STUDYING THE EFFECT OF ADDING CMC ON RHEOLOGICAL PROPERITES OF NON –NEWTONIAN FLUIDS

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Abstract

In this research, set of experimental works are performed by adding carboxyl methyl cellulose (CMC) to the water to made non – Newtonian fluids to find out some of relationships in this subject. Tests are done by FANN-VG instrument after preparing the samples for test. Comparative graphs of shear stress vs. shear rates are plotted for experimental work, power law and Herschel – bulkley models. The behaviour of shear stress with shear rate is examined and finds that the relation between them is proportional for all them. The percentage error of power law and Herschel- bulkley models with CMC% established. It can see that the percentage error decrease when CMC% increase. Also the relationship for (n) values with CMC% concentration found, decreases with increasing CMC%. At last yield point over plastic viscosity with CMC% are plotted and found proportional.

Keyword: carboxyl methyl cellulose, Herschel – bulkley models, plastic

تأثير إضافة CMC على ريولوجية الموائع اللانيوتينية

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الخلاصة

في هذا البحث ، مجموعة من التجارب أنجزت بإضافة مادة CMC إلى الماء لتكوين موائع لانيوتينية لإيجاد بعض العلاقات ضمن هذا الموضوع. التجارب أجريت على جهاز FANN-VG وذالك بعد تحضير العينات المطلوبة. تم مقارنة الرسومات البيانية لإيجاد العلاقة بين إجهاد القص ومعدل القص للتجارب مع موديلان هما power law and Herschel – bulkley . تم فحص سلوك إجهاد القص مع معدل القص ووجدت إنها طردية في كل التجارب. وجدت أيضا نسبة الخطأ لكل من الموديلين مع تركيز CMC. والواضح إن نسبة الخطأ تقل مع زيادة التركيز و كذلك العلاقة بين قيمة (n) وتركيز البوليمر المستخدم. أخيرا وجدت العلاقة بين نقطة المطاوعة على اللزوجة البلاستيكية مع تركيز البوليمر إنها طردية.

Nomenclature

k : Viscosity. kg/m.sec
K: consistency index.
n : power law exponent.
Pv : Plastic viscosity. kg/m.sec
Yp : Yield point.
τ_0 : yield stress. lb/100ft^2
τ : Shear stress. lb/100ft^2
γ : Shear rate. 1/sec
μp : plastic viscosity. kg/m.sec
Φ : velocity r.p.m.
τ_{mea} : shear stress (experimental). lb/100ft^2
τ_{cal} : shear stress (theoretical). lb/100ft^2
V_w : volume of water use. cm^3
P.E.: percentage error.
$\bar{n}$: flow behavior index.
$\bar{\mathbf{k}}$: consistency index.
Θ : dial reading.

INTRODUCTION

Fluid loss during drilling operations has a very significant effect on both reservoir formation damage and monetary terms. There are many additives to control this unwanted phenomenon. Nevertheless, most of these substances are artificial chemicals. Thus, they are not only expensive. The use of highly viscous non-Newtonian fluids is very frequent in many industrial operations, particularly in mixing processes. Such fluids often have complex rheological properties, which can increase operating costs and create other problems during mixing process. The viscosity as one of the most important property of the fluid has a great significance in processes, in which the rheological properties of the fluid are complex and can change with time [Iscan & Kok, 2007]. Rheology can be defined the science and study of the deformation and flow of matter. The term is also used to indicate the properties of a given fluid, as in mud rheology. Rheology is important property of drilling mud, drill-in fluids, work over and completion fluids, cements and specialty fluids and pills. Mud rheology is measured on a continual basis while drilling and adjusted with additives or dilution to meet the needs of the operation [Lauzan, 1982].
Newtonian fluid is a fluid that has a constant viscosity at all shear rates at a constant temperature and pressure, and can be described by a one-parameter rheological model. An equation describing a Newtonian fluid is given below

$$\tau = k(\gamma) \quad (1)$$

Water, sugar solutions, glycerin, silicone oils, light-hydrocarbon oils, air and other gases are Newtonian fluids. Most drilling fluids, cement confection and paints are non-Newtonian. Non-Newtonian fluids do not exhibit a linear relationship between shear stress and shear strain. A certain threshold stress must be applied to initiate flow [Gray & Darlcy, 1981].

In water-base fluids, water quality plays an important role in how additives perform. Temperature affects behavior and interactions of the water, clay, polymers and solids in a mud. Down hole pressure must be taken into account in evaluating the rheology of oil mud [Lauzan, 1982]. Rheological Properties of the drilling fluids and crude oils are often studied by six speeds Fann V.G. meter in field labs. The fluids often obey power law equation. Fann V.G. meter gives six data sets of RPM and corresponding dial readings. These speeds and dial readings are converted into shear rate and shear stress respectively by, multiplying them with suitable constant [Gray & Darlcy 1981]. To evaluate the power law parameters like Power Index (n) and Consistency Index (K), a graph is plotted between logarithms of shear rate and shear stress. A straight line results, Slope of the line gives Power Index (n) and intercept on y-axis gives Log K, from which K can be calculated. [Craft & et.al. 1962]

CMC Polymer

CMC (sodium salt of Carboxy Methyl Cellulose)is a water-soluble polymer made from cellulose through chemical modification. Technical-grade CMC with high viscosity can employ in the drilling mud to control fluid loss. CMC is produced by reacting alkali cellulose with monochloroacetic acid (MCA) or monochloro acetate (SMCA) under well controlled conditions. Technical quality CMC contains these impurities and the purified CMC is obtained by extracting these impurities by a solvent washing process. After washing the CMC is dried, milled and screened according to the desired particle size. Nowadays many companies are shifting to purify CMC because of the better results of pure CMC in final application. Cellulose is a linearly constructed and high polymer [Lauzan, 1982]. It is the combination of (cellobios) units, side by side. Every (cellobios) units is made of two (anhydroglycose) units repeated (anhydroglycose) units are bonded to each other with glycoside. In the construction of cellulose molecules (n) represents the number of anhydroglycose units, bonded each other by oxygen. This number is equal to value of polymerization degree of cell.

