Available online at http://ijcpe.uobaghdad.edu.iq and www.iasj.net
Iraqi Journal of Chemical and Petroleum Engineering
Vol.21 No.2 (June 2020) 47 – 56
EISSN: 2618-0707, PISSN: 1997-4884

Studying the Rheological Properties of Non-Newtonian Fluids under the Effect of temperature Using Different Chemical Additives

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Abstract

This research studies the rheological properties (plastic viscosity, yield point and apparent viscosity) of Non-Newtonian fluids under the effect of temperature using different chemical additives, such as (xanthan gum (xc-polymer), carboxyl methyl cellulose (High and low viscosity) ,polyacrylamide, polyvinyl alcohol, starch, Quebracho and Chrome Lignosulfonate). The samples were prepared by mixing 22.5g of bentonite with 350 ml of water and adding the additives in four different concentrations (3, 6, 9, 13) g by using Hamilton Beach mixer. The rheological properties of prepared samples were measured by using Fan viscometer model 8-speeds. All the samples were subjected to Bingham plastic model. The temperature rang studied is from 50 to 200 °F. The results shows that the rheological properties (plastic viscosity, apparent viscosity and yield point) decreased as temperature increased for all prepared samples of non-Newtonian fluids.

Keywords: Rheological properties, Non-Newtonian fluids, Bingham plastic model

Received on 28/11/2019, Accepted on 20/01/2020, published on 30/06/2020

https://doi.org/10.31699/IJCPE.2020.2.6

1- Introduction

The fluid is defined as a substance that is constantly distorted under the influence of external force. In another meaning, the fluid can flow and does not have consolidated three as dimensional defaults. The ideal fluid can be defined the fluid that has no friction. Thus the forces acting on any internal section of the fluid are purely pressure forces, even during motion **[1]**.

In a real fluid, shearing (tangential) and extensional forces always come into play whenever motion takes place, thus given rise to fluid friction, because these forces oppose the movement of one particle relative to another.

These friction forces are due to a property of the fluid called viscosity. The friction forces in fluid flow result from the cohesion and momentum interchange between the molecules in the fluid.

The viscosity of most of the fluids we encounter in everyday life is independent of the applied external force. There is, however, a large class of fluids with a fundamental different behavior.

This happens, for example, whenever the fluid contains polymer macromolecules, even if they are present in minute concentrations.

Two properties are responsible for this behavior. On one hand, polymers change the viscosity of the suspension by changing their shape depending on the type of flow.

On the other hand, polymer have long relaxation times associated with them, which are on same order as the time scale of the flow, and allow the polymers to respond to the flow with a corresponding time delay. Other complex systems consisting of several phases, such as suspensions or emulsions and most of the biological fluids, behave in a similar manner **[1]**.

Diego et al. studied the rheological properties of carboxy methyl cellulose. The results exhibited that the aqueous solutions of CMC exhibited a non-Newtonian flow behavior to reduce shear. The effect of the polymer concentration is an increase in the apparent viscosity. When the temperature raises a decrease in apparent viscosity and shear thinning occurred **[2]**.

Khaled et al. studied the non-Newtonian fluids It contains different types of salt (NaCl and KCl) in different concentrations. The results of this study led to the conclusion that when the temperature increased the rheological properties of non-Newtonian fluids were decreased **[3]**.

Mohd et al. studied the rheological behavior of polyacrylamide solutions at different temperatures by rheometry. When surfactants were added, the viscosity of polyacrylamide solution increased and when the temperature increased the rheological properties of non-Newtonian fluids were decreased. **[4]**

Vassilios et al. studied the effect of temperature on the rheological behavior of bentonite water dispersion. High temperature increased shear stress at low shear rates while the effect was much smaller in higher shear rates.

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The Bingham yield stress, from the low shear rate data, increased linearly with temperature, while plastic viscosity decreased with temperature, in a manner very similar to the decrease of water viscosity with temperature **[5]**.

The aim of present work is as follow: Studying the rheological properties of Non-Newtonian fluids under the addition of different chemical additives. It is also aimed to study the effect of temperature on the rheological properties of the Non-Newtonian fluids, and finding the best additive that made a Non-Newtonian fluid stable with temperature.

2- Basic Rheological Concepts

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 **[6]**.

2.1 Viscosity of a Fluid

The viscosity is defined as the proportion of shear stress (τ) to shear rate (γ). **[7]** Mathematical relation is:

$$\mu = \frac{\tau}{\gamma} \quad (1)$$

The viscosity units can be described as (Newton . seconds / m^2), (Pascal Seconds) or poise (dyne seconds / cm^2).

2.2. Shear Stress

The shear stress (τ) is defined as the force wanted to maintain the motion of a special kind of fluid inflow across the region **[8]**. Mathematical relation is:

$$\tau = \frac{F}{A} \quad (2)$$

Where: τ is shear stress in unit (N/m^2), (Pascal) or ($Dynes/cm^2$), F is the force in unit Newton, A is the area of surface subject to stress in unit (m^2).

2.3. Shear Rate

The rate of shear (γ) is defined as the ratio of the average of variation in velocity while a layer of fluid pass into an adjacent layer, the space separating of them. It was expressed in sec^{-1} (reciprocal seconds) **[9]**.

