LABORATORY REPORT COVER PAGE

GROUP NUMBER T1

EXPERIMENT NUMBER 6

TITLE Biorheology- Viscosity of Aqueous Biopolymer Solutions

DATE SUBMITTED 9/28/00

GROUP GRADE 100/100

ROLE ASSIGNMENTS

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SUMMARY OF CONCLUSIONS

Viscosity was determined quantitatively and qualitatively using three different procedures. In the first procedure, the Brookfield viscometer was used to determine the viscosity values and nature of a 50% weight sucrose solution and a CMC solution. A plot of viscosity versus shear rate for the 50% sucrose solution revealed the Newtonian nature (independent of shear rate) of the viscosity of the sugar solution, with a value of 15.119 ± 0.007 cP (95% confidence limit). This is significantly different from the literature value, listed in the CRC manual as 15.40 cP, thereby yielding a standard error of 1.85%. For the CMC solution, a Power plot of ln(viscosity) versus ln(shear rate) yielded a power index of $n = 0.8269 \pm 0.007$ (95% CI), which indicates a pseudoplastic fluid whose viscosity is a function of shear rate. In the second procedure, falling ball viscometer measurements of the terminal velocities and diameter of the balls were taken, and the ratio of diameter squared to terminal velocity was used to determine that η (viscosity) was non-constant, and thereby pseudo-plastic NOT ALL NON-NEWTONIAN FLUIDS ARE PSEDOPLASTIC. In the final procedure, the viscosity of the guar gum solution before and after the addition of sodium borate was quantitatively observed. Viscosity??? was shown to increase with the addition of sodium borate, which increased the number of cross-links in the polymer chains, thereby strengthening the substance.

GOOD- GRADE 20/20

Results

Fig 1. Linear plot, 50% sucrose

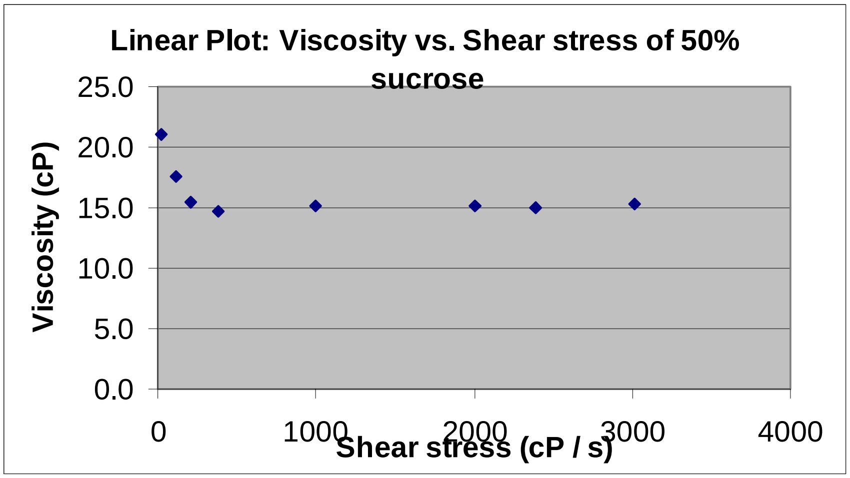
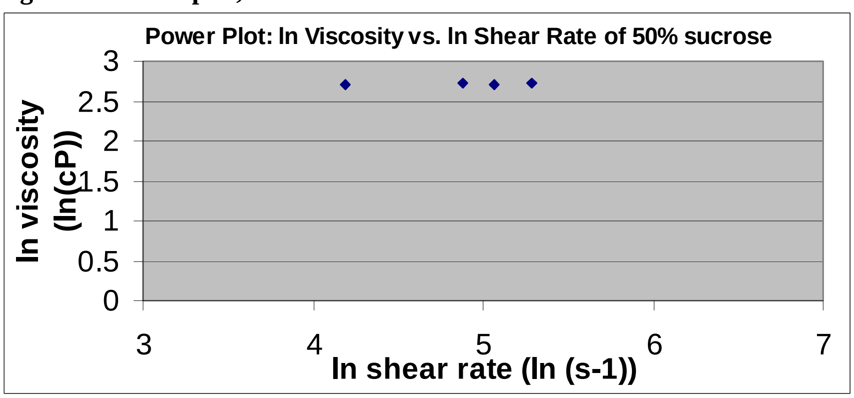