The uses of CMC are [Hghes& et.al. 1993]:-

1. Oil drilling grade CMC used in fracturing fluid, drilling fluid and well cementing fluid as fluid loss controller and testifier. It can protect the shaft wall and prevent mud loss thus enhance recovery efficiency.
2. Detergent grade CMC, when used in liquid, paste detergent, acts as stabilizing agent and thickening agent; when used in detergent powder, CMC can effectively prevent washes from becoming contaminated after being washed by synthetic detergent.
3. CMC used in textile and dyeing industry as sizing agent and dying adjuvant to make stock limpidity and transparence. It is easy a good stabilizer of the stock and helps to form film.

Yield Point

A parameter of the Bingham plastic model YP is the yield stress extrapolated to a shear rate of zero. (Plastic viscosity, PV, is the other parameter of the Bingham-plastic model.) A Bingham plastic fluid plots as a straight line on a shear rate (x-axis) versus shear stress (y-axis) plot, in which YP is the zero-shear-rate intercept. (PV is the slope of the line.) YP is calculated from 300- and 600-rpm viscometer dial readings by subtracting PV from the 300-rpm dial reading. YP is used to evaluate the ability of a mud to lift cuttings out of the annulus. A high YP implies a non-Newtonian fluid, one that carries cuttings better than a fluid of similar density but lower YP. YP is lowered by adding deflocculated to a clay-based mud and increased by adding freshly dispersed clay or a flocculants, such as lime [Lauzon & Reid 1979].

Types of mathematical models

Bingham plastic model

A two parameter rheological model are widely used in the drilling fluids industry to describe flow characteristics of many types of mud. It can be described mathematically as follows:-

$$\tau = yp + pv(\gamma) \tag{2}$$

Fluids obeying this model are called Bingham plastic fluids and exhibit a linear shear-stress, shear-rate behavior after an initial shear stress threshold has been reached. Plastic viscosity (PV) is the slope of the line and yield point (YP) is the threshold stress. PV should be as low as possible for fast drilling and is best achieved by minimizing colloidal solids. YP must be high enough to carry cuttings out of the hole, but not so large as to create excessive pump pressure when starting mud flow. YP is adjusted by judicious choices of mud treatments. The direct-indicating rotational rheometer was specifically designed to apply the Bingham plastic fluid model [Gray & Darcly1981].

Power law model

The Power Law model (sometimes known as the Ostwald model) is an easy-to-use model that is ideal for shear-thinning, relatively movable fluids such as weak gels and low-viscosity dispersions. The model is nothing more than the Newtonian model, with an added exponent on the shear rate term. [Hghes & et.al. 1993]

$$\tau = k\gamma^{n} \tag{3}$$

$$n = \frac{\Sigma\, log\,(\tau_{mea}) * \Sigma\, log(\Upsilon) - N\Sigma\, log(\tau_{mea}) * log\,(\Upsilon)}{(\Sigma\, log\,(\Upsilon))^2 - N * \Sigma(log(\Upsilon))^2} \tag{4}$$

$$log(k) = \frac{\Sigma\, log\, \tau_{mea} - n * \Sigma\, log \Upsilon}{N} \tag{5}$$

$$log(k) = \frac{\Sigma\, log\, \tau_{mea} - n * \Sigma\, log \Upsilon}{N} \tag{6}$$

$$P.E. = \frac{\left|\frac{\tau_{mea} - \tau_{cal}}{\tau_{mea}}\right|}{N} \tag{7}$$

This equations used in tables for found the constants (n) and log (k) and this lead to found log (τ) Shear thinning, non-Newtonian behavior can be quantified by the (n) factor which indicates that the degree of non-Newtonian behavior that a fluid exhibits over a defined shear rate range.

Herschel –bulkley model

Called also modified power law, its fluid described by a three-parameter rheological model. A Herschel-Bulkley model can be described mathematically as follows:-

$$\tau = \tau_0 + K(\gamma)^{n} \tag{8}$$

$$\tau_y = \tau_1 \quad (9)$$

$$\bar{n} = \frac{\Sigma \log\left(\tau_{mea} - \tau_y\right) * \Sigma \log(\gamma) - N\Sigma\left(\log\left(\tau_{mea} - \tau_y\right) * \log(\Upsilon)\right)}{\left(\Sigma \log(\Upsilon)\right)^2 - N * \Sigma\left(\log(\Upsilon)\right)^2} \quad (10)$$

$$\log \bar{k} = \frac{\Sigma \log\left[\left(\tau_{mea} - \tau_y\right]\right) - \bar{n} * \Sigma \log(Y)}{\square} \quad (11)$$

$$\tau_{cal} = yp + \bar{k} * \gamma^{\bar{n}} \quad (12)$$

This equations used in tables for found the constants ($\bar{n}$) and log($\bar{k}$) and this lead to found (τ_{cal}) The Herschel-Bulkley equation is preferred to power law or Bingham relationships because it results in more accurate models of rheological behavior when adequate experimental data are available. The yield stress is normally taken as the 3 rpm reading, with n and K values then calculated from the 600 or 300 rpm values or graphically. **[**Lscan & Kok, 2007 **]**

Fig (1) shows the relationship between shear stress versus shear rate for Newtonian and non-Newtonian fluids.

Experimental Work

To know the influence of adding the polymer on rheological of non- Newtonian fluids, the following experimental steps are done, obtain the number of grams of CMC from the following equation:-

$$\log \bar{k} = \frac{\Sigma \log\left[\left(\tau_{mea} - \tau_y\right]\right) - \bar{n} * \Sigma \log(Y)}{\square} \quad (5)$$

The percentage of CMC is (0.5, 0.75, 1, 1.5, and 2) % respectively, where Vw is the volume of water that taken equal to 500 cm^3. Then suppose that Vw= 500cc and must be deference the accuracy in measurements to avoid the errors in calculations. Add the calculated quantity from eq. (5) to water gradually and mix, continue adding and mix until add all amount of CMC. This process should continue at least one hour until the quantity dissolved completed, put 300cc from the mixture in the cup of FANN-VG until reach to the sign in the cup. Obtain the readings of speeds in r.p.m (Φ 600, Φ 300, Φ200, Φ100, Φ6, Φ3) from Instruction. Clean the Instruction very well in each time because the sediment in the cup of Instrument leads to incorrect readings in next time.

