STUDY OF HYDROGEL MODIFIED DRILLING FLUID: PREPARATION, RHEOLOGICAL PROPERTIES AND SWELLING BEHAVIORS OF CHITOSAN N-ISOPROPYLACRYLAMIDE HYDROGEL

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ABSTRACT

Chitosan N-Isopropylacrylamide hydrogels were synthesized by thermal and gamma radiation methods. The thermal method used an initiator and a crosslinker while the gamma radiation process was done in absence of any kind of initiator or crosslinker agent. The study found that the gamma radiation method produced hydrogels with higher water swelling ratio. The rheological properties of the hydrogels used in the preparation of drilling fluids were investigated. Properties such as apparent viscosity, plastic viscosity, gel strength, and yield point were compared with those of Carboxymethyl Cellulose (CMC) and Xanthenes (XC) resins, which are widely used in drilling fluids. The hydrogel synthesized by gamma radiation improved rheological properties of drilling fluids better than CMC, XC, and thermal prepared hydrogel. Also, comparison results show that whereas linear polymer effects on mud properties are more significant in low polymer concentration, prepared crosslinked hydrogel effects are more prominent at high concentrations.

KEYWORDS

N-Isopropylacrylamide; hydrogel; drilling fluid; rheological properties; thermal method; gamma radiation method

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1. INTRODUCTION

The primary role of drilling fluids was to transfer cutting materials from well bottom to ground surface. However, with the progress in drilling technologies, some duties also were added to the functions of drilling fluids (**NIOC manual, 2002**). Nowadays, drilling fluids key functions are transferring hydraulic power pumps to bores and downloading sand and other materials upon sieve. Rheological properties of drilling muds are important because they are used to characterize properties of the mud such as its well cleanses, erosion preservation, cutting material removal, hydraulic calculation, and pump system (**NIOC manual, 2002**).

Two water-soluble polymers, methyl cellulose and poly vinyl alcohol, were suggested to solve the instability problem of the treated mud toward shear stresses experienced during circulation of the mud. It was found that small amounts of these polymers were capable of obtaining the rheological properties achieved by using large amounts of caustic soda. More importantly, it was shown that the properties of muds treated with these polymers did not deteriorate as quickly as the muds treated with caustic soda. To sustain a desirable yield point of 25 lb/100 ft² after 24h of aging, 3.78 pounds of poly vinyl alcohol per barrel of caustic soda were needed, whereas only 0.23 pounds of methyl cellulose were sufficient (**Dairanieh and Lahalih, 1988**).

Kadaster et al. (1992) made significant changes in mud systems using partially hydrolyzed polyacrylamide polymer (PHPA) for inhibiting troublesome shale. The most significant changes were: maintaining constant the balance of materials and the supplemental addition of PHPA, controlling fluid loss, and selecting the use of seawater and NaCl for inhibition. Their achievements led to improvements in drilling operation through shale and mud in order to carry low-gravity drill solids out of the borehole and remove shale microparticles by the solids-control equipment accumulated in the mud. It established a guideline for comparing how viscosities of conventional clay and polymer-based muds are controlled by mud products in progress applications.

New sulfonate polymer was introduced to

control fluid loss during the drilling process. This polymer showed excellent stability against salinity even at increased salt concentration and high temperatures up to 400 °C (**Liu and Guo, 2001**).

Network microstructures of acrylamide (AAM)-based hydrogels were investigated by light scattering methods. The hydrogels were prepared by free-radical crosslinking copolymerization of the monomers acrylamide, N, N-dimethylacrylamide (DMA), and N-Isopropylacrylamide with N, N-methylenebisacrylamide as a crosslinker in aqueous solutions. It was found that the addition of DMA or N, N-methylenebisacrylamide into the comonomer feed caused an increase of frozen concentration fluctuations in polyacrylamide hydrogels (**Kuru et al., 2007**).

A new superabsorbent copolymer, poly (sodium acrylate-co-sodium 1-acryloyloxy propan-2-yl phosphate) [P(SA-co-SAPP)], was synthesized by a fabricated monomer, 1-acryloyloxy propan-2-yl phosphoryl dichloride. The swelling properties of the superabsorbent were evaluated by comparing its properties with the ones of poly sodium acrylate (PSA) and copolymer of poly (sodium acrylate-co-2-hydroxypropyl acrylate) [P(SA-co-HPA)]. The results presented show that the superabsorbent polymer had higher water swelling at general testing conditions. It was also observed that the swelling process and the saturated water absorbency of all superabsorbents were affected remarkably by cations (**Chen et al., 2007**).

Khodja et al. (2010) optimized drilling conditions in the Hassi Messaoud Algerian field and investigated rheological and filtration characteristics of water-based muds with different polymers. They determined that the addition of anionic polymers (PAC and XC) to drilling mud increased the viscosity of the solutions. Also, it was found that the viscosity range is higher for KCl-polymer solutions than for polymers, and that the action of PHPA may avoid disintegration of shale material.