Fig 1.1 Data Analysis for Linear Plot, from points #5 - 8

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	15.03930818	0.115006023	130.7697434	5.84719E-05	14.54447685	15.5341395
X Variable 1	0.000738517	0.000783995	0.941992544	0.445632511	-0.002634742	0.004111777

WHAT IS THE AVERAGE OF POINTS 5-8?

Figure 2. Power plot, 50% sucrose



In this plot, points which lie outside of the accuracy range of the viscometer are not included

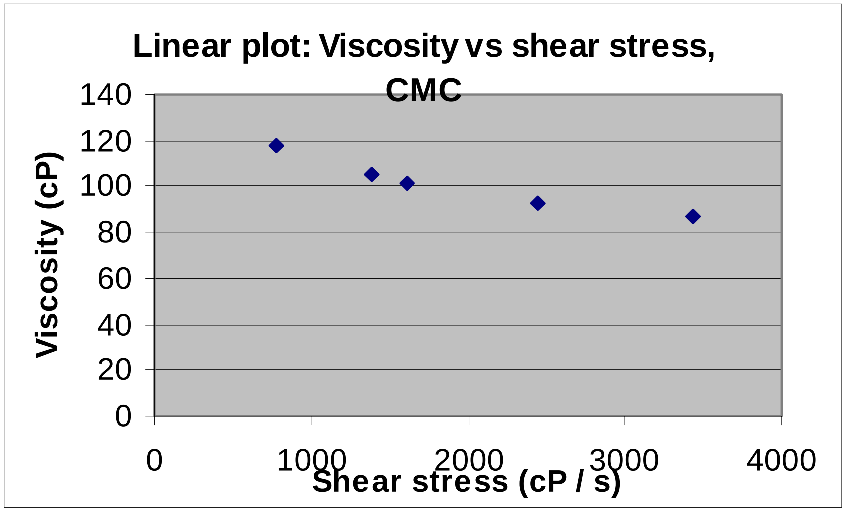
Figure 2.1 Data Analysis for Power Plot

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.717066	0.03265	83.21742	1.25E-07	2.626414	2.807718
X Variable 1	-0.00028	0.007544	-0.03761	0.971799	-0.02123	0.020662
k=	15.13585	plus / minus	1.094888	CI		
n=	0.999716	plus / minus	0.020945	CI		

NOTE: the fact that n is smaller than 1 means that it's non-Newtonian

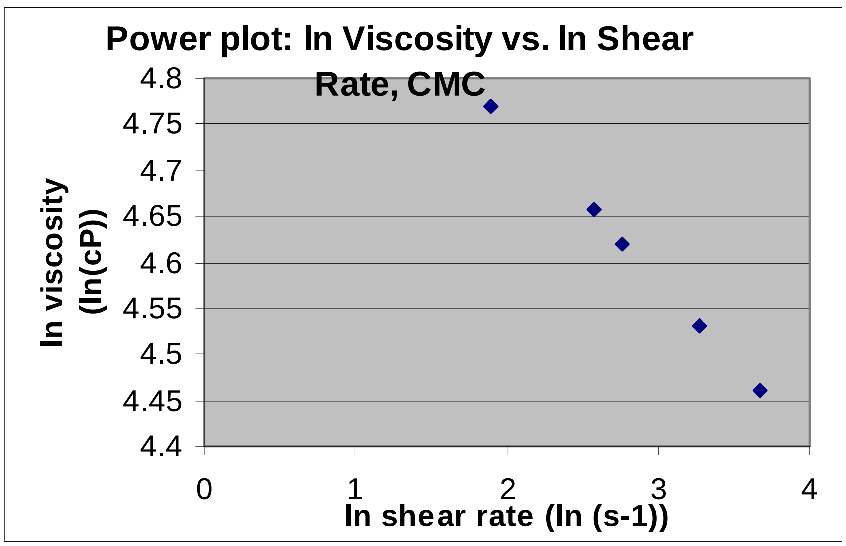
BUT N IS NOT SMALLER THAN 1 ACCORDING TO YOUR NUMBERS

Fig 3. Linear plot, CMC



In this plot, points which lie outside of the accuracy range of the viscometer (as determined from the sucrose data) are not included.