Description of instrument

The model viscometer determines the flow characteristics of oils and drilling fluids in terms of shear stress, shear rate at atmospheric pressure. An optional cup heater is used to raise the temperature of the test sample. The model is suitable for both field and laboratory because easy for portable and uses a motor-driven electronic package to provide drilling fluid engineers. The principle in measuring is the torque that needs to rotate inner rotation in test cup filled by clay. The rotation done by, motor with two speeds high and low.

The apparatus of instrument are:-[To ̆rul & Arslan, 2003]

1. The r.p.m. range knob is used to obtain six velocities for axis rotation (3, 6, 100, 200, 300, 600), the dial reading use for reading the results.
2. Thermo cup used to maintains the temperature of sample.
3. Rotating cylinder used to rotate the inner cup.
4. Outer cylinder contain mud sample and must be constant.
5. Thermometer used to keep the temperature constant.

RESULT AND DISCUSSION

In this research, we must remark to that the temperature neglected because we use the thermometer to keep the temperature constant. Any addition of CMC leads to changing in properties of non -Newtonian fluids because CMC will increase the shearing stress because it leads to increase in viscosity and it leads to increase in gel resistance. This properties influence on the drilling fluids. Figures from (3-7) explain the relation between shear rate and shear stress for experimental, power law and modified power law (Herschel – bulkley) models, It can see that this relation is proportional for all them. Figure (8) explain the relation between percentage error and CMC concentration , it seen that the percentage error decrease when CMC% increase because when CMC increasing is lead to increase in shear stress and increase in shear rate, this lead to decrease in percentage error, for power law model the percentage error become very little whenever CMC increasing. But in modified power law it little increase. Figure (9) show that the power law exponent (n) decrease with increasing in CMC%. Figure (10) show the relation between yield points with CMC% that is proportional.

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Table (1) Experimental and theoretical (power law model) with conc. = 0.5%

Φ	$\gamma = 1.703 * \Phi$	Θ	$\tau_{mea} = 1.067\ \theta$	Log τ_{mea}	Log γ	Log γ* Log τ_{mea}	(Log $\gamma)^2$	Log τ_{cal}	$\left\lvert \frac{\tau_{mea} - \tau_{cal}}{\tau_{mea}} \right\rvert$
3	5.11	.75	.801	- .0967	.708	-.0680	.5010	-.13	.4130
6	10.27	1	1.067	.0281	1.01	.0284	1.022	.060	1.112
100	170.3	6	6.402	.806	2.23	1.800	4.97	.848	.05250
200	340.6	10.5	11.20	1.05	2.53	2.650	6.412	1.04	.00567
300	511.9	14	14.93	1.174	2.71	3.182	7.344	1.15	.01345
600	1021	22	23.47	1.37	3.00	4.124	9.055	1.35	.01330
				Σ=4.33	Σ=12	Σ=11.72	Σ=29		Σ=1.61

Table (2) Experimental and theoretical (power law model) with conc. = 0.75%

Φ	$\gamma = 1.703\ \Phi$	θ	$\tau_{mea} = 1.067\ \theta$	Log τ_{mea}	Log γ	Log γ* Log τ_{mea}	(Log $\gamma)^2$	τ_{cal}	Log τ_{cal}	$\left\lvert \frac{\tau_{mea} - \tau_{cal}}{\tau_{mea}} \right\rvert$
3	5.11	1.2	1.337	.125	.708	.0885	.5010	.78	-.10	.414
6	10.2	2	2.134	.329	1.01	.333	1.022	1.1	.06	.458
100	170.3	13	13.87	1.142	2.23	2.547	4.97	5.5	.747	.597
200	340.6	22.5	24.01	1.38	2.53	.9622	6.412	8.2	.916	.656
300	511.9	28.5	30.41	1.483	2.71	4.019	7.344	10	1.01	.659
600	1021	42	44.8	1.65	3.00	4.97	9.055	15	1.18	.01330
				Σ=5.11	Σ=12	Σ=12.919	Σ=29			Σ=1.61

Table (3) Experimental and theoretical (power law model) with conc. = 1%

Φ	$\gamma = 1.703 * \Phi$	θ	$\tau_{mea} = 1.067 * \theta$	Log τ_{mea}	Log γ	Log γ* Log τ_{mea}	(Log $\gamma)^2$	Log τ_{cal}	τ_{cal}	$\left\lvert \frac{\tau_{mea} - \tau_{cal}}{\tau_{mea}} \right\rvert$
3	5.11	2.7	2.88	.46	.708	.325	.5010	.506	3.2	.1138
6	10.2	5	5.33	.727	1.01	.7355	1.022	.693	5	.075
100	170.3	28	29.87	1.475	2.23	3.29	4.97	1.445	27.9	.0657
200	340.6	43	45.88	1.661	2.53	4.20	6.412	1.630	42.8	.0658
300	511.9	51	54.41	1.735	2.71	4.701	7.344	1.741	55.1	.0128
600	1021	72	76.824	1.885	3.00	5.674	9.055	1.925	84.3	.0975
				Σ=7.9	Σ=12	Σ=18.93	Σ=29			Σ=.4303

Table (4) Experimental and theoretical (power law model) with conc. =1.5%

Φ	$\gamma = 1.703*\Phi$	θ	$\tau_{mea} = 1.067*\theta$	Log τ_{mea}	Log γ	Log γ* Log τ_{mea}	(Log $\gamma)^2$	Log τ_{cal}	τ_{cal}	$\left\lvert\frac{\tau_{mea}-\tau_{cal}}{\tau_{mea}}\right\rvert$
3	5.11	6	6.402	.806	.708	.571	.5010	.839	6.9	.078
6	10.2	10	10.67	1.028	1.01	1.04	1.022	1.020	10.5	.0168
100	170.3	61	65.08	1.813	2.23	4.046	4.97	1.75	56.5	.131
200	340.6	92	98.16	1.99	2.53	5.045	6.412	1.933	85.7	.126
300	511.9	100	106.7	2.028	2.71	5.5	7.344	2.09	109	.027
600	1021	132	140.88	2.148	3.00	6.466	9.055	2.22	165	.176
				Σ=9.81	Σ=12	Σ=22.6	Σ=29			Σ=.555