2.4. Plastic Viscosity

The plastic viscosity is the tendency of the stress of shear / rates of shear line at the highest 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 **[10]**.

The mathematics equation of the Bingham plastic fluid as follows:

$$\tau = YP + PV(\gamma) \quad (3)$$

Mathematical relation is: $PV = \theta_{600} - \theta_{300}$

Where: PV is plastic viscosity in unit cp, θ_{600} is shear stress at 600 rpm shear rate, in lb. /100 ft^2. θ_{300} is shear stress at 300 rpm shear rate, in lb. /100 ft^2 .

2.5. Yield Point

The Yield Point (YP) is a second variable of Bingham model and it is a measurement of electrochemical intensity or attractive intensity in the liquid. This part of the flowing impedance can be domination by appropriate chemical remediation**. [11]**

Mathematical relation is:

$$YP = \theta_{300} - PV \quad (4)$$

Where: YP is yield point in unit (lb. /100 ft^2) or (Pa.s)

PV is the plastic viscosity in unit CP

θ_{300} is shear stress at 300 rpm shear rate, in lb. /100 ft^2.

2.6 Apparent Viscosity

The apparent viscosity is fluid viscosity determined by the shear rate given by the API. In the rheology of Bingham plastic model, AV represents half the dial reading at 600 rpm (i.e. the shear rate is equal to 1022 sec^{-1}) using a viscometer **[12]**. Mathematical relation is:

$$AV = \frac{\theta_{600}}{2} \quad (5)$$

Where: AV is apparent viscosity in unit CP

θ_{600} is shear stress at 600 rpm shear rate, in lb. /100 ft^2 .

3- Non - Newtonian Fluid Behavior

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.

3.1. Time-Independent Behavior

Fluids of time-independent type whose flow properties are independent of the duration of shearing may be described in simple shear by a rheological equation of the form: $\tau_{yx} = f(\dot{\gamma}_{yx})$

This equation means that the rate of shear at any point within the sheared fluid is determined solely by the current value of the shear stress at that point, or vice versa. Depending upon the form of equation, these fluids may be further subdivided into three different types: [**13]**

1. Shear-thinning or pseudoplastics
2. Visco-plastics
3. Shear-thickening or dilatant

3.2. Time-Dependent Behavior

Ideally, Time-dependent materials are considered to be inelastic with viscosity function which depends on time. The response of the substance to stress is instantaneous and the time, dependent behavior is due to change in the structure of the material itself. In contrast, time effects found in viscoelastic substances arise because the response of stress to applied strain is not instantaneous and not related with a structural variation in the materials. Also, the time scale of thixotropy may be quite than the time scale of associated with viscoelasticity: the most dramatic effects are usually observed in situations involving short process time. Note too, that real materials may be time-dependent and viscoelastic. **[14]**

3.3 Effect of Temperature on the Rheological Properties

The temperature effects on the rheological properties (plastic viscosity, yield point and apparent viscosity) of Non-Newtonian fluids. The rheological properties (plastic viscosity, yield point and apparent viscosity) of Non-Newtonian fluids were decreased as temperature increased. Increasing temperature causes decreased in viscosity of the continuous phase of polymer fluids, which results in the reduction of plastic viscosity values through decreasing the friction forces between particles in the sample. Also, increasing temperature causes decreasing in the attraction forces between particles in the polymer fluid due to the increase in distance between particles causing a reduction interaction between clay-polymer colloids. **[15]**

4- Experimental Work

4.1. Materials

All the polymers used in this work were as follows: Bentonite was supplied from Qingdao Easthony Inc. China. Xanthan Gum (XC- POLYMER) was supplied from Fengchen Group, Qingdao, China. Carboxy methyl cellulose (CMC) high viscosity is supplied from Dalian chem. Imp. and Exp. Group Co., Ltd. China. Carboxy methyl cellulose (CMC) low viscosity was supplied from Denkim Denizli Kimya A.S., Turkey. Polyacrylamide (PAM) was supplied from Henan province. Henan Di Luo Environmental Protection Technology Co., Ltd., China, Poly vinyl alcohol was supplied from Elgin, Kolkata. Peekay Agencies Private Limited, India. Starch was supplied from Amstel products B.V. Company, Netherlands.

Chrome lignosulfonate (CLS) and Quebracho were supplied from laboratories of petroleum engineering department, College of engineering, University of Baghdad.

4.2. Preparation of Samples

1- Four concentrations of (xanthan gum (XC-polymer), carboxy methyl cellulose (High and low viscosity) ,polyacrylamide, polyvinyl alcohol, starch, Quebracho and Chrome Lignosulfonate) are weighed which are (3,6,9,13) grams. Also weighed four concentrations of bentonite (22.5 grams) with four cups each one contains water (350 ml).
2- By using Hamilton Beach mixer and cup, the sample was prepared by adding the first concentration of additives to the clay suspension mixture of bentonite and water.
3- Continue mixing until the polymer is dissolved in the clay suspension and then prepare the second, third, and fourth concentrations of additives in the same way.
4- The prepared solutions was poured into a properly labeled bottle and sealed.
5- Then the prepared solutions were kept and save at room temperature for 24 hours prior to conducting the rheological measurements.