Fig 4. Power plot, CMC

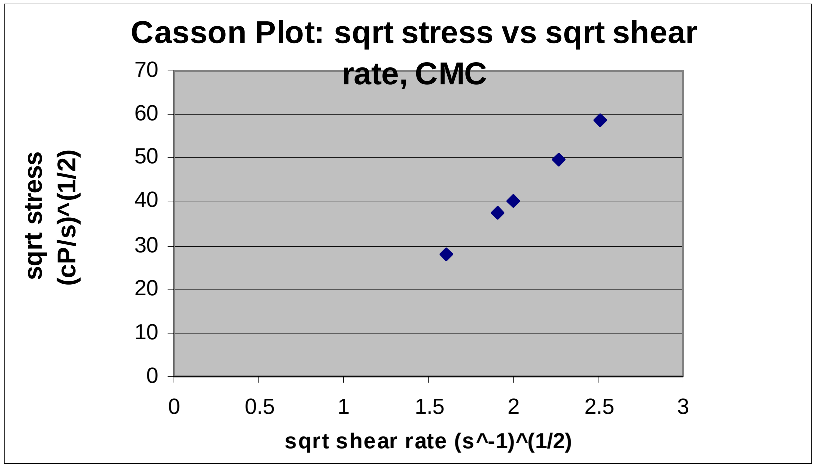


In this plot, points which lie outside of the accuracy range of the viscometer (as determined from the sucrose data) are not included.

Figure 4.1 Data Analysis for CMC power plot

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	5.098794448	0.0065656	776.5922632	4.70857E-09	5.077899757	5.119689138
X Variable 1	-0.173092336	0.002262686	-76.49861713	4.92315E-06	-0.180293219	-0.165891453
k=	163.8242894	plus / minus	1.021114513	CI		
n=	0.826907664	plus / minus	0.007200883	CI		
NOTE: the fact that n is smaller than 1 means that it's non-Newtonian						

Fig 5. Casson plot, CMC



In this plot, points which lie outside of the accuracy range of the viscometer (as determined from the sucrose data) are not included.

Figure 5.1 Data Analysis for Casson plot, CMC.

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-27.00439415	1.803007229	-14.97741868	0.000646002	-32.74237322	-21.26641507
X Variable 1	33.89094102	0.867208867	39.0804826	3.68611E-05	31.13109278	36.65078927
A=	33.89094102	plus / minus	2.759848243	CI		
Taught naught…						

Notice that in the data analysis, taught naught ($\tau_{0)}$ cannot be calculated. This is because according to the equation give below,

$$\sqrt{\tau} = \sqrt{\tau_0} + A\sqrt{\gamma'} \qquad \text{Eqn 1}$$

square root of taught naught ($\tau_{0)}$ is the y-intercept of the Casson plot. However, since our intercept as determined in Fig 5.1 above is negative, taught naught ($\tau_{0)}$ cannot be calculated. INTERESTING!