Table (5) Experimental and theoretical (power law model) with conc. = 2%

Φ	$\gamma = 1.703*\Phi$	θ	$\tau_{mea} = 1.067*\theta$	Log τ_{mea}	Log γ	Log γ* Log τ_{mea}	(Log $\gamma)^2$	Log τ_{cal}	τ_{cal}	$\left\lvert\frac{\tau_{mea}-\tau_{cal}}{\tau_{mea}}\right\rvert$
3	5.11	16	17.07	1.232	.708	.872	.5010	1.26	18.3	.0766
6	10.2	25	26.67	1.426	1.01	1.442	1.022	1.41	26.1	.019
100	170.3	117	124.8	2.09	2.23	4.676	4.97	2.03	108.4	.131
200	340.6	154	164.3	2.21	2.53	5.61	6.412	2.18	153.5	.065
300	511.9	177	188.86	2.27	2.71	6.16	7.344	2.22	189.3	..0025
600	1021	222	236.87	2.37	3.00	7.14	9.055	2.42	268.3	.132
				Σ=11.6	Σ=12	Σ=26	Σ=29			Σ=.428

Table (6) Experimental and theoretical (Herschel-Bulkley model) with conc. = 0.5%

Φ	$\gamma = 1.703\ \Phi$	θ	τ_{mea}	Log γ	$\tau-\tau_y$	Log($\tau-\tau_y$)	Log($\tau-\tau_y$)* Log γ	(Log $\gamma)^2$	τ_{cal}	$\frac{\tau_{mea}-\tau_{cal}}{\tau_{mea}}$
3	5.11	.75	.8005	.708	0	0	0	.5010	1.22	-.536
6	10.2	1	1.067	1.01	.2667	-.574	-.58	1.022	1.52	.425
100	170.3	6	6.4	2.23	5.6	.748	1.7	4.97	6.6	-.029
200	340.6	10.5	11.2	2.53	10.4	1.017	2.5	6.412	10.5	.064
300	511.9	14	15	2.71	14.13	1.150	3.11	7.344	13.9	.069
600	1021	22	23.47	3.00	22.67	1.355	4.07	9.055	22.6	.0336
				Σ=12		Σ=3.697	Σ=10.8	Σ=29		Σ=1.158

Table (7) Experimental and theoretical (Herschel-Bulkley model) with conc. = 0.75%

Φ	$\gamma = 1.703*\Phi$	θ	τ_{mea}	$Log\ \gamma$	$\tau-\tau_y$	$Log(\tau-\tau_y)$	$Log(\tau-\tau_y)*Log\ \gamma$	$(Log\ \gamma)^2$	τ_{cal}	$\frac{\tau_{mea}-\tau_{cal}}{\tau_{mea}}$
3	5.11	1.25	1.337	.708	0	0	0	.5010	1.616	-.211
6	10.2	2	2.134	1.01	.80	-.967	-.978	1.022	1.9	.112
100	170.3	13	13.8	2.23	12.53	1.098	2.45	4.97	10.5	.241
200	340.6	22.5	24	2.53	22.67	1.355	3.4	6.412	19.6	.182
300	511.9	28.5	30.4	2.71	29.07	1.463	3.96	7.344	28.76	.054
600	1021	42	44.8	3.00	43.48	1.638	4.93	9.055	55.8	-.245
				Σ=12		Σ=4.5	Σ=13.8	Σ=29		

Table (8) Experimental and theoretical (Herschel-Bulkley model) with conc. = 1%

Φ	$\gamma = 1.703*\Phi$	θ	τ_{mea}	$Log\ \gamma$	$\tau-\tau_y$	$Log(\tau-\tau_y)$	$Log(\tau-\tau_y)*Log\ \gamma$	$(Log\ \gamma)^2$	τ_{cal}	$\frac{\tau_{mea}-\tau_{cal}}{\tau_{mea}}$
3	5.11	2.7	2.88	.708	0	0	0	.5010	4.10	-.425
6	10.2	5	5.33	1.01	2.45	.39	.394	1.022	5.05	.0534
100	170.3	28	29.87	2.23	26.99	1.43	3.19	4.97	24.45	.181
200	340.6	43	45.88	2.53	43	1.633	4.13	6.412	40.9	.108
300	511.9	51	54.41	2.71	51.5	1.71	4.64	7.344	55.93	-.027
600	1021	72	76.82	3.00	73.94	1.86	5.6	9.055	96.25	-.252
				Σ=12		Σ=7.03	Σ=17.98	Σ=29		

Table (9) Experimental and theoretical (Herschel-Bulkley model) with conc. = 1.5%

Φ	$\gamma = 1.703*\Phi$	θ	τ_{mea}	$Log\ \gamma$	$\tau-\tau_y$	$Log(\tau-\tau_y)$	$Log(\tau-\tau_y)*Log\ \gamma$	$(Log\ \gamma)^2$	τ_{cal}	$\frac{\tau_{mea}-\tau_{cal}}{\tau_{mea}}$
3	5.11	6	6.4	.708	0	0	0	.5010	6.71	-.048
6	10.2	10	10.67	1.01	4.26	.63	.63	1.022	9.43	.116
100	170.3	61	65.08	2.23	58.68	1.76	3.94	4.97	45.8	.296
200	340.6	92	98.16	2.53	91.76	1.96	4.97	6.412	80.6	.178
300	511.9	100	106.7	2.71	100.3	2.003	5.42	7.344	114.1	-.07
600	1021	132	140.8	3.00	134.44	2.12	6.4	9.055	208.9	-.483
				Σ=12		Σ=8.4	Σ=21.38	Σ=29		