4.3. Experimental Procedure

The procedure for measuring the rheological properties of all prepared samples, using Viscometer 800-8 speeds as shown in Fig. **1** is as follows: Clean the device thoroughly before starting. It is necessary to clean the bob column and the rotor also before submerging the rotor and bob in the samples whose rheological properties should be measured. Fill the cup to the scribed line with calibration fluid and place it on the viscometer stage. Move the stage upward until the fluid level is to the fill line on the sleeve. The instrument stage was so high that the rotor was immersed at the appropriate immersion depth. Never immerse the sleeve in fluids above the fill line. The speed of the machine turned to 600 rpm and recorded the disc reading. After recording, the speed of the device should be stirred for a short time for 2-3 minutes to prevent the formation of the sample and repeat the speed of the device at 300 rpm and record the reading of the request as well. Repeat the previous step and recorded the dial reading at speeds of 200, 100, 60, 30, 6 and 3 rpm. **[16]**

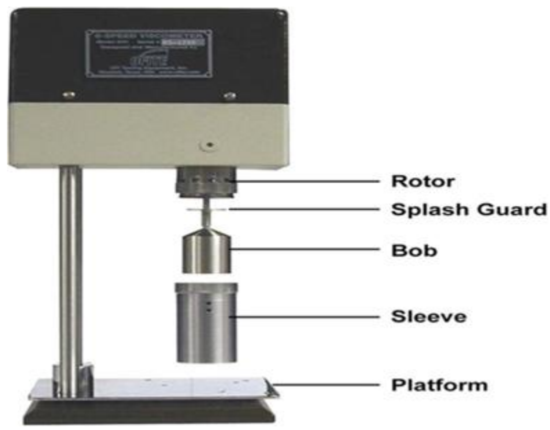

Fig. 1. Fann VG- Viscometer model 800

For the purpose of measuring the rheological properties under the influence of heat, the following procedure should be followed: The heating device (heater) must be turned on for a period before use.

Firstly, measuring the rheological properties of the sample at room temperature which is reaches50 °F, using Speed Viscometer model 800-8.Then the cup is taken that contains the sample to be heated using the thermometer to measure temperature with continuous stirring to prevent the occurrence of a conglomeration in the sample, the sample must be cover by the appropriate cap to prevent the evaporation of the sample during heating.

When the sample temperature reaches100 °F, the cup should be taken and placed in the rheological device (Speed Viscometer model 800-8). Take the sample speed readings and record them. Repeat above steps until temperatures reaches 150 and200 °F **[16].**

5- Results and Discussion

The results shows that the plastic viscosity of the non-Newtonian fluids at 22.5g of bentonite at various concentrations with additives (XC-polymer, CMC low viscosity, CMC high viscosity, Polyacrylamide, Polyvinyl alcohol, starch, Chrome Lignosulfonate and Quebracho) were decreased by increasing the temperature. Increasing temperature causes decreased in viscosity of the continuous phase of polymer fluids, which results in the reduction of plastic viscosity values through decreasing the friction forces between particles in the sample.

Also, increasing temperature causes decreasing in the attraction forces between particles in the polymer fluid, this is due to the increase in distance between particles causing a reduction interaction between clay-polymer colloids **[15].**

The results showed that the decrease in plastic viscosity begins after the temperature of 50°F and gradually increases at a temperature of 100 °F and 150 °F until it reaches 200 °F for all four concentrations prepared. As shown in Fig. **2** to Fig. **6**. It can also notice that the effect of temperature is often higher at the concentration of 13 grams and less at 3 grams.

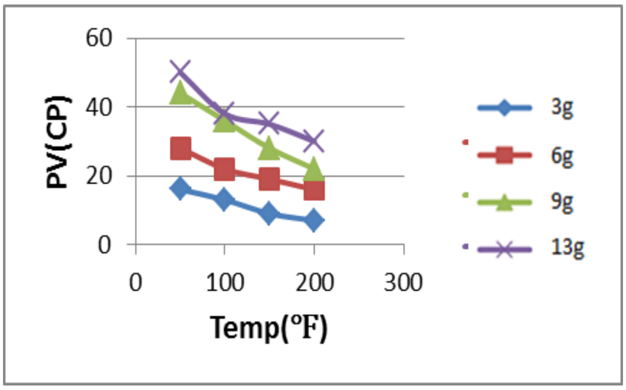

Fig. 2. The effect of temperature on the plastic viscosity of the fluid when adding XC-polymer

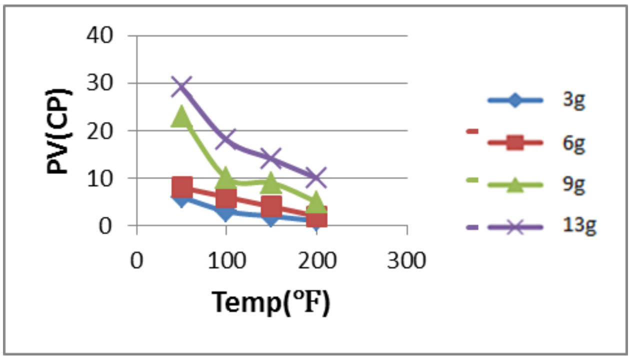

Fig. 3. The effect of temperature on the plastic viscosity of the fluid when adding CMC L.V