Fig 6. Falling ball viscometer data.

ball size (cm)	ball #	time traveled (s)	velocity (cm/s)	average velocity (cm/s)	StDev (cm/s)	d^2/V (cm*s)
0.953	1	443.28	0.069933			
0.953	2	405.57	0.076436			
0.953	3	394.22	0.078636			
0.953	4	406.65	0.076233	0.075309	0.0037458	12760.68
1.270	1	238.41	0.130028			
1.270	2	238.47	0.129995			
1.270	3	242.59	0.127788			
1.270	4	245.47	0.126288	0.128525	0.0018228	7477.152
1.905	1	141.06	0.219765			
1.905	2	138.19	0.224329			
1.905	3	135.65	0.228529			
1.905	4	137.22	0.225915	0.224634	0.0036795	4278.064

Guar gum observations:

Prior to addition of the sodium borate, the guar gum exhibited fluid motion when shaken or tested with a stirring rod. When probed with the stirring rod, the rod easily passed through the solution with little resistance and droplets of the solution clung easily to the probe when the probe was removed from solution. This shows that the original guar gum solution exhibited very fluid qualities, which is associated with a lower viscosity. LOWER IS NOT LOW- LOWER THAN WHAT? THAT SOLUTION WAS QUITE VISCOUSHowever, its viscosity was still considerably greater than a NaCl or sugar solution, which can be inferred from the slower motion of the solution when shaken and disturbed. GOODWhen sodium borate was added, the solution became more viscous. Its motion was slower than the original guar gum solution, and it was more resistant to being probed by the stirring rod. These qualities become even more emphasized when even more sodium borate was added: the guar gum became a viscoelastic solution. When the balls were dropped into this solution, they did not submerge into the solution. Several hours after adding sodium borate, the solution was observed to exhibit almost solid-like properties with high viscosity. When tested with the stirring rod, droplets of the solution did not cling to the rod due to the highly sticky nature of the substance.

GOOD AND COMPLETE PRESENTATION GRADE 40/40

Analysis

I. Sucrose analysis.

The plot of viscosity vs. shear rate (Fig 1) for 50% sucrose shows that at first the viscosity decreases with respect to shear stress then levels off. The fact that the graph approaches a constant value seems to indicate that the sucrose solution is a Newtonian fluid, in which the viscosity doesn't change with respect to either the stress or the strain rate. The initial points, though, seem to refute this hypothesis. Upon closer inspection, however, it can be seen that the initial points lie within the region of torque < 10%. This is the region where the measurements are extremely uncertain due to instrumental limitations (at 1 rpm and torque less than 5%, viscosity measurement ranged from 9 to 24 cP).

Regression analysis reveals that the leveling off region is reached after shear stress reaches 203.94 (cP / s), which corresponds to a viscosity of 15.5 cP and a maximum torque of 24.9%, with slope = 0.000739 $\pm$ 0.00337 (95% CI). The average viscosity in the linear region is 15.119 ± 0.007 (95% confidence limit). This significantly differs from the literature value of 15.40 cP, giving us standard error of only 1.85%. IS THIS EXPECTED? WHAT IS THE EXPECTED ACCURACY OF THE INSTRUMENT? IF YOU HAD INCLUDED THE INDIVIDUAL VALUES NOT JUST THE GRAPH I MIGHT HAVE FIGURED OUT WHAT HAPPENED. YOU CSAN'T JUST LEAVE US HANGING LIKE THAT!

II. CMC analysis.

The Power law plot of the CMC reveals a straight line with a slope of -0.173 ± 0.007 (95% CI), resulting in a power index (n) of 0.8269 ± 0.007 (95% CI). This number is significantly less than one, meaning that the CMC solution is a pseudoplastic fluid. As a pseudoplastic fluid, the behavior of CMC deviates from linear behavior, and since K is large (about 10 times that of sucrose) this fluid has a viscosity much greater than that of sucrose. The higher viscosity, as well as the deviation from linear behavior is understandable, since the carboxymethyl cellulose consists of polymeric polysaccharide chains, rather than the small disaccharide molecules in sucrose. The polysaccharide chains interfere with one another causing increased viscosity, and at lower shear rate, more deviation from linearity.