Table (10) Experimental and theoretical (Herschel-Bulkley model) with conc. = 2%

Φ	$\gamma = 1.703*\Phi$	θ	τ_{mea}	Log γ	τ-τ_y	Log(τ-τ_y)	Log(τ-τ_y)* Log γ	(Log $\gamma)^2$	τ_{cal}	$\frac{\tau_{mea}-\tau_{cal}}{\tau_{mea}}$
3	5.11	16	17.07	.708	0	0	0	.5010	19.4	-.136
6	10.2	25	26.67	1.01	9.6	.98	.993	1.022	21.6	.19
100	170.3	117	124.8	2.23	107.76	2.03	4.533	4.97	82.27	.34
200	340.6	154	164.3	2.53	147.24	2.16	5.49	6.412	143.03	.13
300	511.9	177	188.8	2.71	171.78	2.235	6.05	7.344	202.56	-.072
600	1021	222	236.87	3.00	219.8	2.342	7.048	9.055	374.75	-.582
				Σ=12		Σ=9.76	Σ=24.122	Σ=29		

Table (11) Concentration of CMC% with (n) value and the percentage error for power law and Herschel-Bulkley models

CMC%	**n**	**Percentage error for power law model**	**Percentage error for Herschel-Bulkley model**
0.5	0.647	0.619	0.193
0.75	0.667	0.231	0.172
1.00	0.650	0.232	0.244
1.50	0.599	0.092	0.230
2.00	0.506	0.062	0.313

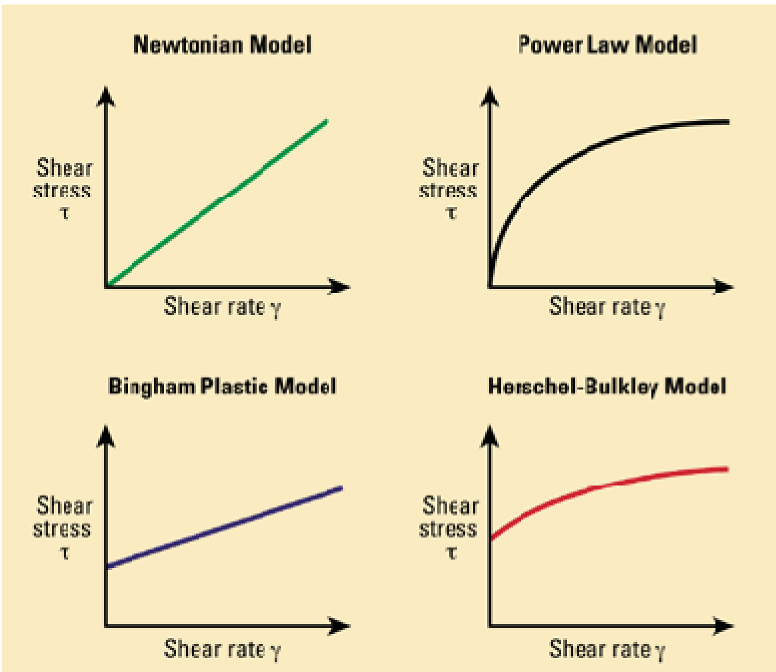


Fig (1) Flow curves of Newtonian and non-Newtonian fluids.

Fig (2) FANN - VG

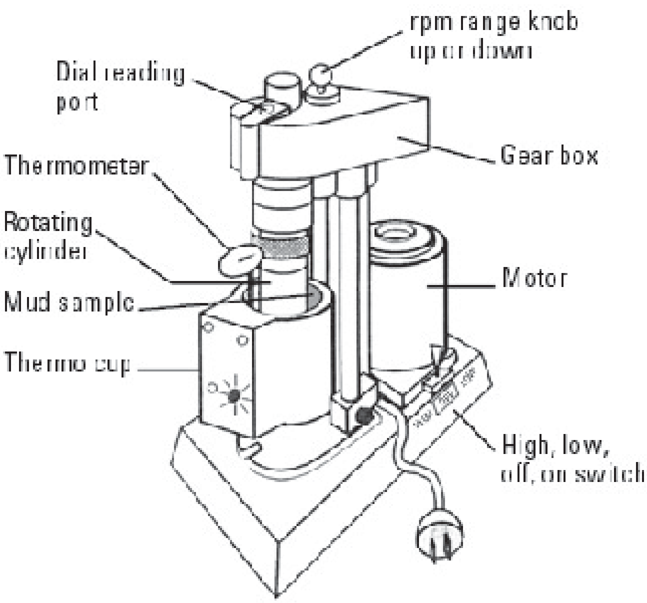


Fig (3) FANN- VG [ ]