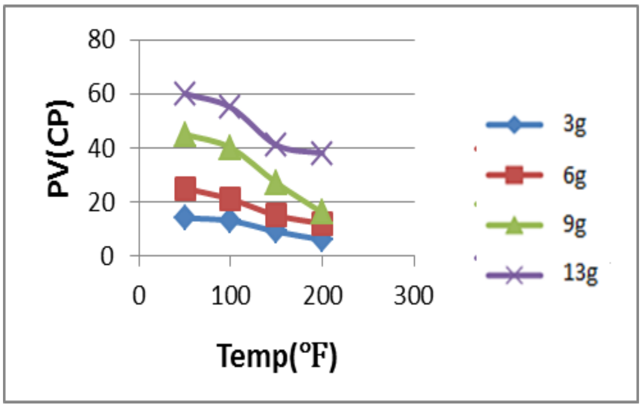

Fig. 4. The effect of temperature on the plastic viscosity of the fluid when adding CMC H.V

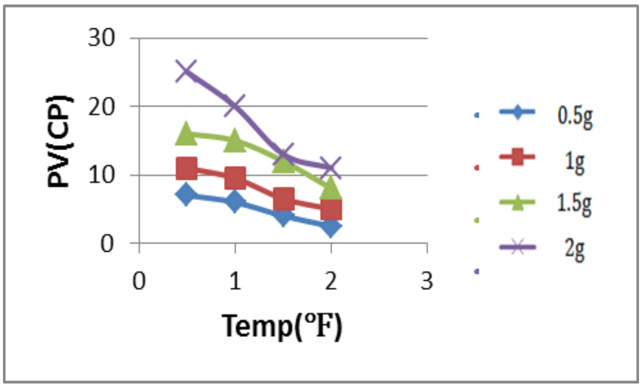

Fig. 5. The effect of temperature on the plastic viscosity of the fluid when adding Polyacrylamide

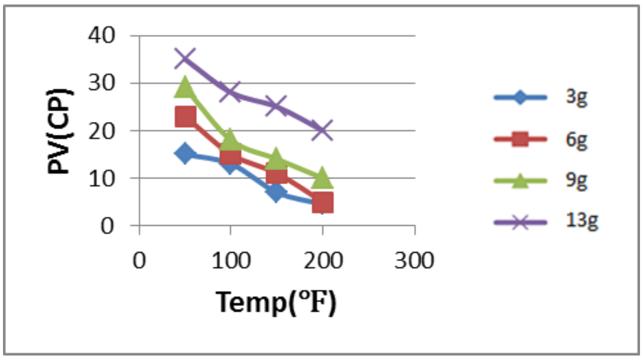

Fig. 6. The effect of temperature on the plastic viscosity of the fluid when adding polyvinyl alcohol

When heating the prepared samples containing the addition of starch, it was observed that there is no heat effect on the starch or little effect. The reason is that during heating, starch molecules may accumulate in the form of lump or aggregate starch molecules. As shown in Fig. **7**. Thus, the effect of temperature on plastic viscosity is minimal or constant.

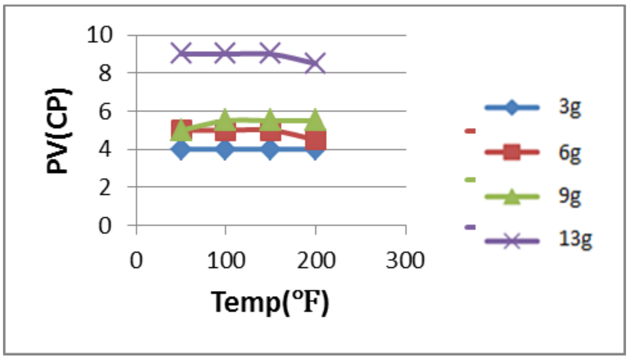

Fig. 7. The effect of temperature on the plastic viscosity of the fluid when adding starch

The results can show that the effect of (Chrome lignosulfonate and Quebracho) on plastic viscosity was decreased by increasing the temperature of additives to non-Newtonian fluids at (22.5) grams of bentonite at four different concentrations. As shown in Fig. **8** and Fig. **9**.

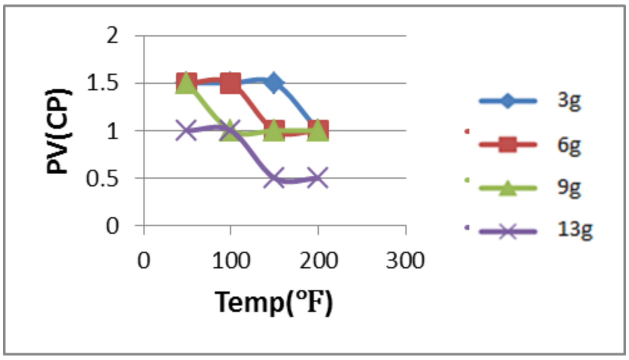

Fig. 8. The effect of temperature on the plastic viscosity of the fluid when adding CL

