



# Studying the Rheological Properties of Non-Newtonian Fluids Under the Addition of Different Chemical Additives

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## Abstract

This research study the rheological properties ( plastic viscosity, yield point and apparent viscosity) of non-Newtonian fluids under the addition of different chemical additives with different concentrations, such as (xanthan gum (xc-polymer) , carboxy methyl cellulose ( high and low viscosity ) ,polyacrylamide, polyvinyl alcohol, starch, quebracho, chrome lignosulfonate, and sodium chloride (NaCl). Fann viscometer model 800 with 8-speeds was used to measure the rheological properties of these samples, that have already been prepared. All samples were subjected to Bingham plastic model. It was concluded that the plastic viscosity, yield point and apparent viscosity should be increased with increasing the concentrations of (xanthan gum (xc-polymer) , carboxy methyl cellulose ( high and low viscosity ) ,polyacrylamide, polyvinyl alcohol, starch and sodium chloride (NaCl), while the opposite is true for quebracho, chrome lignosulfonate.

**Keywords:** Non-Newtonian Fluids, Rheological Properties, Bingham Plastic Model.

## دراسة خواص الموائع الغير النيوتونية تحت اضافة اضافات كيميائية مختلفة

دعاء حسين علي , محمد عبد الرزاق محمد

### الخلاصة:

يدرس هذا البحث الخواص الريولوجية (اللزوجة البلاستيكية ، نقطة الخضوع واللزوجة الظاهرية) للسوائل غير النيوتونية تحت إضافة إضافات كيميائية مختلفة لتركيزات مختلفة ، مثل زانثان بوليمر ، كربوكسي ميثيل السليلوز ( اللزوجة العالية والمنخفضة) ، بولي أكريلاميد ، كحول بولي فينيل ، نشا ، كيوبراجو ، كروم ليجنو سلفونات ، وكلوريد الصوديوم (NaCl) ، تم استخدام نموذج مقياس اللزوجة فان ثمانية ذو ثمان سرعات لقياس الخواص الريولوجية لهذه العينات ، التي تم إعدادها بالفعل. النتائج اظهرت ان العينات تخضع لنموذج البلاستيك بينغهام. لقد تم استنتاج ان (اللزوجة البلاستيكية ، نقطة الخضوع واللزوجة الظاهرية) تزداد مع زيادة تراكيز (الزائنان بوليمر ، كربوكسي ميثيل السليلوز ) (اللزوجة العالية والمنخفضة) ، بولي أكريلاميد ، كحول بولي فينيل ، نشا ، وكلوريد الصوديوم (NaCl)، بينما العكس صحيح مع كيوبراجو ، كروم ليجنو سلفونات .

## 1-Introduction:

To understand the concept of non-Newtonian fluids, it is important to first remember the Newtonian fluids in physics lessons, in reference to Newton's theory, under normal pressure and temperature. Fluids which have a constant viscosity and take the shape of the container where they are poured into, it was identified as Newtonian fluids. On the other hand, an advanced study in fluid mechanics has shown that there are some heterogeneous fluids that show a change in the viscosity state or a change

in their conditions when applying shear stress. These fluids can be classified as non-Newtonian fluids [1].

Non-Newtonian fluid is a liquid that does not have a constant relationship between shear stress and shear rate. In other words, when the shear rate changes, shear stress is not different in the same proportion. Thus, the variation in shear strength leads to a change in the viscosity of these fluids. This is also called the "apparent viscosity" of the fluid. It is accurate only when experimental parameters are provided. Non-Newtonian fluids can be interpreted



as fluids consisting of a mixture of molecules of different shapes and sizes. When passing each other, as during flow, their size, shape, and cohesion will determine the amount of force required to move them [2].

The Bingham plastic model is a two parameter model that is vastly used in the petroleum industry to characterize the flow features of many type of fluids. Fluids that show Bingham plastic behavior are distinguished by a yield point and a plastic viscosity that is independent of the shear rate. [3].

The Non - Newtonian fluid that was used in these experiments is the clay water suspensions. Which is basically composed of Bentonite. Bentonite is basically a highly plastic clay containing at least 85% metallic clay, montmorillonite. It gets his name from the place where it discovered his presence and uses for the first time - Fort Benton, America. Bentonite is of great commercial importance has bleaching properties inherent soil such as Fuller, and then known as clay bleach. There are two types of bentonites, namely, non-swelling-type or calcium bentonite and swelling- type or sodium bentonite. Sodium bentonite is usually referred to as bentonite, whereas calcium bentonite is called Fuller's earth. The commercial importance of bentonite depends more on its physical and chemical properties than on chemical composition [4].

Salami et al. [2000] [5] studied the rheological behavior of several polymers on the properties of non-Newtonian fluids. The polymers that were used; PHPA (Partially-Hydrolyzed Poly Acrylamide), XC (Xanthan Gum) and CMC (Carboxy Methyl Cellulose). The test fluids were gotten by dissolving 1,2 and 3 grams of each one of the three polymers in 350 ml water and 21 grams of bentonite. It was found that the rheological properties increased by increasing the concentration of these addition additives.

Garnier et al. [2001] [6] performed the rheological properties of industrial quebracho, pine, and pecan poly flavonoid tannin extracts water solutions were tested at various concentrations by measuring rheometry of both dynamic equations as a function of stress capacitance at differing frequency. These include the intersection of flexive and viscosity curves at the lower concentrations of the probing range noting some differences between each tannin and other. Pine and quebracho tannin extracts showing the more remarkable viscoelastic behavior.

Song et al. [2006] [7] carried out the characteristic of steady shear flow of xanthan gum solutions at various concentrations that were widely measured from shear rates. One can summarize the main results obtained from this study as follows: Concentrated xanthan gum solutions show a limited amount of yield stress and exhibit remarkable behavior of non-Newtonian shear-thinning. Finally, they exhibit a quite important elastic flow behavior.

Glenn et al. [2014] [8] performed a development of polyvinyl alcohol (PVA) solution when adding borax by using rotational viscometry. The rheological properties were calculated and it was showed that the

rheological properties increased by increasing the concentrations of polyvinyl alcohol PVA.

Ahmed et al. [2018] [9] performed the electrical resistivity and rheological properties of a water-based bentonite clay drilling mud modified with the lightweight polymer (guar gum). The bentonite contents in the drilling muds were varied up to 8% by the weight of water. The guar gum content was varied between 0% and 1% by the weight of the drilling mud to modify the rheological properties and enhance the sensing electrical resistivity of the drilling mud modification increased (YP) and (PV) by 58%. The results also showed that 1% guar gum decreased the electrical resistivity of the drilling mud from 50% to 90% based on the bentonite content. The rheological properties of the drilling muds have been correlated to the electrical resistivity of the drilling mud using nonlinear power and hyperbolic relationships.

Mohamed et al. [2019] [10] manifested a new method is introduced to produce sodium bentonite by treating calcium bentonite using seawater to eliminate the use of freshwater and reduces the amount of soda ash required for the treatment, which significantly minimizes the cost of bentonite production. calcium bentonite was collected as rocks from local resources, ground, purified, characterized, and the physical properties were measured. Then, bentonite was treated using seawater under heating and stirring for different time periods to optimize the treatment conditions. Soda ash was also added with different concentrations, and the produced bentonite samples were characterized, evaluated, and compared to the standard sodium bentonite used in drilling fluid formulation. The results of this study showed that the treatment with soda ash under heating and stirring in seawater environment converts calcium bentonite into sodium bentonite by sodium and calcium cations exchange between soda ash and calcium bentonite. This exchange will improve the rheological and swelling properties of bentonite that can efficiently be used as a drilling fluid and cement additive.

## 2- Non-Newtonian Fluids

For a Non- Newtonian fluid, the flow curve (shear stress versus shear rate) is not arranged in a straight line. Wherever apparent viscosity (shear stress / shear rate) is not fixed at certain temperature and pressure but depends on flow states like flow geometry, shear rate and so on. And occasionally as well the kinetic history of the liquid component that is under study. These materials can be collected comfortably in three broad categories: [11]

- 1) Fluids that the shear rate is specified during any step only through the value Shear stress at that stage at that moment. It was be defined those fluids with multiple names such as Time Independent, pure viscous, inflexible or generalized Newtonian fluid (GNF).
- 2) Many combination fluids have a relationship among shear stress and shear rate Supports, moreover, on the period and histories of the shear. This fluid called "time-dependent fluid".



- 3) Materials that show the properties of both perfect fluids and flexible solids show fractional regeneration elasticity, after distortion, they are classified as " visco-elastic fluids ".

### 3- Rheological Properties

The domain of rheology is the field of distortion and the flux of substance. By conducting a specific mensuration on the liquid. It is conceivable to limit how the flow of liquid under a set of states, encompass of temperature, pressure and the rate of shear. [12]

#### 3.1 Plastic viscosity

The PV is the tendency of the stress of shear / rate of shear line at the high-rise the yield point. PV appears the viscosity of the fluid while generalized to an infinite rate of shear based on the mathematics of the Bingham model. [13]

Mathematical relation is:

$$PV = \theta_{600} - \theta_{300} \dots\dots (1)$$

Where, PV is plastic viscosity in unit CP,  $\theta_{600}$  is shear stress at 600 rpm shear rate, in lb. /100 ft<sup>2</sup>.  $\theta_{300}$  is shear stress at 300 rpm shear rate, in lb. /100 ft<sup>2</sup>.

