Coal Content in Exit Sample(%)
2.6	2.4	344	37
4.6	3.9	557	36
6.8	6.1	995	34
8.3	6.5	906	35
10.2	5.3	439	36

Table 5.

Flow Rate of 15% CWS Through 0.8mm Capillary Tube

P(bar)	Flow Rate(ml/s)	Reynolds Number	Coal Content in Exit Sample(%)
1.2	2.6	1047	14
3.1	5.2	1858	13
4.6	7.2	3851	14
6.3	9.6	4947	14

Figure 1. Storage Modulus As a Function of Frequency.



Date: 27.06.95, 15:05 Operator: yolanda Sample: floatation (63%)
Sensor system : Q45 System : CV20

Figure 2. Storage Modulus As A Function of Frequency.
(Freshly Prepared Samples).

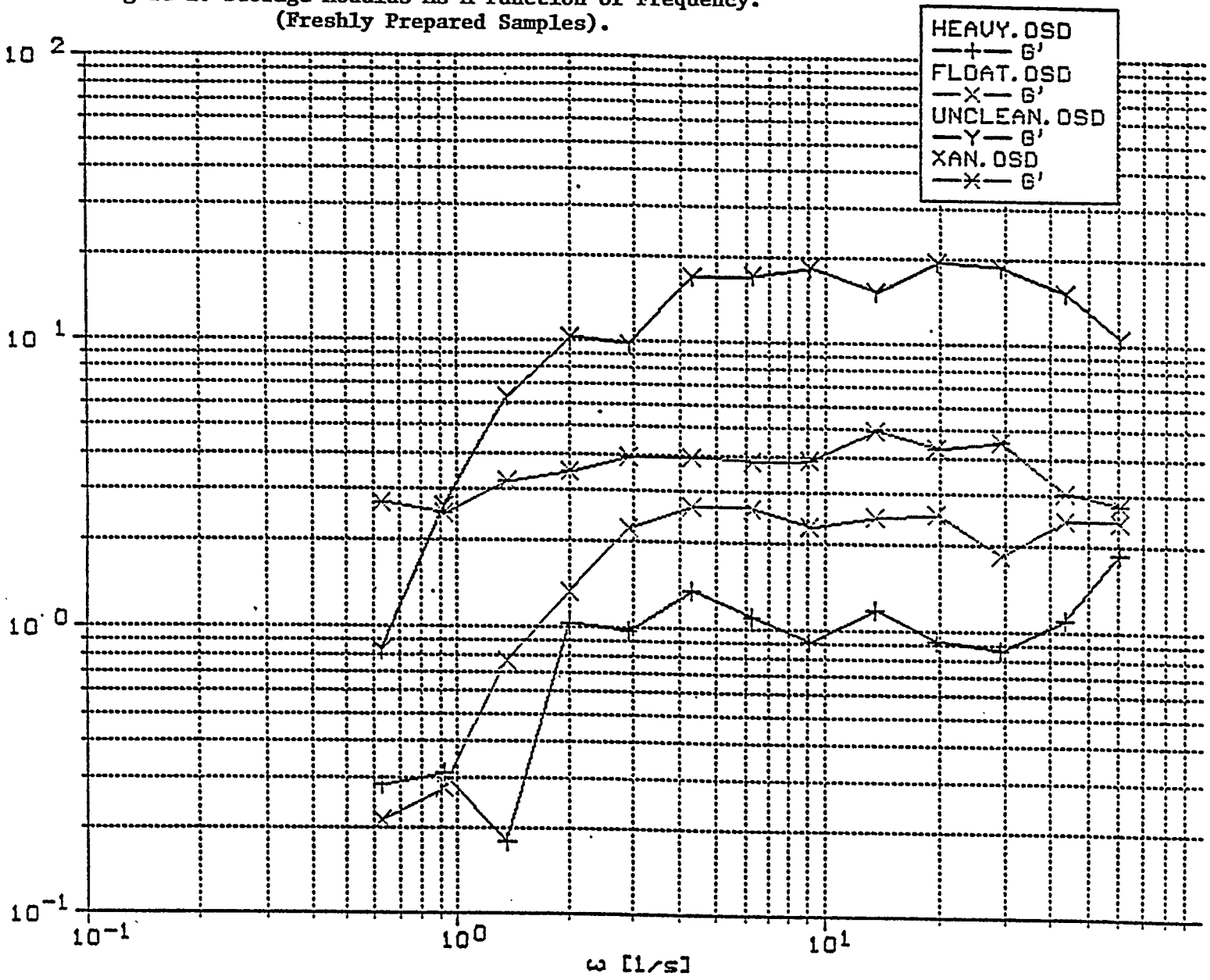


Figure 3. Flow Curves of 63% Coal Water Slurries.