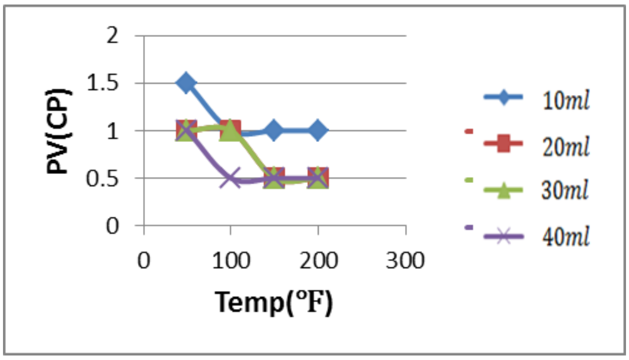

Fig. 9. The effect of temperature on the plastic viscosity of the fluid when adding Quebracho

This is because of all hydroxides react with clay minerals at temperatures above about 200°F (94°C). With low alkalinity fluids, such as those treated with Quebracho tannin or lignosulfonate, the effect on their rheological properties is not significant, except to the extent that the loss of alkalinity lessens the effectiveness of the thinner. But with highly alkaline fluids the effect may be severe, depending on the temperature and the species of metal ion of the hydroxide.

The results shows that the yield point of the non-Newtonian fluids at 22.5g of bentonite at various concentrations with additives (XC-polymer, CMC low viscosity, CMC high viscosity, Polyacrylamide and Polyvinyl alcohol) were decreased with increasing the temperature. Temperature causes reduction in the viscosity of non-Newtonian fluid and in the friction forces between the solid particles in the non-Newtonian fluid mixtures due to increase the space between particles, which will result in a noticeable decrease in yield point of non-Newtonian fluid samples **[16]**.

The results showed that the decrease in yield point begins after the temperature of 50°F and gradually increases at a temperature of 100 °F and 150 °F until it reaches 200 °F for all four concentrations prepared. As shown in Fig. **10** to Fig. **14**. It can also noticed that the effect of temperature is often higher at the concentration of 13 grams and less at 3 grams.

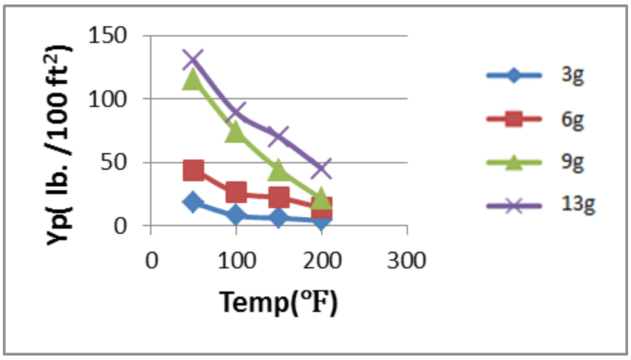

Fig. 10. The effect of temperature on the Yield point of the fluid when adding XC-polymer

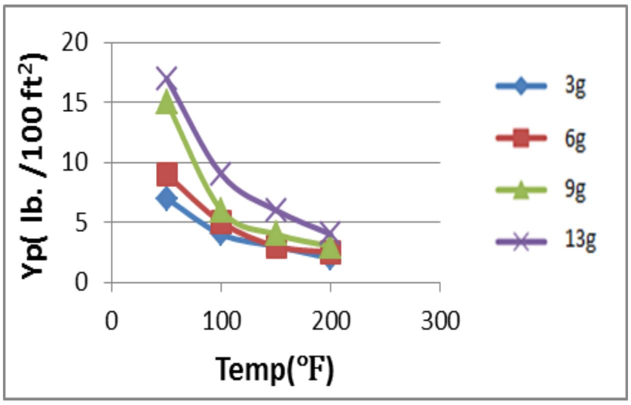

Fig. 11. The effect of temperature on the Yield point of the fluid when adding CMC L.V

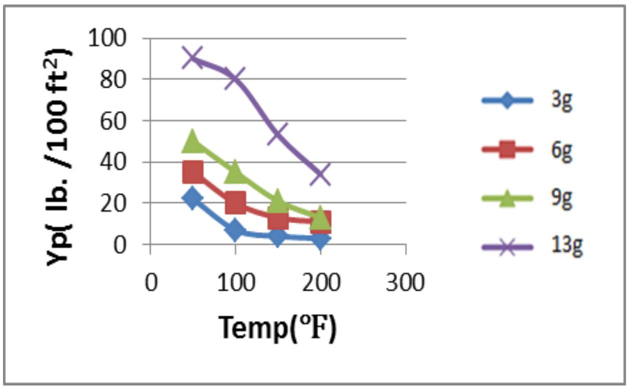

Fig. 12. The effect of temperature on the Yield point of the fluid when adding CMC H.V

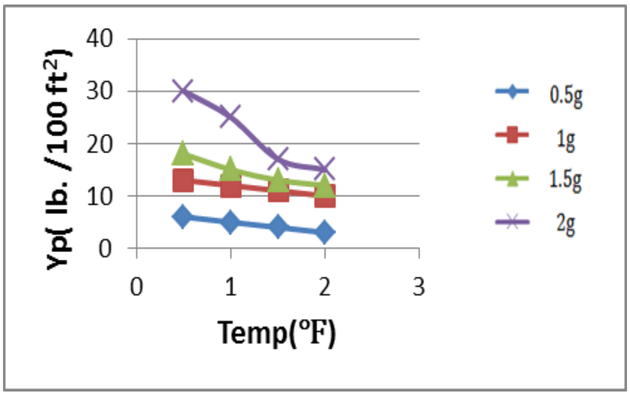

Fig. 13. The effect of temperature on the Yield point of the fluid when adding Polyacrylamide