When a line of best fit is applied to the Casson plot for CMC, the result is a line with a negative y-intercept, meaning that taught naught ($\tau_{0)}$ cannot be calculated (see explanations in results, Figure 5.1). This indicates that although the CMC is a fluid made of long polymer chains that interact with one another, there is no apparent yield stress and when the fluid is still, no shear stress need be applied to restart flow. NO- IT MEANS THAT IN THE RANGE OF SHEAR RATES WHERE YOUR DATA WERE GOOD, THE CASSON PLOT IS NOT A GOOD REPRESENTATION OF THE MATERIAL

III. Falling ball viscometer: Guar gum.

In order to determine if the guar gum is a Newtonian liquid, its apparent viscosity must be examined. For the guar gum to be Newtonian, the viscosity of the solution must be constant and independent of the shear and strain rates. However, most Newtonian liquids are simple and dilute, whereas the guar gum solution is more likely to follow non-Newtonian behavior because it is so closely related to a polymer solution. HOW? WHAT IS IT CHEMICALLY? IT'S YOUR JOB TO TELL US

The falling ball viscometer makes the assumption that the ball conforms to the Stokes Law THIS IS NOT STOKES LAW. IT IS THE EXPECTED TERMINAL VELOCITY OF A SPHERE GIVEN MANY ASSUMPTIONS, ONE OF WHICH IS STOKES LAW

$$Vt = [g(\rho_b-\rho)d^{\wedge}2]/18\eta \qquad \text{Eqn 2}$$

where Vt is the terminal velocity of the falling ball due to the viscosity of the liquid, g= the gravitational constant, and ρ_b and ρ are the densities of the ball and liquid respectively, d is the diameter of the ball dropped, and η is the apparent viscosity

When solving for viscosity η, the equation becomes

$$\eta=[g(\rho_b-\rho)d^{\wedge}2]/18Vt \qquad \text{Eqn 3}$$

It can be seen that in Eqn 3, $g(\rho_b-\rho) / 18$ is a constant. Thus, η is proportional to d^2 / Vt. If d^2 / Vt varies according to ball size, then η would also vary. Fig 6 indicates that d^2 / Vt *does* indeed vary according to ball size. Thus, η is dependent on shear and strain rates, making guar gum non-Newtonian. GOOD

Taking this a step further, it can be seen that the data shows that for the 0.953cm diameter ball the apparent viscosity η= (0.091929-0.06567ρ). The apparent viscosity of the 1.270cm diameter ball was η=(0.09567-0.06835ρ), and the viscosity for the 1.905cm diameter ball was η=(0.12316-0.087959ρ). Since the density of guar gum is not given, we can assume that its density is greater than that of water and thus is greater than one, however the density of the guar gum must be 1.4 or higher for it to behave as pseudo-plastic in order to achieve a trend of decreasing viscosity while the stress rate increases. With this assumption the apparent viscosity of the solution lessens as the stress rate, in this case the diameter of the falling ball, which is proportional to the surface area of the sphere, increases with increasing ball size. However, the non- linear nature of the viscosity data shows that the guar gum is definitely non-Newtonian. . GOOD- YOU ALMOST GOT IT!

IV. Guar gum: addition of sodium borate.

On the molecular scale, this increase in viscosity with the addition of sodium borate can explained with the concept of crosslinks. In the original guar gum polymer, there were very few and weak bonds formed between the chains of molecules. This results in fast and easy motion of chains sliding past one another, which explains the macroscopic property of the fluid and low viscous nature of the solution. The addition of sodium borate causes hydrogen bonds to form between the chains, creating bonds called cross-links, that serve to increase the strength of the substance. Due to this increase in bonds between the chains, the substance now is more likely to retain its shape and be resistant to applied forces and stresses. This results in the increased viscous behavior of the solution. The observation that the solution had strengthened even more several hours after the last addition of sodium borate could possibly be caused by the diffusion of the sodium borate throughout the guar gum solution to create a uniform substance. In the lapsed time, the sodium borate became even distributed, thereby creating crosslinks throughout the solution, resulting in the final, highly viscous substance.
PRETTY GOOD ANALYSIS GRADE 40/40

References

1. Litt, Mitchell. BE 309 Bioengineering Laboratory II Laboratory Manual, Fall 2000, Exp. 6
2. Handbook of Physics and Chemistry, CRC Press, 63rd Edition