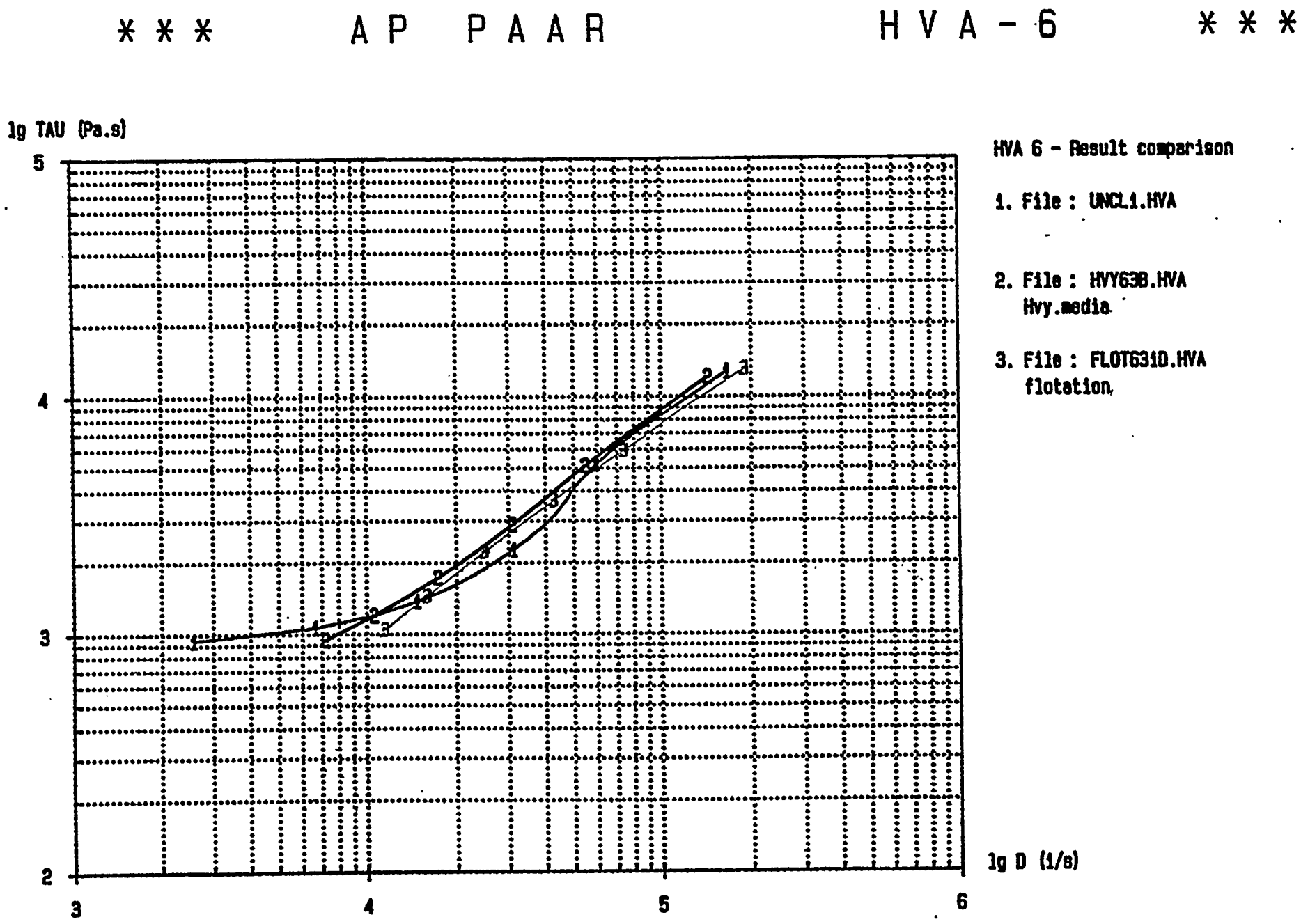


Figure 4. Log P(bar) Vs. Log Volumetric Flow Rate (mL/