#### 3.2 Yield Point

The Yield Point (YP) is a second variable of Bingham model and it is a mensuration of electrochemical intensity or attractive intensity in the liquid. This part of the flowing impedance can be domination by appropriate chemical remediation. [14]

Mathematical relation is:

$$YP = \theta_{300} - PV \dots\dots (2)$$

Where, YP is yield point in unit (lb. /100 ft<sup>2</sup>) or (N/m<sup>2</sup>), PV is the plastic viscosity in unit CP,  $\theta_{300}$  is shear stress at 300 rpm shear rate, in lb. /100 ft<sup>2</sup>.

#### 3.3 Apparent viscosity

The AV is the shear stress applied to a fluid divided by the shear rate For a Newtonian fluid, the apparent viscosity is constant, and equal to the Newtonian viscosity of the fluid, but for non-Newtonian fluids, the apparent viscosity depends on the shear rate. Apparent viscosity has the SI derived unit Pa·s (Pascal-second, but the centipoise is frequently used in practice: (1 mPa·s = 1 cp). [15]

Mathematical relation is:

$$AV = \frac{\theta_{600}}{2} \dots\dots (3)$$

Where, AV is apparent viscosity in unit CP,  $\theta_{600}$  is shear stress at 600 rpm shear rate, in lb. /100 ft<sup>2</sup>.

### 4- Experimental work

All practical experiments were performed in the Faculty of Engineering Laboratory. In the petroleum engineering department. At the University of Baghdad.

#### 4.1 Experimental apparatus

The main instruments used in this study were as follows: Hamilton Beach mixer and cup, Fann VG-Viscometer model 800, Balance, Microwave oven, Hot plate heater, Thermometer, Stop watch.

#### 4.2 Materials

All the polymers that used in this work were as follows: Bentonite was supplied from China. Qingdao Easthony Inc, Xanthan Gum (XC-POLYMER) was supplied from Qingdao, China. Fengchen Group, Carboxy methyl cellulose (CMC) two commercial products of CMC have been used in this study. The first was supplied from China. Dalian chem. Imp. And Exp. Group Co., Ltd. And the second was supplied from Turkey. Denkim Denizli Kimya A.S., Polyacrylamide (PAM) was supplied from China, Henan province. Henan Di Luo Environmental Protection Technology Co., Ltd., Poly vinyl alcohol was supplied from India. Elgin, Kolkata. Peekay Agencies Private Limited, Starch was supplied from Netherlands. Amstel products B.V. company, Chrome lignosulfonate (CLS) and Quebracho were supplied from laboratories department of petroleum engineering. University of Baghdad.

#### 4.3 Experimental procedure:

Three samples were prepared by mixing different concentrations of bentonite with water using a mixing device Hamilton Beach mixer and cup. Bentonite ratios and water used to prepare clay suspensions are as follows: 22.5 grams of Bentonite was mixed with 350 ml Fresh water. Double the weight of bentonite to become (45 grams mixed with 350 ml Fresh water). The third weight of bentonite is (67.5 grams mixed with 350 ml Fresh water).

Then each of these three samples was treated with different types of additives at different concentrations to measure the rheological properties (plastic viscosity, yield point and apparent viscosity).

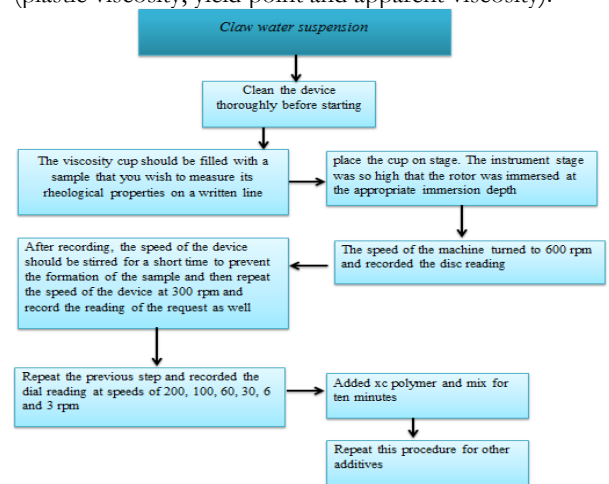


Figure (1): Flow diagram of the effect of chemical additives on clay-water suspensions

### 5- Results and Discussion

The results of rheological properties (plastic viscosity, yield point, apparent viscosity) for samples of non-Newtonian fluids were analyzed under the addition of different chemical additives.

Bentonite has been added to the water to prepare the fluid. it was found that when adding 22.5 g the plastic viscosity and the point of submission and the apparent viscosity increased and when doubling the



bentonite to 45 g it was noticed an increased in the rheological properties and finally when doubling the bentonite to 67.5 g it was noticed an increased in the rheological properties and reaching a state of stability.

The results show that the plastic viscosity and apparent viscosity of samples prepared with additives (XC-polymer, CMC low viscosity, CMC high viscosity, Polyacrylamide, Polyvinyl alcohol and starch) were increased by increasing the concentration of additives to non-Newtonian fluids at (22.5, 45, 67.5) g of bentonite at four temperature (10°C, 37.8 °C, 65.6 °C, 93.4 °C). This rise in the plastic viscosity is due to the increased in the intermolecular interactions between the non-Newtonian fluids molecules. Due to the increased in the mechanical friction between molecules [16]. But the results shows that the plastic viscosity and apparent viscosity of samples prepared with additives (Chrome Lignosulfonate and Quebracho) were decreased by increasing the concentration of additives to non-Newtonian fluids at 22.5, 45, 67.5 g of bentonite (10°C, 37.8 °C, 65.6 °C, 93.4 °C). It was noticed the concentration of starch has little or does not significant on the plastic viscosity of these samples. It was noticed that the highest concentration of additives, which is 13 grams is the best concentration and therefore concentrations higher than this value was not chosen because the plot shows that the plastic viscosity starts to stabilize after this concentration, this conclusion is for most additions used. So the highest plastic viscosity of additives is at CMC (H.V.) and the lowest is at starch. Because starch was acting as a colloid or water thickener. In most cases they affect the flow properties. So, the plastic viscosity of starch increased slowly. These results are identical to other studies, such as the researcher's study [17]  
 CMC (H.V.) > XC > PVA > CMC (L.V.) > PAC > Starch

The results of all these conclusions was cleared in the figures (2) to (7):

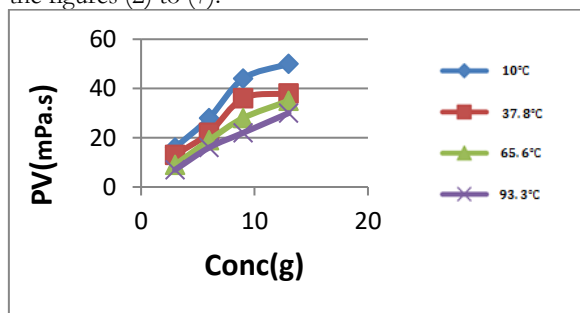


Figure (2): Plastic viscosity vs. concentrations of XC-polymer at 22.5g bentonite

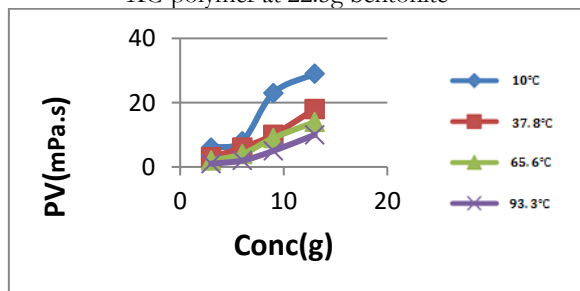


Figure (3): Plastic viscosity vs. concentrations of CMC low viscosity at 22.5g bentonite

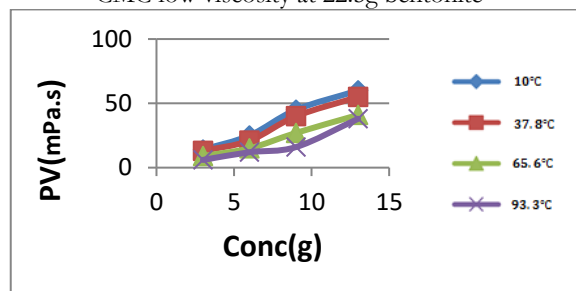


Figure (4): Plastic viscosity vs. concentrations of CMC high viscosity at 22.5g bentonite

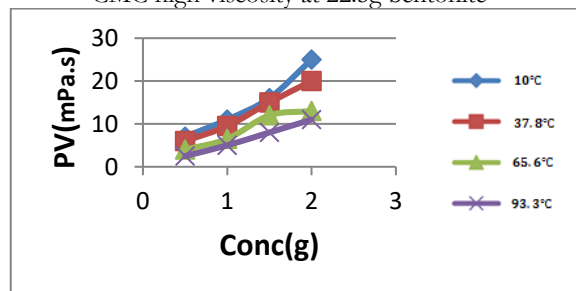


Figure (5): Plastic viscosity vs. concentrations of Polyacrylamide at 22.5g bentonite