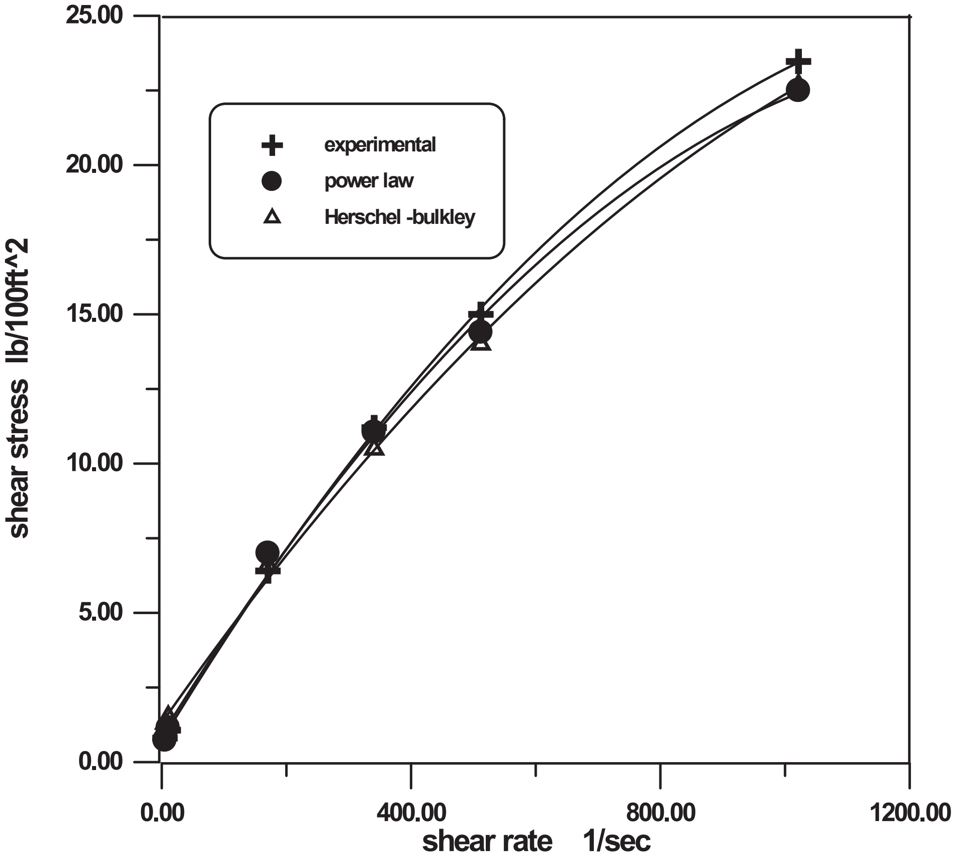


Fig (3) shear stress versus shear rate for the concentration of 0.50%

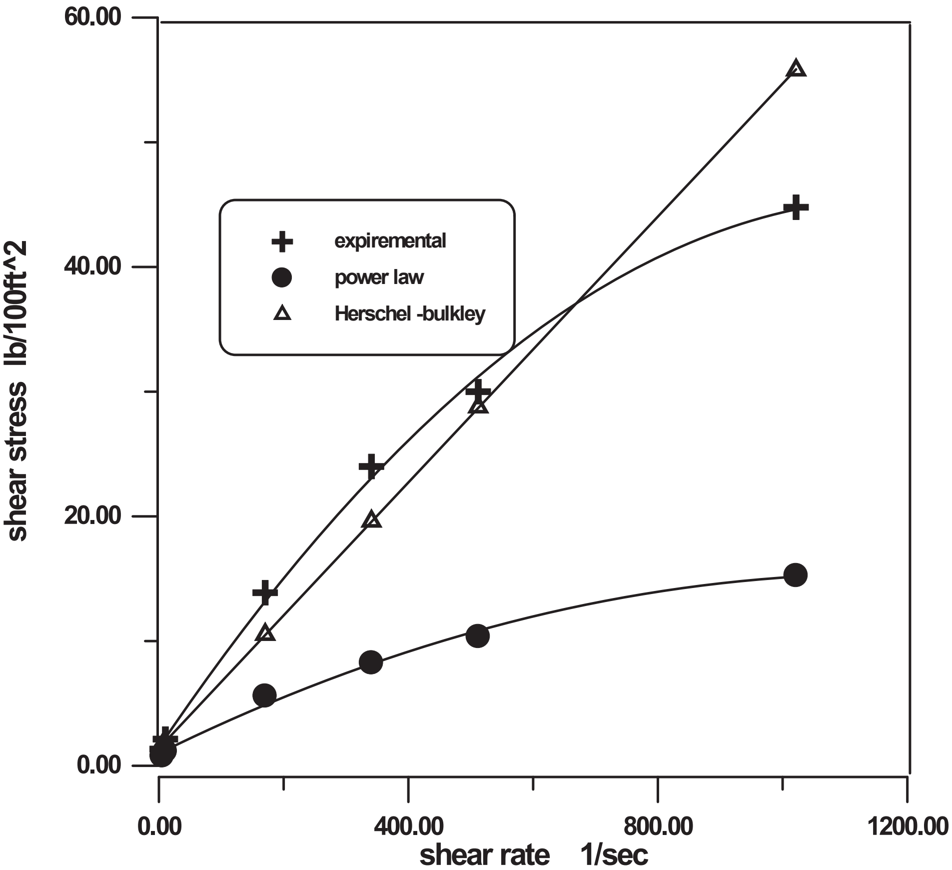
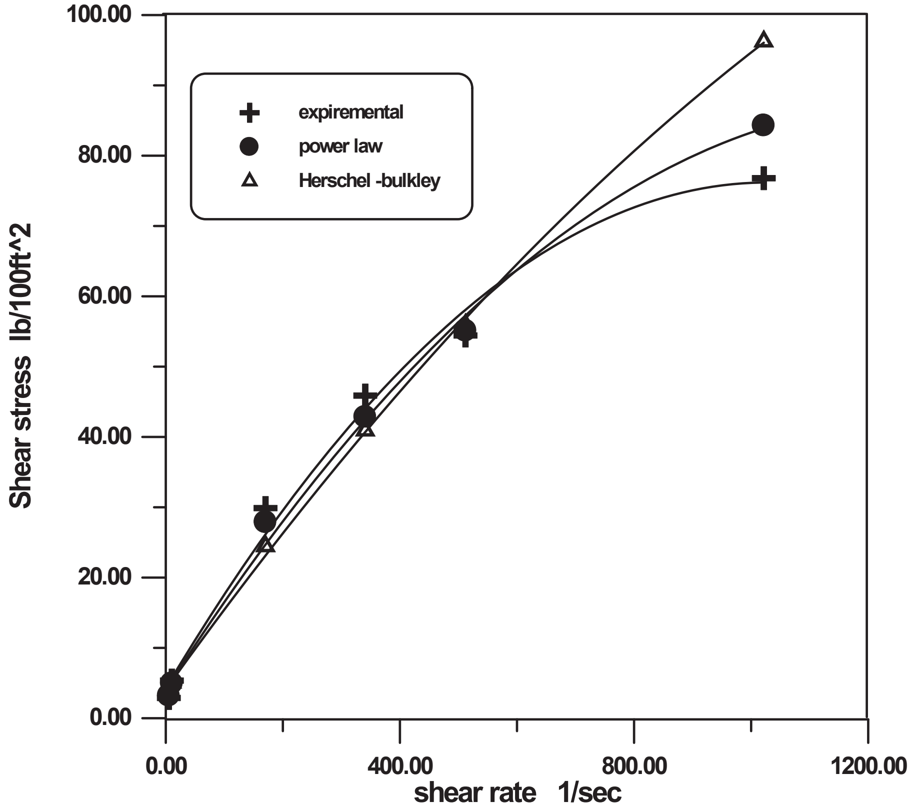