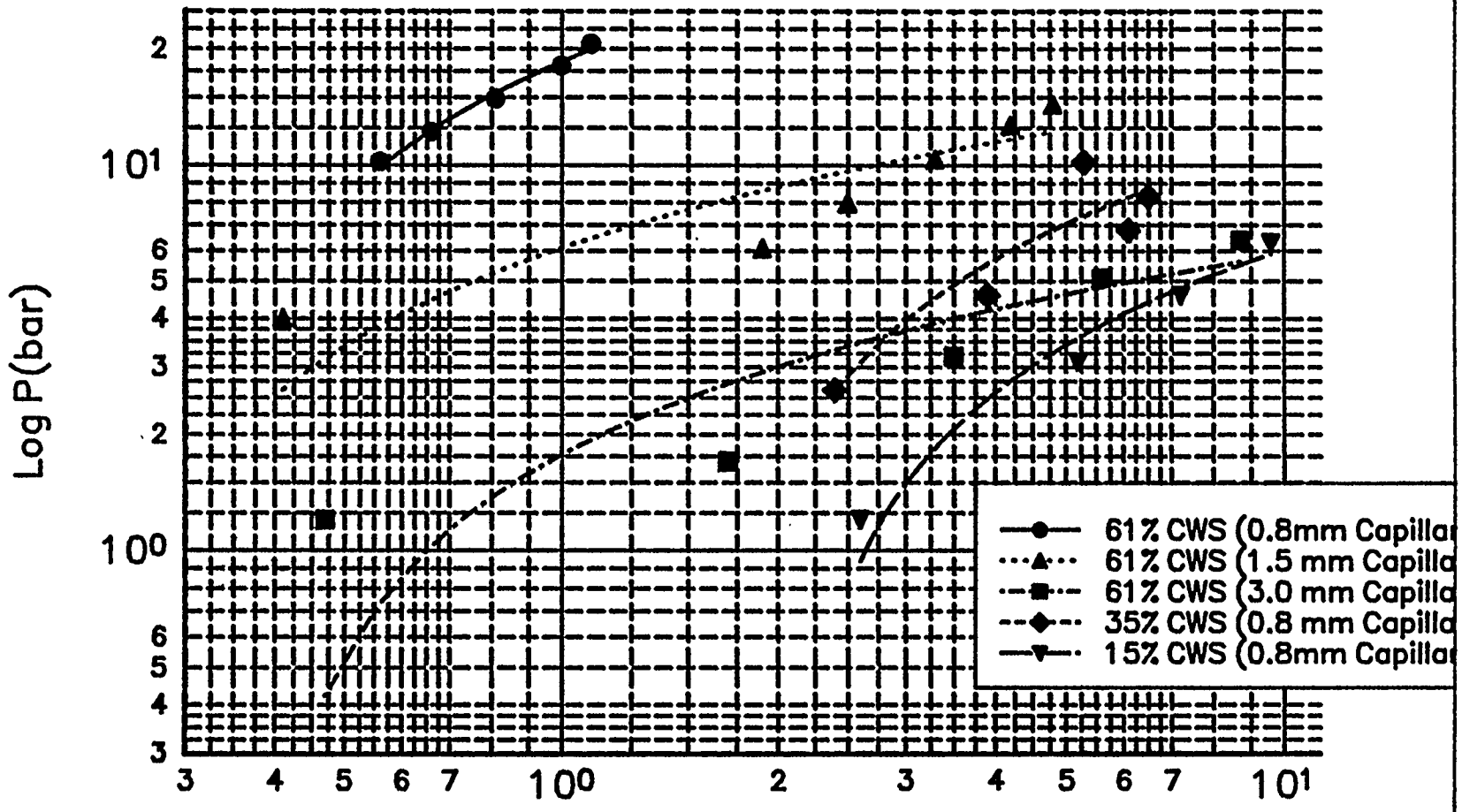


Figure 4. Log P(bar) vs. Log Volumetric Flow Rate.