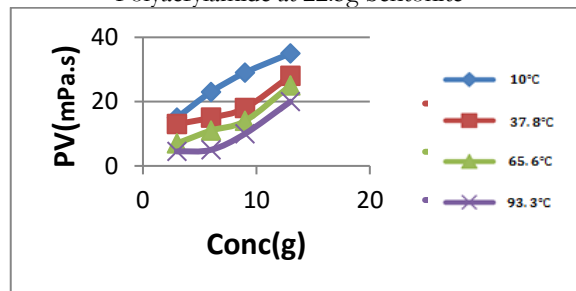


Figure (6): Plastic viscosity vs. concentrations of Polyvinyl alcohol at 22.5g bentonite

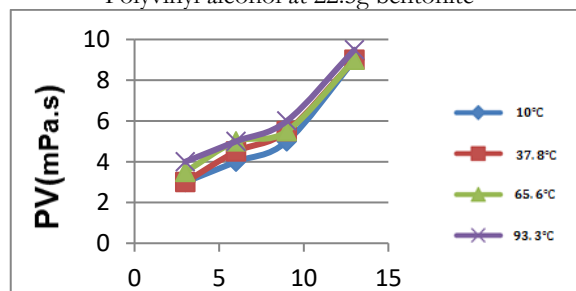


Figure (7): Plastic viscosity vs. concentrations of starch at 22.5g bentonite

From the results in figures (8) to (19) when increasing the bentonite to 45 g, it will noticed an increased in the plastic viscosity of all materials used except starch. From the results it will also notice that when the concentrations of the additives increased on the double bentonite, the plastic viscosity will be increased except the starch which is not regulated. Because the concentration of solid particles will increased, then increased the friction forces between these particles. Because starch was acting as a colloid or water thickener. In most cases they affect the flow



properties. So the plastic viscosity of starch increased slowly. These results are identical to other studies, such as the researcher's study [17]

It was also noted that the highest concentration of additives, which is 13 grams is the best concentration and therefore concentrations higher than this value was not chosen because the drawings show that the plastic viscosity starts to stabilize after this concentration. So the highest viscosity of the plastic is at CMC (H.V.) and the lowest is at starch

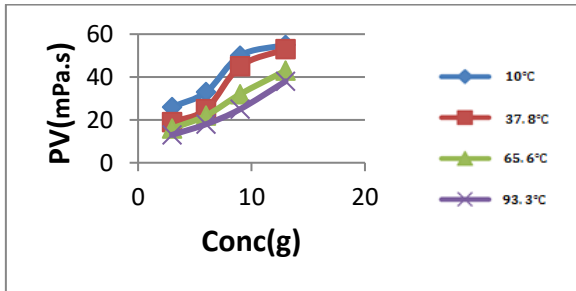


Figure (8): Plastic viscosity vs. concentrations of XC-polymer at 45g bentonite

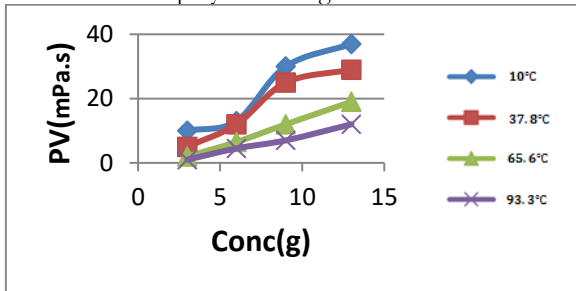


Figure (9): PV vs. Conc. of CMC I.V. at 45g bentonite

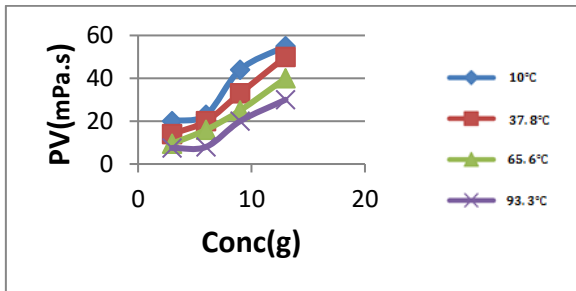


Figure (10): PV vs. Conc. of CMC H.V. at 45g bentonite

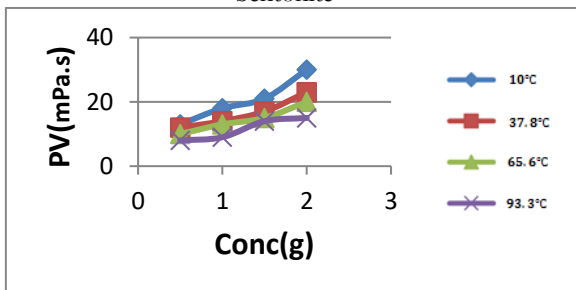


Figure (11): Plastic viscosity vs. concentrations of Polyacrylamide at 45g bentonite

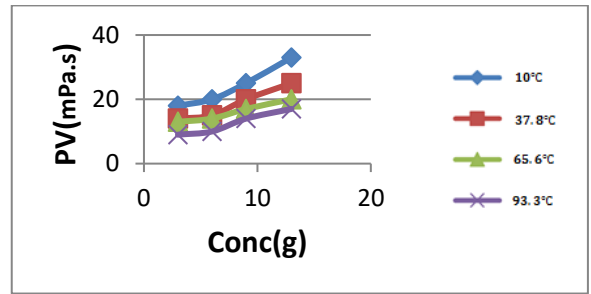


Figure (12): Plastic viscosity vs. concentrations of Polyvinyl alcohol at 45g bentonite

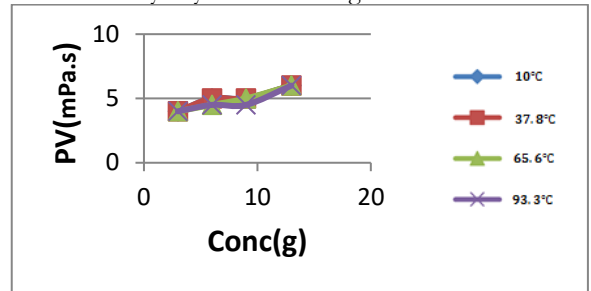


Figure (13): Plastic viscosity vs. concentrations of starch at 45g bentonite

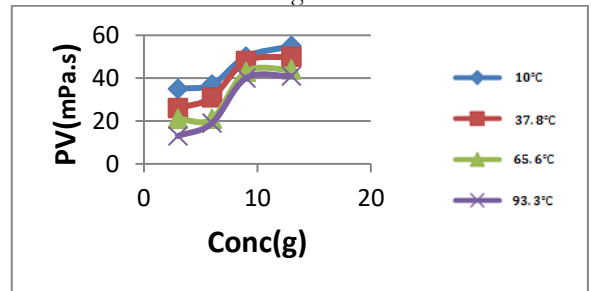


Figure (14): Plastic viscosity vs. concentrations of XC-polymer at 67.5g bentonite

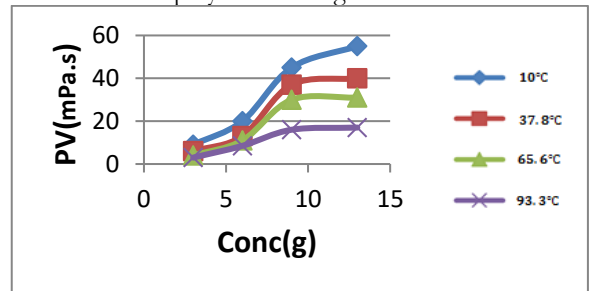


Figure (15): PV vs. Conc. of CMC I.V. at 67.5g bentonite

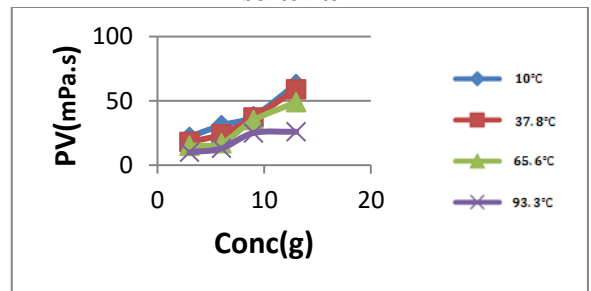
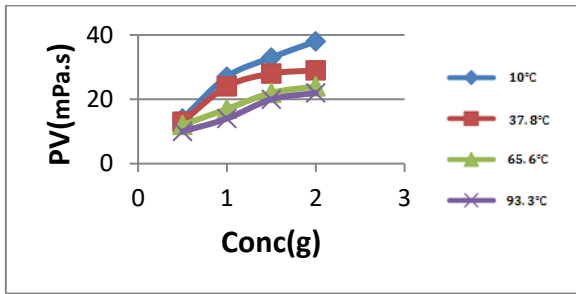
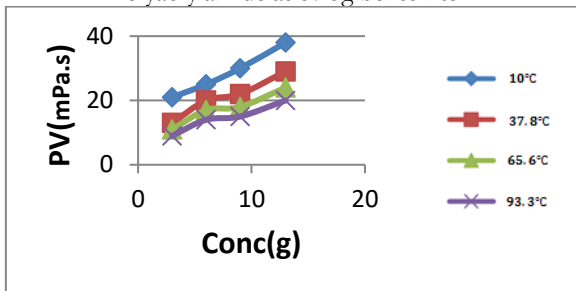