Fig (4) shear stress versus shear rate for the concentration of 0.75%



Fig(5) shear stress versus shear rate for the concentration of 1%

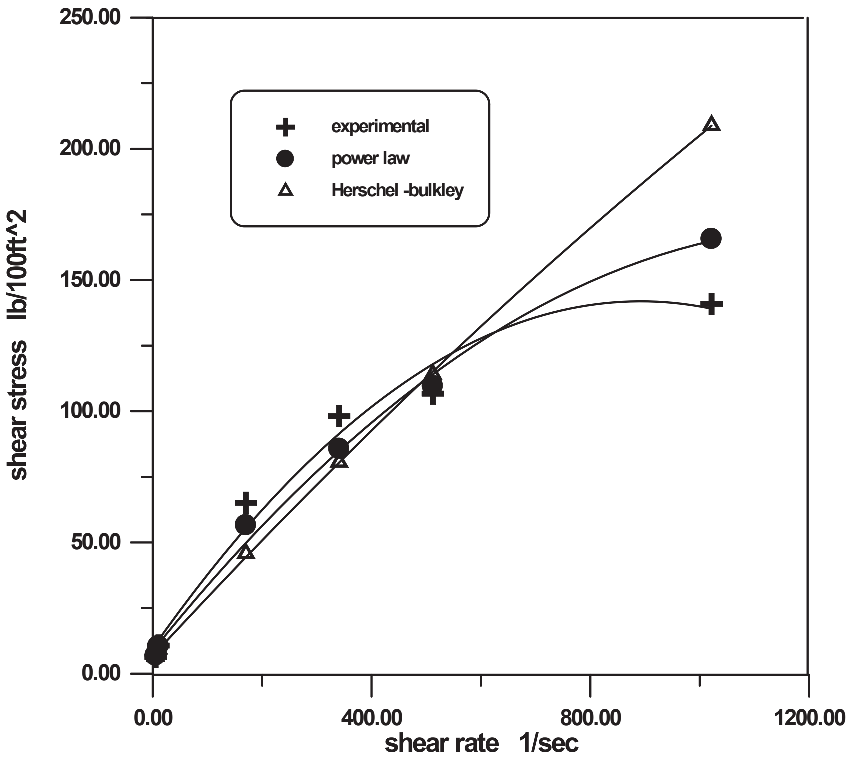
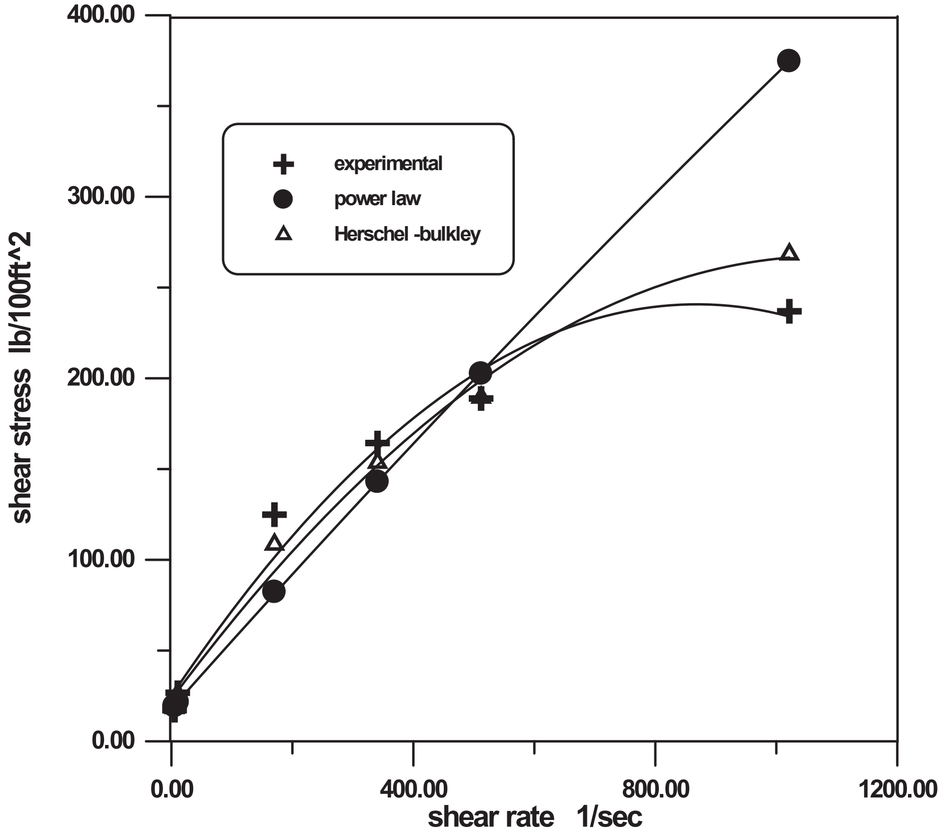
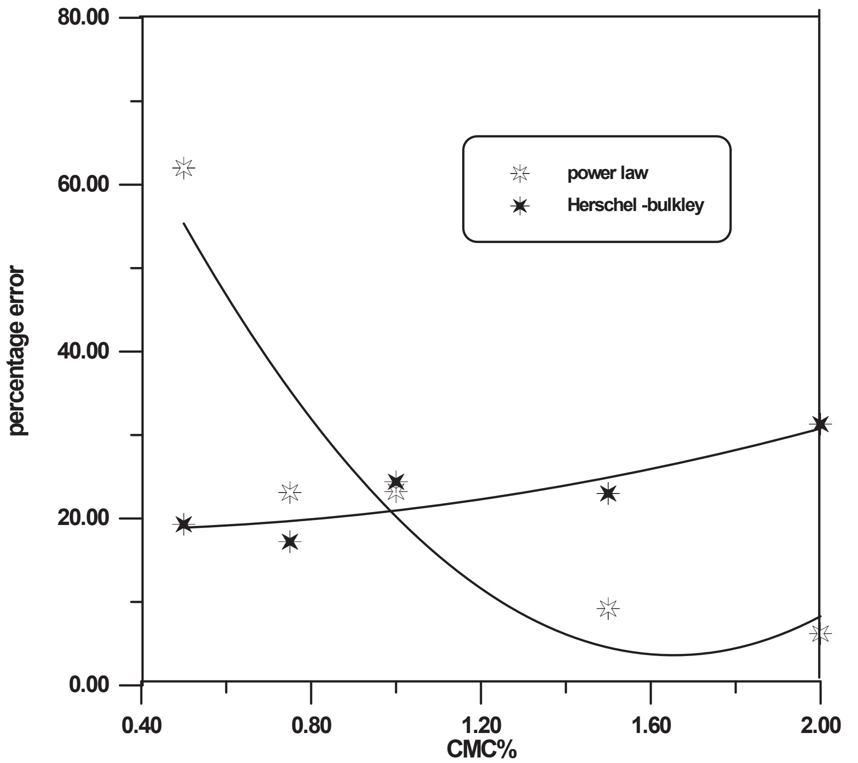