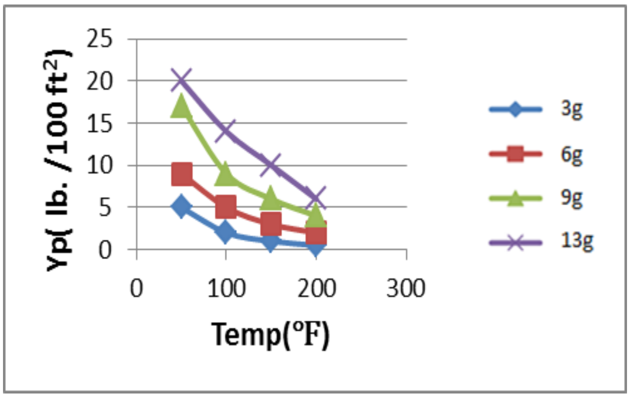

Fig. 14. The effect of temperature on the Yield point of the fluid when adding polyvinyl alcohol

When heating the prepared samples containing the addition of starch, it was observed that there is no heat effect on the starch or little effect.

The reason is that during heating, starch molecules may accumulate in the form of lump or aggregate starch molecules. As shown in Fig. **15**. Thus, the effect of temperature on yield point is minimal or constant.

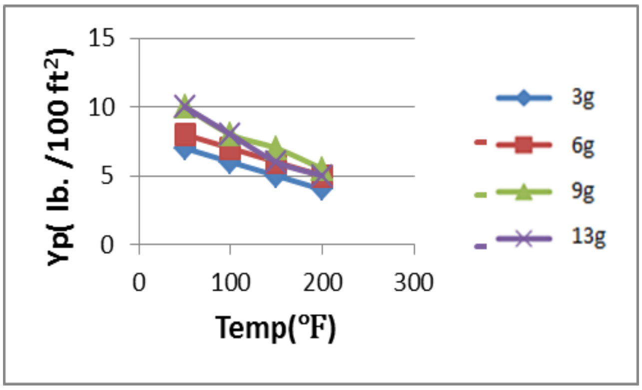

Fig. 15. The effect of temperature on the Yield point of the fluid when adding starch

The results can show that the effect of (Chrome lignosulfonate and Quebracho) on yield point was decreased by increasing the temperature of additives to non-Newtonian fluids at (22.5) grams of bentonite at four different concentrations. As shown in Fig. **16** and Fig. **17**.

This is because of all hydroxides react with clay minerals at temperatures above about 200°F (94°C). With low alkalinity fluids, such as those treated with Quebracho tannin or lignosulfonate, the effect on their rheological properties is not significant, except to the extent that the loss of alkalinity lessens the effectiveness of the thinner. But with highly alkaline fluids the effect may be severe, depending on the temperature and the species of metal ion of the hydroxide.

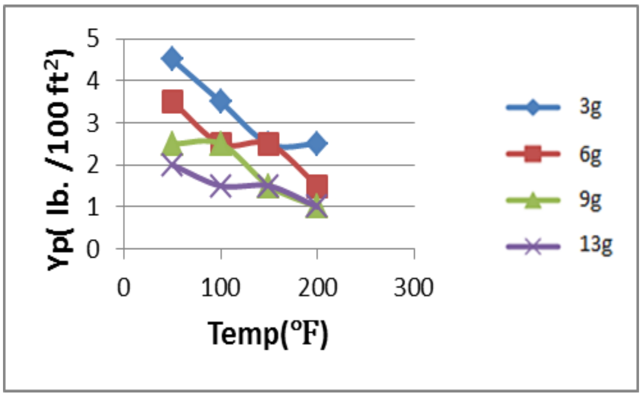

Fig. 16. The effect of temperature on the Yield point of the fluid when adding Chrome Lignosulfonate

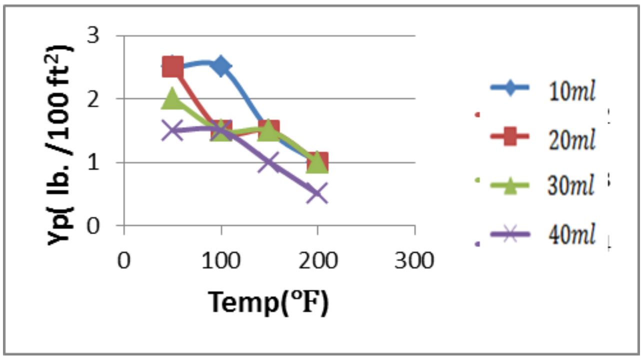

Fig. 17. The effect of temperature on the Yield point of the fluid when adding Quebracho

The results shows that the apparent viscosity of the non-Newtonian fluids at 22.5g of bentonite at various concentrations with additives (XC-polymer, CMC low viscosity, CMC high viscosity, Polyacrylamide, Polyvinyl alcohol, starch, Chrome Lignosulfonate and Quebracho) were decreased by increasing the temperature.

Apparent viscosity decreases with increasing temperature; this is due to the increasing in distance between clay-polymer colloids as temperature increases causes low attraction forces.