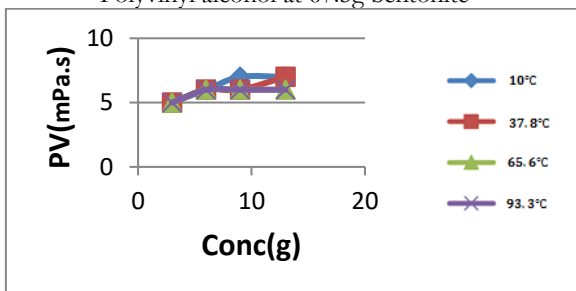
Figure (16): PV vs. Conc. of CMCH.V. at 67.5g bentonite



**Figure (17):** Plastic viscosity vs. concentrations of Polyacrylamide at 67.5g bentonite

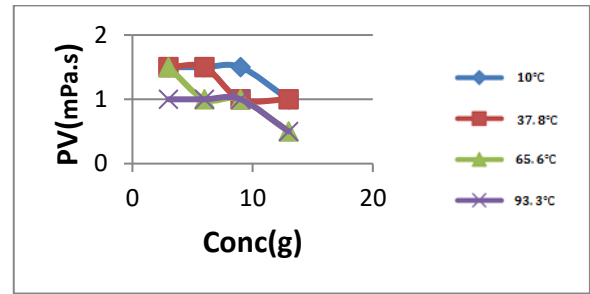


**Figure (18):** Plastic viscosity vs. concentrations of Polyvinyl alcohol at 67.5g bentonite

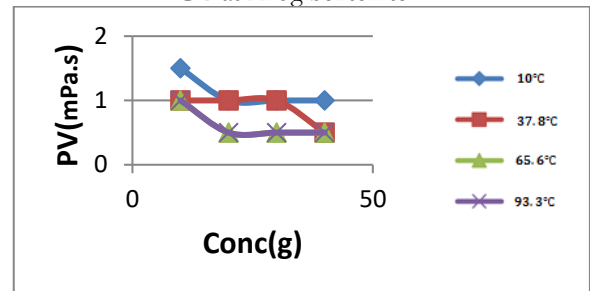


**Figure (19):** Plastic viscosity vs. concentrations of starch at 67.5g bentonite

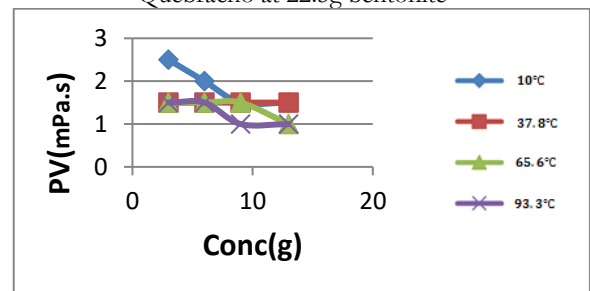
From figures (20) to (25) can be shown that the plastic viscosity of non-Newtonian sample of 22.5, 45, 67.5 grams bentonite samples prepared with additives (Chrome Lignosulfonate and Quebracho) were decreased by increasing the concentrations of these additives at temperature (10, 37.8, 65.6, 93.4) °C. This is because these additives will deflocculates a clay suspension. Flocculation is caused by a positive charge site at the edge of a clay platelet linking to the negative surface of another platelet. The primary effect of a thinner is believed to be a neutralization of the positive charge, which destroys the ability of the platelets to link together in this manner. This renders the platelets completely negatively charged and causes them to repel one another, or to avoid contact. Thus, the resistance to flow of the suspension is reduced. These results are identical to other studies, such as the researcher's study Garnier et al. [2001] [6]



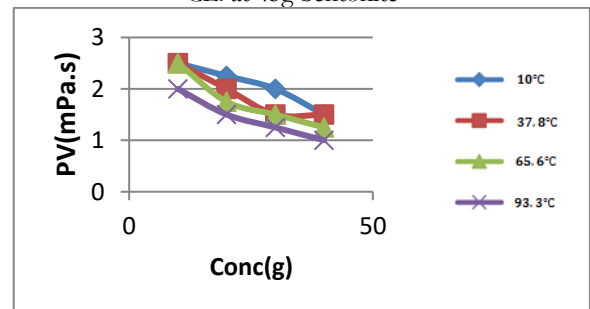
**Figure (20):** Plastic viscosity vs. concentrations of CL at 22.5g bentonite



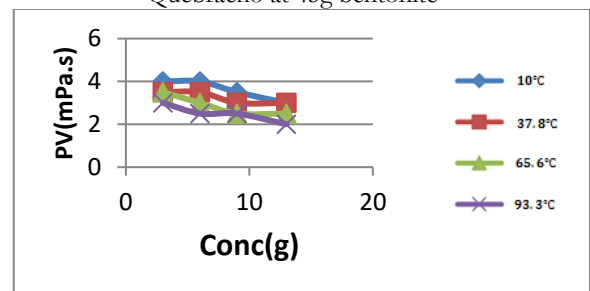
**Figure (21):** Plastic viscosity vs. concentrations of Quebracho at 22.5g bentonite



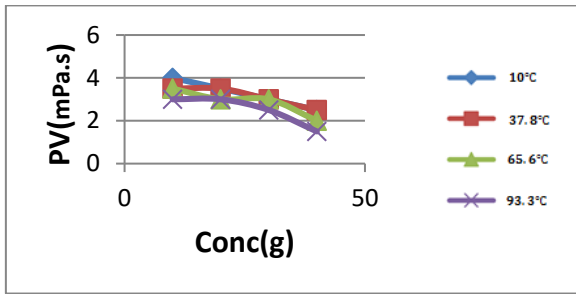
**Figure (22):** Plastic viscosity vs. concentrations of CL at 45g bentonite



**Figure (23):** Plastic viscosity vs. concentrations of Quebracho at 45g bentonite



**Figure (24):** Plastic viscosity vs. concentrations of CL at 67.5g bentonite

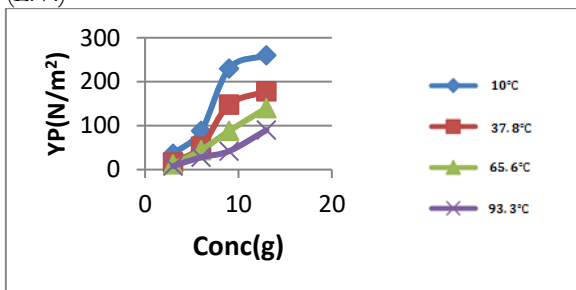


**Figure (25):** Plastic viscosity vs. concentrations of Quebracho at 67.5g bentonite

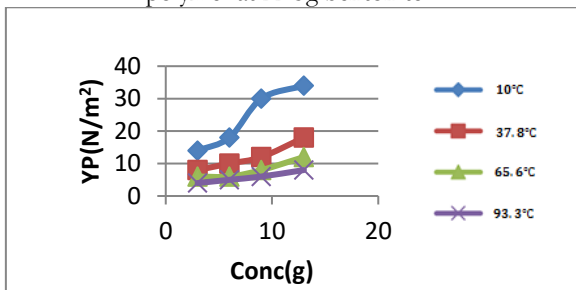
From figures (26) to (31), it can be shown that the yield point of samples prepared with additives (XC-polymer, CMC low viscosity, CMC high viscosity, Polyacrylamide, Polyvinyl alcohol and starch) was increased by increasing the concentration of additives to non-Newtonian fluids at 22.5 g of bentonite at four different temperatures (10, 37.8, 65.6, 93.4) °C. This rise in the yield point is due to forces of attraction and repulsion between molecules. These results are identical to other studies, such as the researcher's study [17]

It was note that the highest concentration of additives, which is 13 grams is the best concentration and therefore concentrations higher than this value was not chosen because the drawings show that the yield point starts to stabilize after this concentration. So, the highest additives is at XC-polymer and the lowest is at CMC (L.V.)

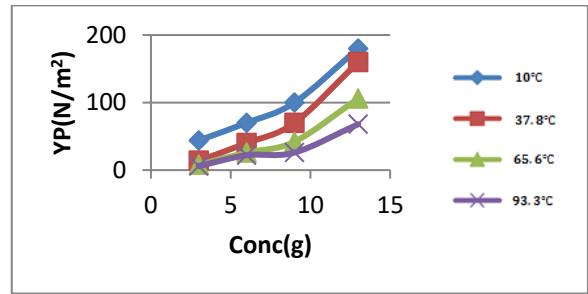
XC > CMC (H.V.) > PAC > PVA > Starch > CMC (L.V.)