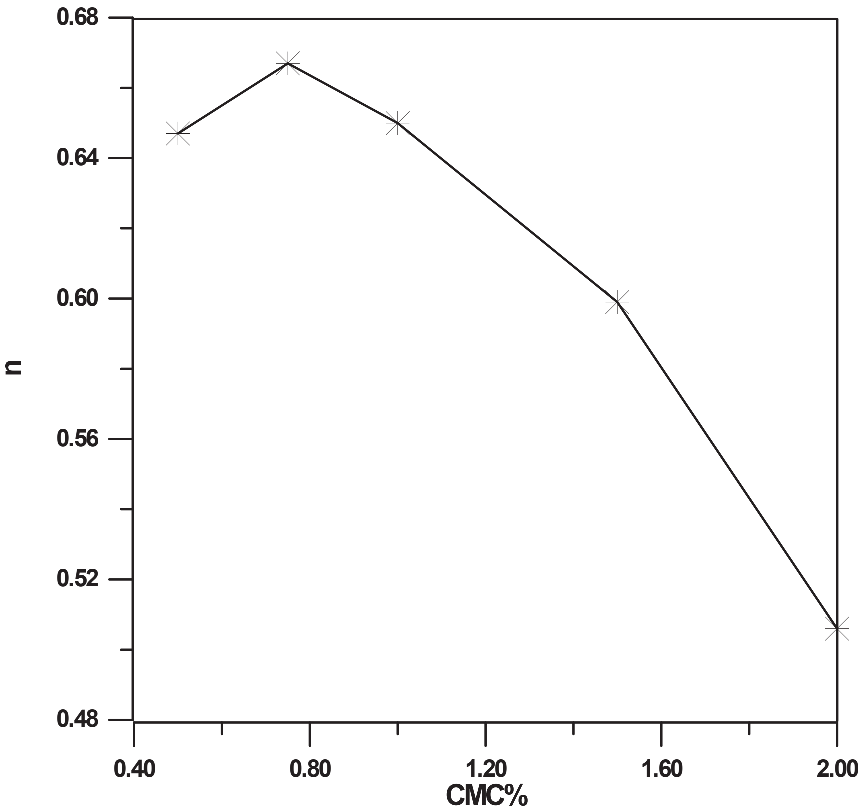
Fig (6) shear stress versus shear rate for the concentration of 1.5%



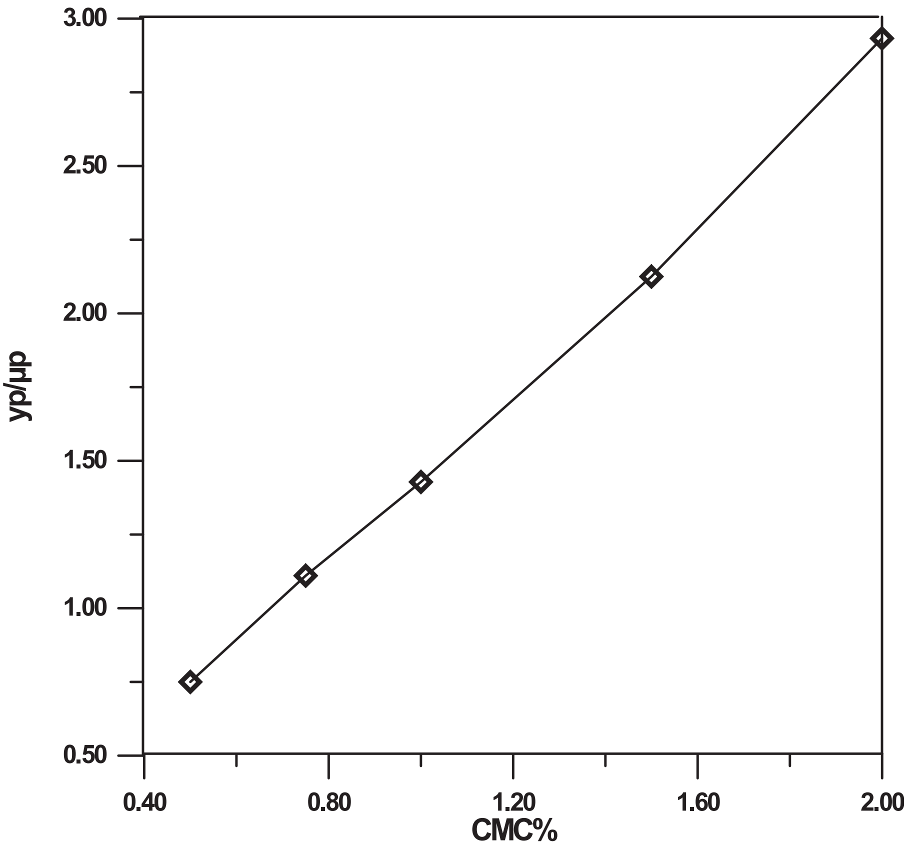
Fig(5) shear stress versus shear rate for concentration of 2%



Fig(8) The percentage error of models versus cmc concentration percentage



Fig(9) The constant (n) versus cmc concentration



Fig(10) yp/μp versus cmc concentration