Also, it can be observed that on gel structure is formed as temperature increased **[16].**

The results showed that the decrease in apparent viscosity begins after the temperature of 50°F and gradually increases at a temperature of 100 °F and 150 °F until it reaches 200 °F for all four concentrations prepared.

As shown in Fig. **18** to Fig. **25**. It can also notice that the effect of temperature is often higher at the concentration of 13 grams and less at 3 grams.

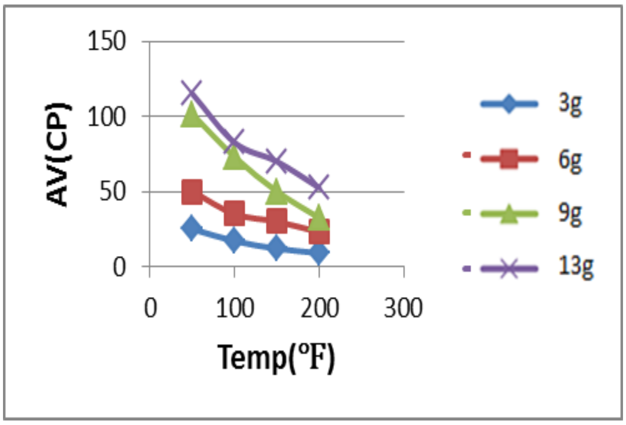

Fig. 18. The effect of temperature on the apparent viscosity of the fluid when adding XC-polymer

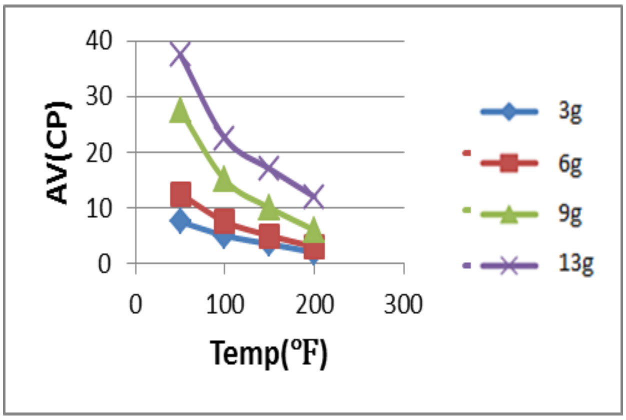

Fig. 19. The effect of temperature on the Apparent viscosity of the fluid when adding CMC L.V

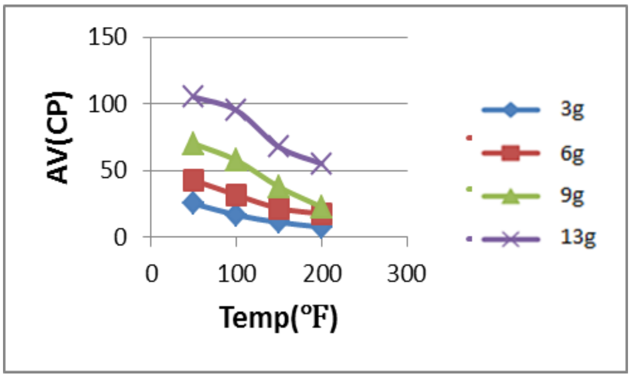

Fig. 20. The effect of temperature on the Apparent viscosity of the fluid when adding CMC H.V

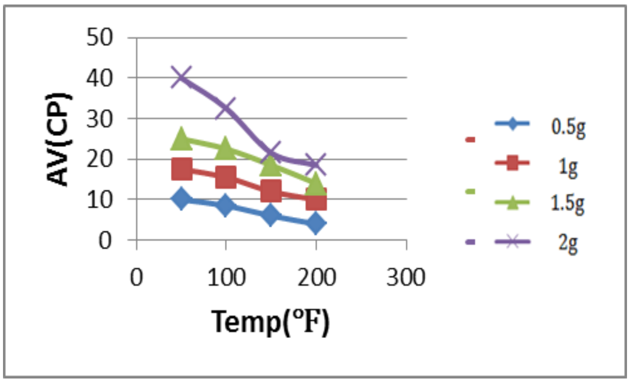

Fig. 21. The effect of temperature on the Apparent viscosity of the fluid when adding Polyacrylamide

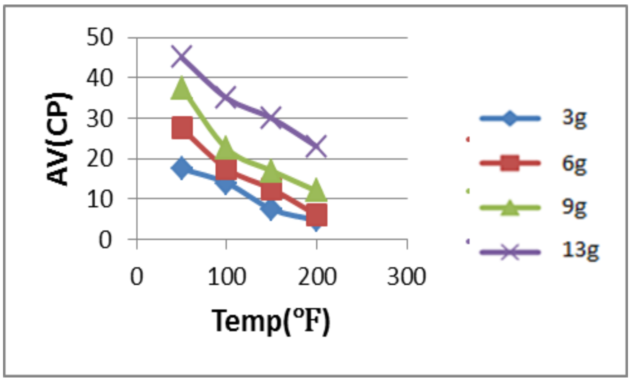

Fig. 22. The effect of temperature on the apparent viscosity of the fluid when adding polyvinyl alcohol