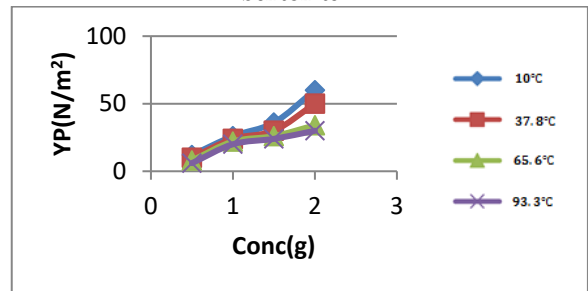
**Figure (26):** Yield point vs. concentrations of XC-polymer at 22.5g bentonite



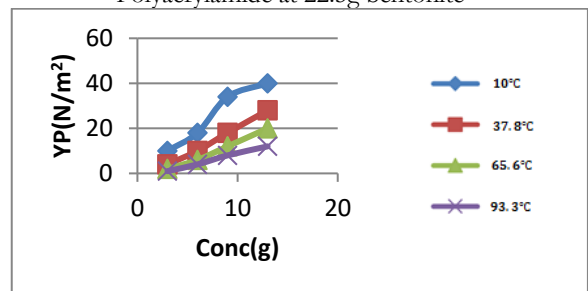
**Figure (27):** YP vs. Conc. of CMCL.V. at 22.5g bentonite



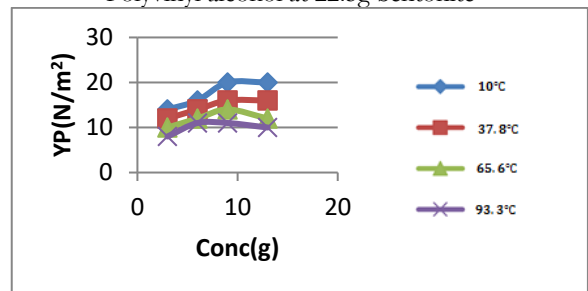
**Figure (28):** YP vs. Conc. of CMCH.V. at 22.5g bentonite



**Figure (29):** Yield point vs. concentrations of Polyacrylamide at 22.5g bentonite



**Figure (30):** Yield point vs. concentrations of Polyvinyl alcohol at 22.5g bentonite



**Figure (31):** Yield point vs. concentrations of starch at 22.5g bentonite

From figures (32) to (41), it can be shown that the yield point of samples prepared with additives (XC-polymer, CMC low viscosity, CMC high viscosity, Polyacrylamide, Polyvinyl alcohol and starch) was increased by increasing the concentration of additives to non-Newtonian fluids at 45 g and 67.5 g of bentonite at four temperatures (10, 37.8, 65.6, 93.4) °C. These results are identical to other studies, such as the researcher's study [17]

When doubling the bentonite to 45g and to 67.5 g, the yield point was increased by increasing the concentration of additives to non-Newtonian fluids. This rise in the yield point is due to forces of attraction and repulsion between molecules. [16]  
 XC > CMC (H.V.) > PAC > PVA > CMC (L.V.) > Starch

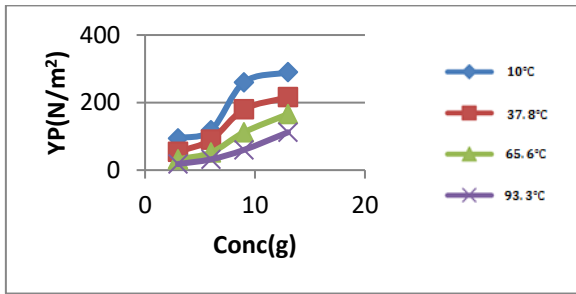


Figure (32): Yield point vs. concentrations of XC-polymer at 45g bentonite

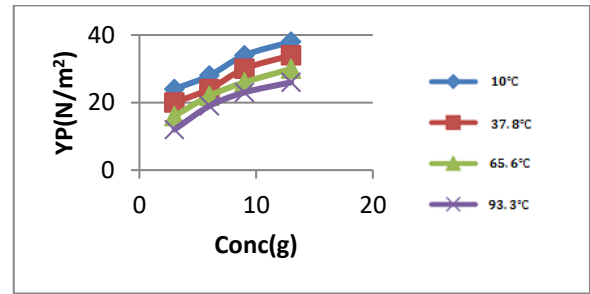


Figure (37): Yield point vs. concentrations of starch at 45g bentonite

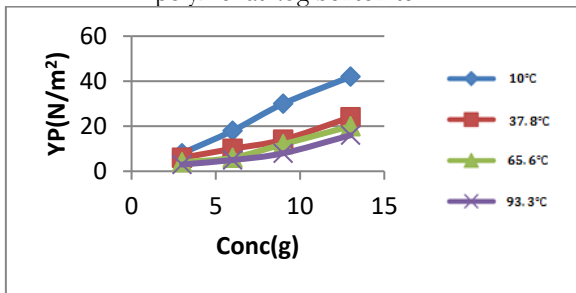


Figure (33): YP vs. Conc. of CMC L.V. at 45g bentonite

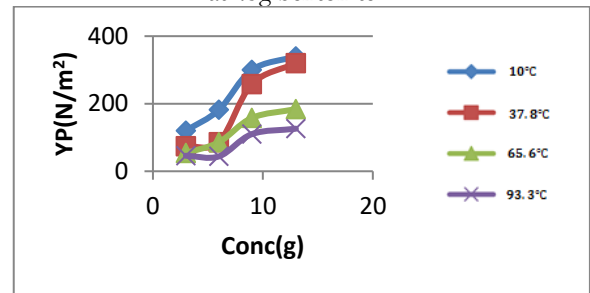


Figure (38): Yield point vs. concentrations of XC-polymer at 67.5g bentonite

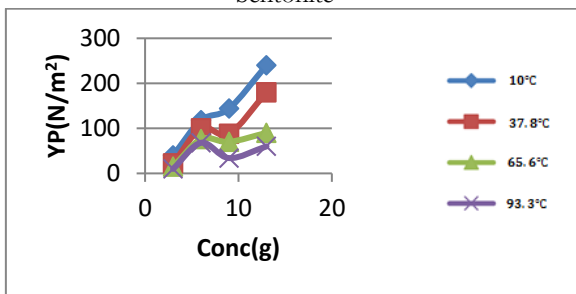


Figure (34): YP vs. Conc. of CMC H.V. at 45g bentonite

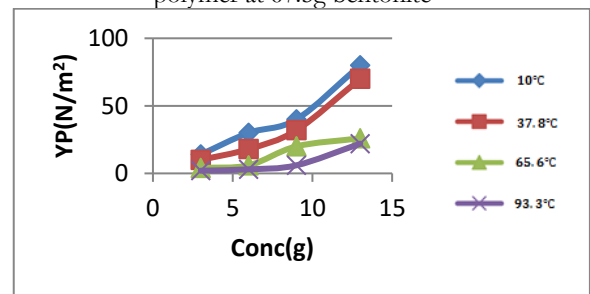


Figure (39): Yield point vs. concentrations of CMC low viscosity at 67.5g bentonite

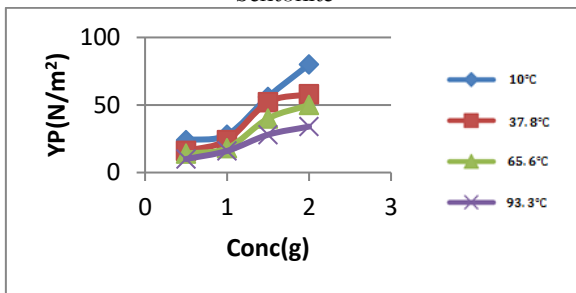


Figure (35): YP vs. Conc. of Polyacrylamide at 45g bentonite

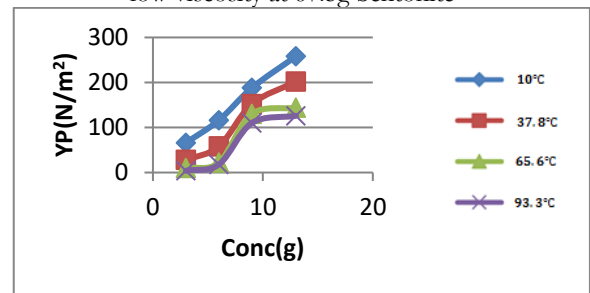


Figure (40): Yield point vs. concentrations of CMC high viscosity at 67.5g bentonite

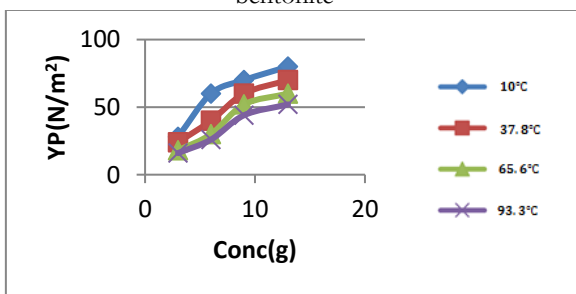


Figure (36): Yield point vs. concentrations of Polyvinyl alcohol at 45g bentonite

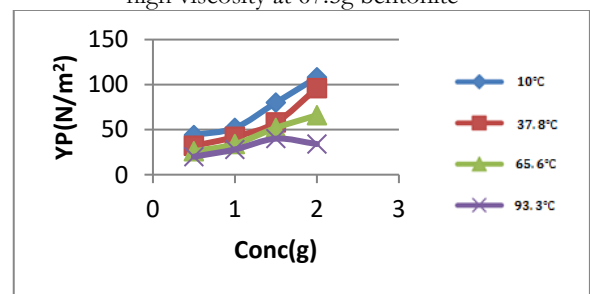


Figure (41): Yield point vs. concentrations of Polyacrylamide at 67.5g bentonite

From the results in figures (42) to (49), it can be shown that the yield point of non-Newtonian fluids with bentonite of ( 22.5 , 45, 67.5 ) grams prepared





with (Chrome Lignosulfonate and Quebracho) was decreased by increasing the concentration of these additives at four temperatures (10, 37.8, 65.6, 93.4) °C.

Flocculation is caused by a positive charge site at the edge of a clay platelet linking to the negative surface of another platelet. The primary effect of a thinner is believed to be a neutralization of the positive charge, which destroys the ability of the platelets to link together in this manner. This renders the platelets completely negatively charged and causes them to repel one another, or to avoid contact. Thus, the resistance to flow of the suspension is reduced. These results are identical to other studies, such as the researcher's study Garnier et al. [2001] [6]

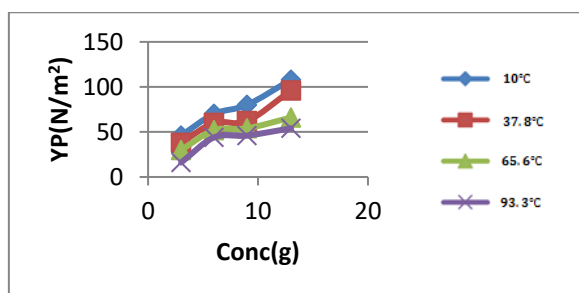


Figure (42): Yield point vs. concentrations of PVA at 67.5g bentonite

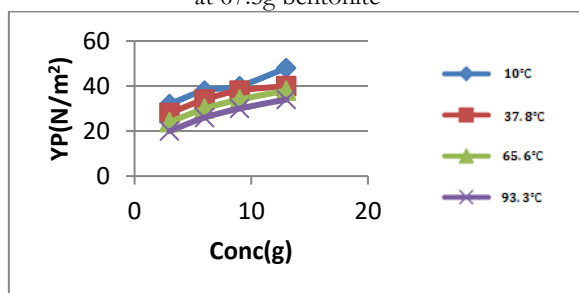


Figure (43): Yield point vs. concentrations of starch at 67.5g bentonite

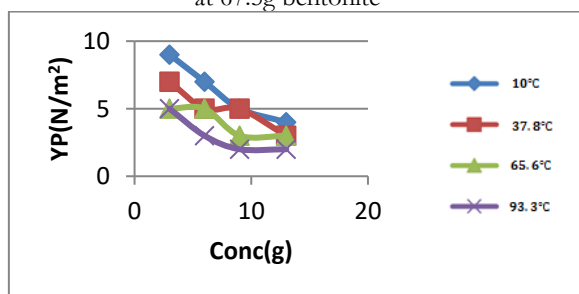


Figure (44): Yield point vs. concentrations of CL 22.5g bentonite

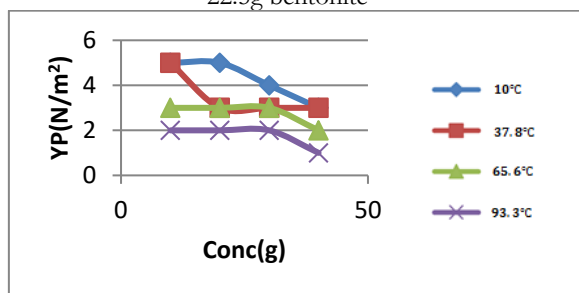


Figure (45): Yield point vs. concentrations of Quebracho at 22.5g bentonite

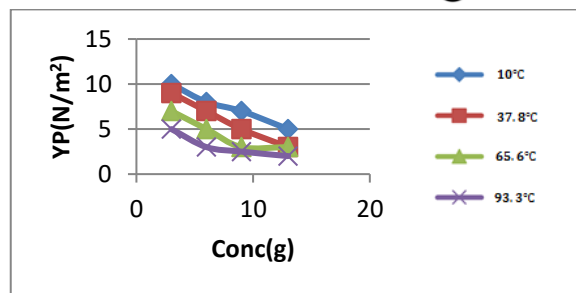


Figure (46): Yield point vs. concentrations of CL 45g bentonite

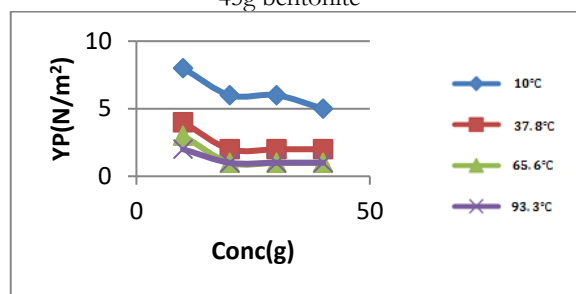


Figure (47): Yield point vs. concentrations of Quebracho at 45g bentonite

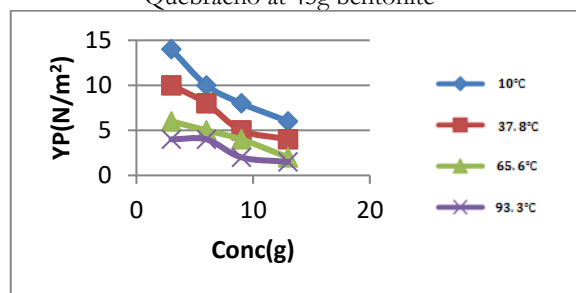


Figure (48): Yield point vs. concentrations of CL at 67.5g bentonite

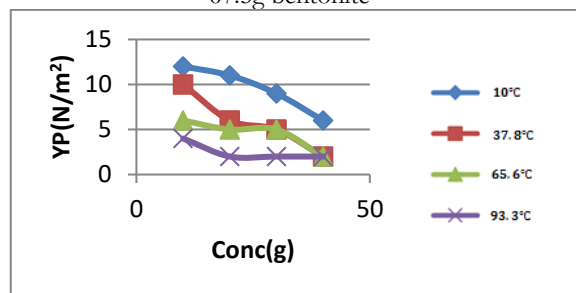


Figure (49): Yield point vs. concentrations of Quebracho at 67.5g bentonite

It can be shown that the apparent viscosity of samples prepared with additives (XC-polymer, CMC low viscosity, CMC high viscosity, Polyacrylamide, Polyvinyl alcohol and starch) was increased by increasing the concentration of additives to non-Newtonian fluids at 22.5 g of bentonite at four different temperature (10, 37.8, 65.6, 93.4) °C. This rise in the apparent viscosity is due to the increased in the intermolecular interactions between the non-Newtonian fluids molecules. [16]

It will noticed that the highest apparent viscosity is at addition XC, and the lowest apparent viscosity is at addition is at starch  
 XC > CMC (H.V.) > PVA > PAC > CMC (L.V.) > Starch



The results of this conclusion were cleared in figures (50) to (55):

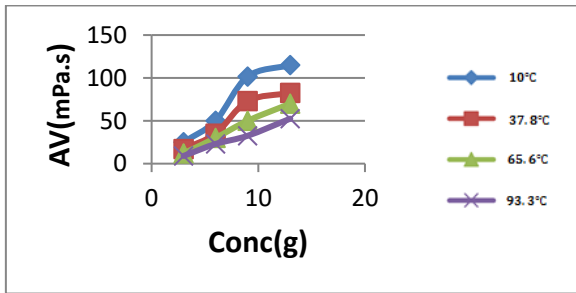


Figure (50): Apparent viscosity vs. concentrations of XC-polymer at 22.5g bentonite

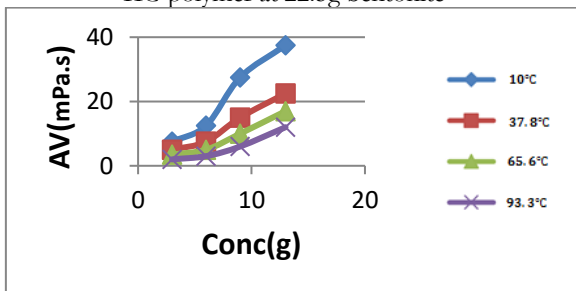


Figure (51): Apparent viscosity vs. concentrations of CMC (L.V.) at 22.5g bentonite

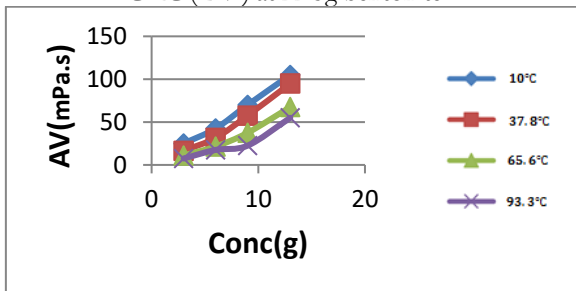


Figure (52): Apparent viscosity vs. concentrations of CMC (H.V.) at 22.5g bentonite

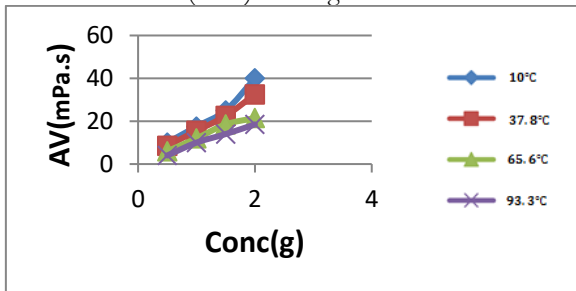


Figure (53): Apparent viscosity vs. concentrations of Polyacrylamide at 22.5g bentonite

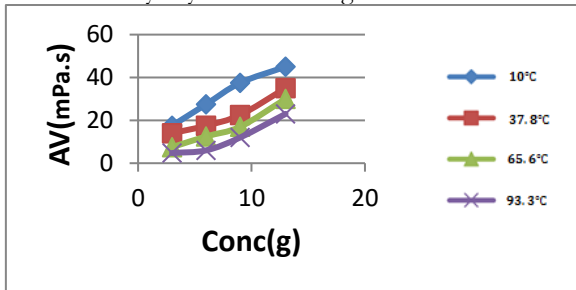


Figure (54): Apparent viscosity vs. concentrations of Polyvinyl alcohol at 22.5g bentonite