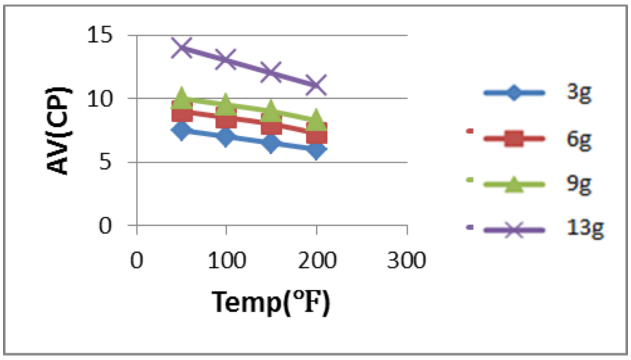

Fig. 23. The effect of temperature on the apparent viscosity of the fluid when adding Starch

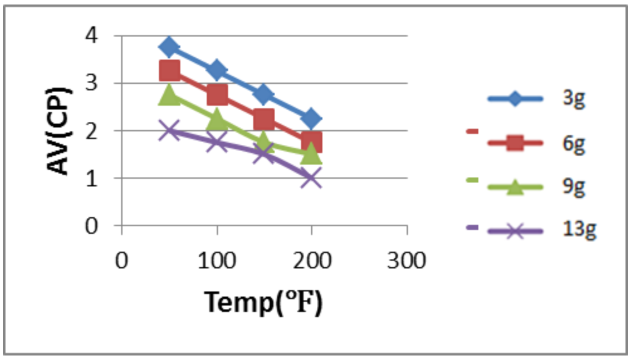

Fig. 24. The effect of temperature on the apparent viscosity of the fluid when adding CL

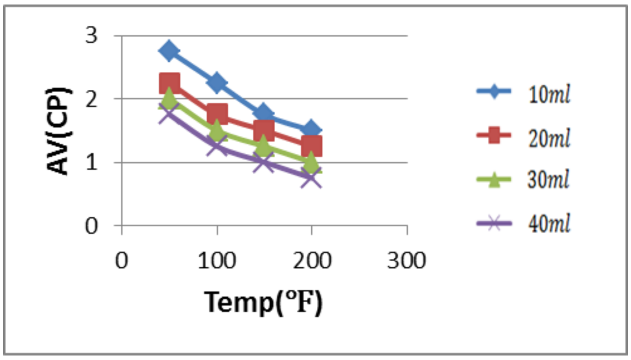

Fig. 25. The effect of temperature on the apparent viscosity of the fluid when adding Quebracho

6- Conclusions

The plastic viscosity of the non-Newtonian fluids at 22.5g of bentonite at various concentrations with additives (XC-polymer, CMC low viscosity, CMC high viscosity, Polyacrylamide, Polyvinyl alcohol, starch, Chrome Lignosulfonate and Quebracho) were decreased by increasing the temperature.

Also, it was found that the yield point of the non-Newtonian fluids at 22.5g of bentonite at various concentrations with additives (XC-polymer, CMC low viscosity, CMC high viscosity, Polyacrylamide and Polyvinyl alcohol) were decreased with increasing the temperature.

Finally, it was concluded that the apparent viscosity of the non-Newtonian fluids at 22.5g of bentonite at various concentrations with additives (XC-polymer, CMC low viscosity, CMC high viscosity, Polyacrylamide, Polyvinyl alcohol, starch, Chrome Lignosulfonate and Quebracho) were decreased by increasing the temperature.

The rheological properties (plastic viscosity, apparent viscosity and yield point) were decreased begins after the temperature of 50°F and gradually increases at a temperature of 100 °F and 150 °F until it reaches 200 °F for all four concentrations prepared. As shown in Fig. (18) to (25). It can also notice that the effect of temperature is often higher at the concentration of 13 grams and less at 3 grams.

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دراسة الخواص الريولوجية للسوائل غير النيوتونية تحت تأثير درجات الحرارة باستخدام إضافات كيميائية مختلفة

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الخلاصة

يدرس هذا البحث الخواص الريولوجية (اللزوجة البلاستيكية ، نقطة الخضوع واللزوجة الظاهرية) للسوائل غير النيوتونية تحت تأثير درجات الحرارة باستخدام إضافات كيميائية مختلفة، مثل زانثان بوليمر ، كربوكسي ميثيل السليلوز (اللزوجة العالية والمنخفضة)، بولي أكريلاميد ، كحول بولي فينيل ، نشا ، كيوبراجو وكروم ليجنو سلفونات، تم تحضير العينات عن طريق خلط 22.5 غرام من البنتونيت مع 350 مل من الماء وإضافة المواد المضافة في أربعة تركيزات مختلفة (3 ، 6 ، 9 ، 13) غرام باستخدام خلاط هاميلتون بيتش. تم قياس الخواص الريولوجية للعينات المحضرة باستخدام نموذج مقياس اللزوجة فان ثمانمئة ذوو ثمان سرعات. تخضع جميع العينات لنموذج بينغهام بلاستيك. تتراوح درجة الحرارة المدروسة من 50 إلى 200 درجة فهرنهايت. أظهرت النتائج أن الخواص الريولوجية (اللزوجة البلاستيكية ، اللزوجة الظاهرية ونقطة الخضوع) انخفضت مع زيادة درجة الحرارة لجميع عينات تحضير الموائع غير النيوتونية.

الكلمات الدالة: الخواص الريولوجية ، السوائل غير النيوتونية ، نموذج البلاستيك بينغهام