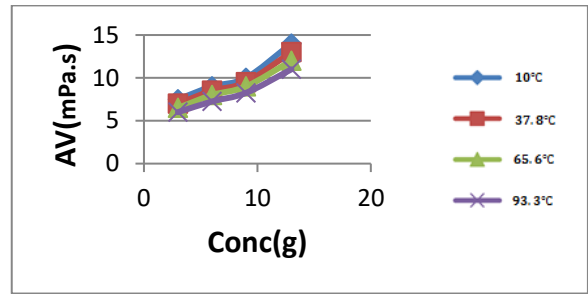


Figure (55): Apparent viscosity vs. concentrations of starch at 22.5g bentonite

It can be shown that the apparent viscosity of samples prepared with additives (XC-polymer, CMC low viscosity, CMC high viscosity, Polyacrylamide, Polyvinyl alcohol and starch) was increased by increasing the concentration of additives to non-Newtonian fluids at 45 g and 67.5 g of bentonite at four different temperature (10, 37.8, 65.6, 93.4) °C. When doubling the bentonite to 45g and to 67.5 g, that will increase the concentration and also increased apparent viscosity. This rise in the apparent viscosity is due to the increased in the intermolecular interactions between the non-Newtonian fluids molecules. [16]

It will noticed that the highest apparent viscosity is at addition XC, and the lowest apparent viscosity is at addition starch

XC > CMC (H.V.) > PVA > PAC > CMC (L.V.) > Starch

The results of this conclusion was cleared in the figures (56) to (67):

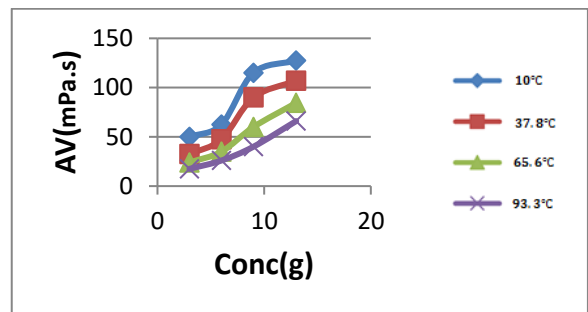


Figure (56): Apparent viscosity vs. concentrations of XC-polymer at 45g bentonite

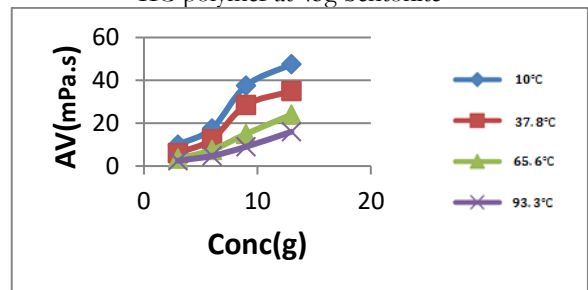


Figure (57): AV vs. Conc. of CMC L.V. at 45g bentonite

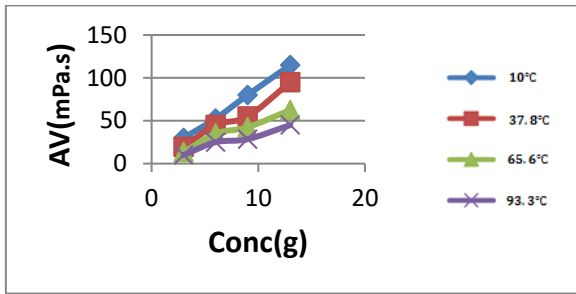


Figure (58): AV vs. Conc. of CMC H.V. at 45g bentonite

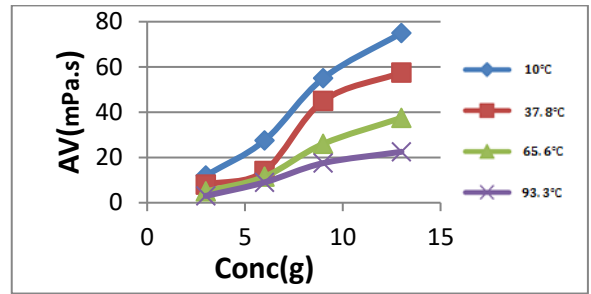


Figure (63): AV vs. Conc. of CMCL.V. at 67.5g bentonite

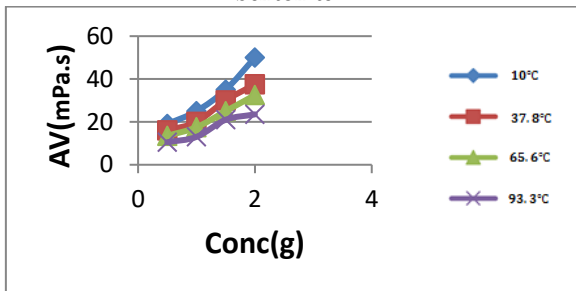


Figure (59): Apparent viscosity vs. concentrations of Polyacrylamide at 45g bentonite

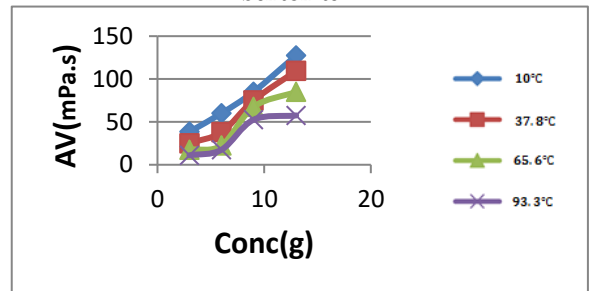


Figure (64): AV vs. Conc. of CMCH.V. at 67.5g bentonite

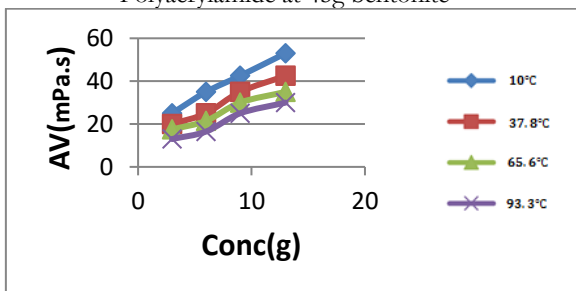


Figure (60): Apparent viscosity vs. concentrations of Polyvinyl alcohol at 45g bentonite

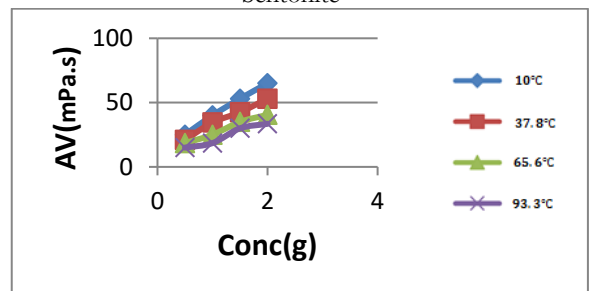


Figure (65): Apparent viscosity vs. concentrations of Polyacrylamide at 67.5g bentonite

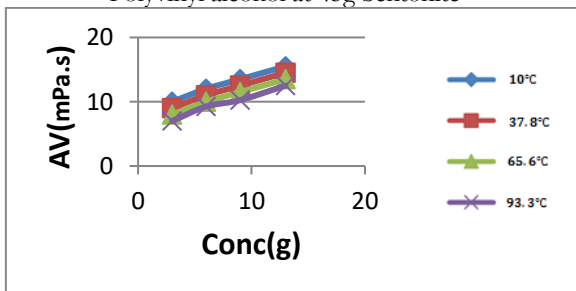


Figure (61): Apparent viscosity vs. concentrations of starch at 45g bentonite

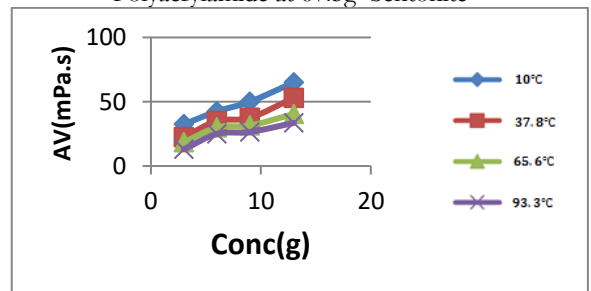


Figure (66): Apparent viscosity vs. concentrations of Polyvinyl alcohol at 45g bentonite

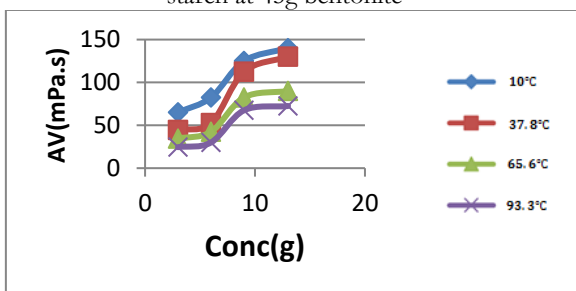


Figure (62): Apparent viscosity vs. concentrations of XC-polymer at 67.5g bentonite

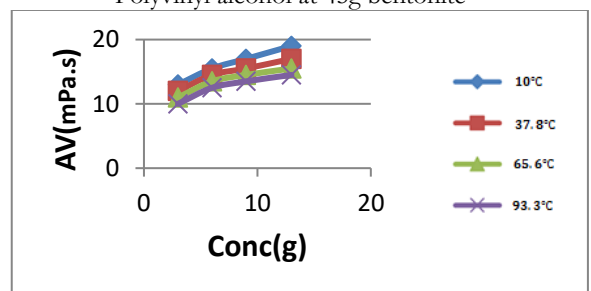


Figure (67): Apparent viscosity vs. concentrations of starch at 67.5g bentonite

It can be shown that the apparent viscosity of samples prepared with additives (Chrome Lignosulfonate and Quebracho) was decreased by



increasing the concentration of additives to non-Newtonian fluids at (22.5, 45, 67.5) grams of bentonite at four different temperature (10, 37.8, 65.6, 93.4) °C.

Flocculation is caused by a positive charge site at the edge of a clay platelet linking to the negative surface of another platelet. The primary effect of a thinner is believed to be a neutralization of the positive charge, which destroys the ability of the platelets to link together in this manner. This renders the platelets completely negatively charged and causes them to repel one another, or to avoid contact. Thus, the resistance to flow of the suspension is reduced. These results are identical to other studies, such as the researcher's study Garnier et al. [2001] [6]

The results of this conclusion was cleared in the figures (68) to (73) :

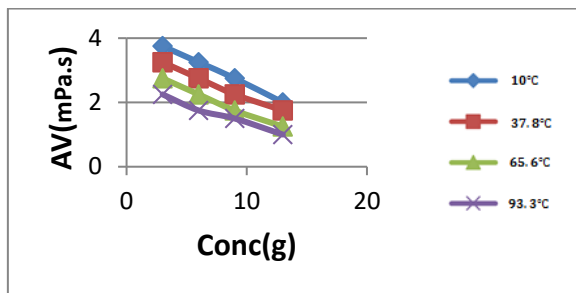


Figure (68): Apparent viscosity vs. concentrations of CL. at 22.5g bentonite

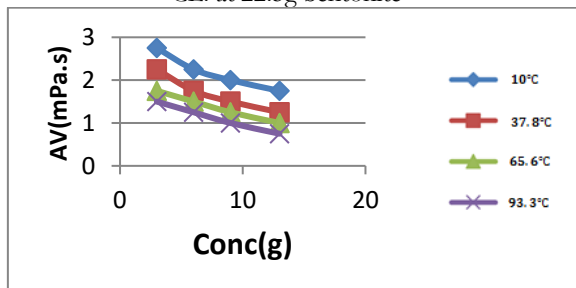


Figure (69): Apparent viscosity vs. concentrations of Quebracho at 22.5g bentonite

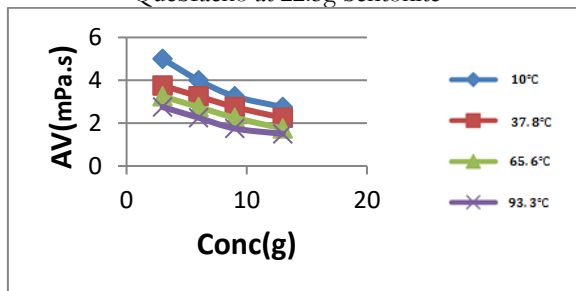


Figure (70): Apparent viscosity vs. concentrations of CL. at 45g bentonite

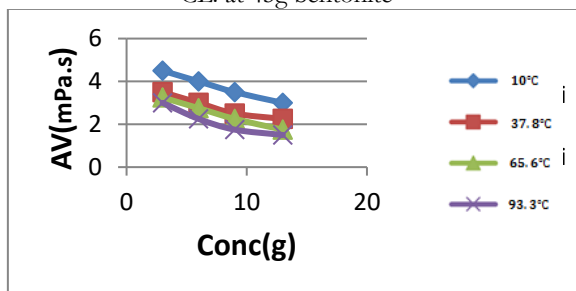


Figure (71): Apparent viscosity vs. concentrations of Quebracho at 45g bentonite

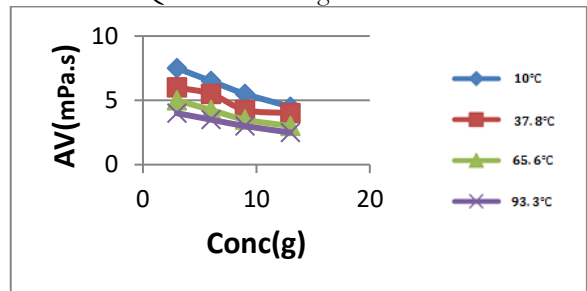


Figure (72): Apparent viscosity vs. concentrations of CL. at 67.5g bentonite

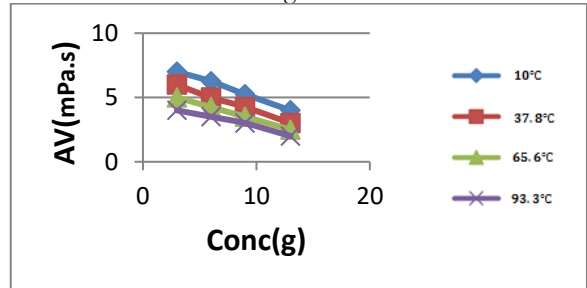


Figure (73): Apparent viscosity vs. concentrations of Quebracho at 67.5g bentonite

The results show that the plastic viscosity, yield point and apparent viscosity increased by increasing the concentration of NaCl until reaches at concentration (6g), after that concentration the plastic viscosity, yield point and apparent viscosity were decreased. This is due to bridging flocculation caused by the influx of bentonite to the fluid, and the cations  $NA^+$  affect the swelling of clay particles. This is cleared in figures (74) to (76):

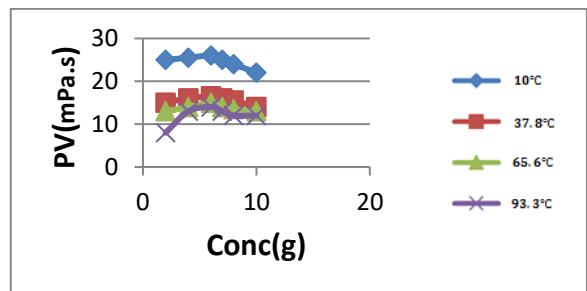


Figure (74): Plastic viscosity vs. concentrations of NACL and CMC high viscosity at concentration(6g) and bentonite concentration 45g.

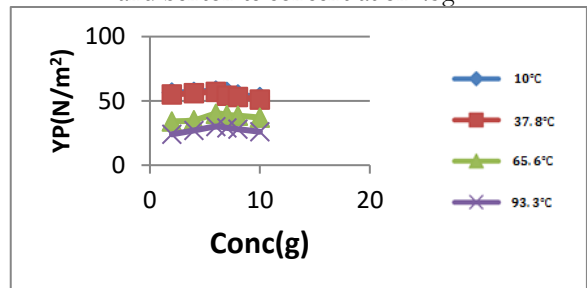
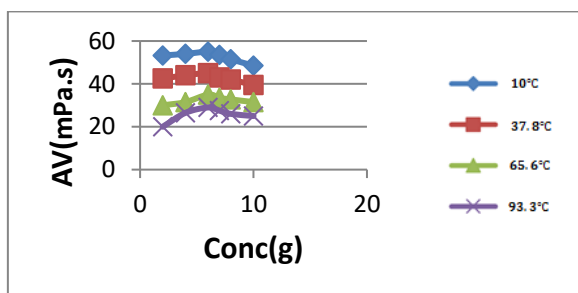


Figure (75): Yield point vs. concentrations of NACL and CMC high viscosity at concentration(6g) and bentonite concentration 45g.



**Figure (76):** Apparent viscosity vs. concentrations of NACL and CMC high viscosity at concentration(6g) and bentonite concentration 45g.

## 6- Conclusions

The following conclusions were drawn from this work:

- 1- It was concluded that the shear stress increased with increasing shear rate in non-linear shape for all non-Newtonian fluid samples.
- 2- It was found that the plastic viscosity, apparent viscosity and yield point of samples prepared with additives (XC-polymer, CMC low viscosity, CMC high viscosity, Polyacrylamide, Polyvinyl alcohol and starch) were increased by increasing the concentration of additives to non-Newtonian fluids at (22.5, 45, 67.5) grams of bentonite.
- 3- It was found that the plastic viscosity, apparent viscosity and yield point of samples prepared with additives (Chrome Lignosulfonate and Quebracho) were decreased by increasing the concentration of additives to non-Newtonian fluids at (22.5, 45, 67.5) grams of bentonite.
- 4- It was found that the plastic viscosity, apparent viscosity and yield point increased by increasing the concentration of NACL until reaches at concentration (6g), after that concentration the plastic viscosity, apparent viscosity and yield point were decreased.

## 7- Nomenclatures

$\tau$  = shear stress

$\gamma$  = shear rate

$\mu$  = viscosity

F = Force

A = Area

$\theta_{600}$  = shear stress at 600 rpm shear rate

$\theta_{300}$  = shear stress at 300 rpm shear rate

K= consistency coefficient

n = flow behavior index

$\tau_y$  = initial yield value

PV = Plastic Viscosity

YP = Yield Point

AV= Apparent Viscosity

XC = Xanthan gum

CMC (L.V.) = Carboxy methyl cellulose (low viscosity)

CMC (H.V.) = Carboxy methyl cellulose (high viscosity)

PVA = Poly vinyl alcohol

PAC = Polyacrylamide

CL = Chrome lignosulfonate

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