Although some publications have been devoted to the effects of some different polymers on drilling fluid behavior, effects of natural hydrogels, such as chitosan hydrogel, on drilling fluid properties remain unreported. Thus, this study used some chitosan modified natural hydrogels prepared by thermal and radiation methods to investigate the effects of these newly prepared

Table 1. Physical properties of chitosan and N-Isopropylacrylamide.

Chitosan				
Acetyl elimination= 89 %	Purity degree= 97 %	Protein= 0.1%	Ash= 0.1%	Humidity = 0.8%
N-Isopropylacrylamide				
Purity = 99%	Melting point= 60-63°C	Boiling point= 89-91°C.		

hydrogels on rheological and swelling behaviors of drilling fluids.

2. MATERIALS AND METHODS

2.1 Materials

In this study, acetic acid (Merck Co., 98%) was used as a solvent to solve chitosan (Merck Co.) and N-Isopropylacrylamide monomer (Merck Co.). Methanol (Merck Co., 99%, Ultra High Purity, grade: 408400) was used as an extractor to purify polymer and sulfate potassium (Merck Co., 99%). Methanol was used also as a radical initiator in the solution. Highly pure formaldehyde and methylenebisacrylamide (MBA) (Merck Co, 98+%) have been used as crosslinking agents. Ferrous Ammonium Sulphate (Mohr's salt) $[\text{FeSO}_4 (\text{NH}_4)_2 \text{SO}_4 \cdot 6\text{H}_2\text{O}]$ was supplied by Chem-Impex International Inc. (99.5%). Physical properties of chitosan and N-Isopropylacrylamide are shown in the Table 1.

2.2 Thermal preparation of hydrogel

Primarily, 1.5 g of chitosan was solved in acetic acid with 2 wt.% concentration. Then, the solution was stirred in a compact mixer (IKA Lab Egg Compact Mixer) during 30 min at 2000 rpm (50 °C), and). N-Isopropylacrylamide (monomer) was added as specified in Table 2 and mixed for 15-20 minutes (IKA Lab Egg Compact Mixer, 2000 rpm). Finally, the crosslinking agent (Formaldehyde or MBA) and the initiator (KPS - sulfate potassium – 0.1g) were added according to Table 2 and temperature of the reaction was kept at 50 °C. In whole manuscript “H” represents the heating (thermal) prepared samples.

2.3 Radiation preparation of hydrogel

The sample preparation procedure via radiation method was similar to the procedure used by the heating method; however, at a later stage of the procedure, crosslinker and initiator were not added. Indeed, they were not necessary for this method. Nevertheless, Ferrous Ammonium

Table 2. Variation condition for hydrogel preparation via heating method.
(chitosan = 1.5 g; T = 50°C; KPS = 0.1g)

Samples	Monomer Concentration (ppm)	Formaldehyde (mL)	MBA(g)
H ₁	30	0	0
H ₂	30	0.1	0
H ₃	30	0.2	0
H ₄	30	0.3	0
H ₅	30	0	0.05
H ₆	30	0	0.1
H ₇	30	0	0.15
H ₈	10	0.1	0
H ₉	20	0.1	0
H ₁₀	40	0.1	0
H ₁₁	50	0.1	0
H ₁₂	60	0.1	0

Table 3. Variation condition for hydrogel production via radiation method.

Samples	Monomer Concentration (ppm)	Irradiation (KGy)	Mohr's salt (g)	Reaction Atmosphere
I ₁	30	4	0.1	Nitrogen
I ₂	30	6	0.1	Nitrogen
I ₃	30	8	0.1	Nitrogen
I ₄	30	10	0.1	Air
I ₅	30	12	0.1	Nitrogen
I ₆	30	25	0.1	Air
I ₇	10	25	0.1	Nitrogen
I ₈	20	25	0.1	Nitrogen
I ₉	40	25	0.1	Nitrogen
I ₁₀	60	25	0.1	Nitrogen
I ₁₁	30	25	0	Nitrogen

Sulphate was added in order to prevent the production of homopolymer. Table 3 shows the molar ratio of used additive materials in the solutions. In whole manuscript "I" represents the radiation prepared samples. Methanol was used as solvent and the extraction time was of 72 hours.

2.4 Preparation of the drilling mud

The experiments were carried out to obtain the rheological properties of the drilling mud, including plastic viscosity, yield point, apparent viscosity and gel strength. To do so, the effect of the addition of polymers on the properties of the mud was investigated under various concentrations. For this purpose, Chitosan N-Isopropylacrylamide crosslinking hydrogel was added to the drilling mud using two ways: 1. Mixer system (MS) (Hamilton Beach model) and 2. Circulation mud machine

(CM); see Figure 1. At the end of the experiment, the results were compared to the effect of adding both polymers: Xanthenes (XC) resins and Carboxymethyl Cellulose (CMC), prepared at the same experimental conditions. All the experiments were carried out in atmospheric pressure and at 35 °C. In all the experiments using the mixer system, 50g bentonite were used in the base of 500mL distilled water/basic mud with the mixing speed (e.g. 6000 rpm). To investigate realistic conditions for the drilling process, a circulation mud machine was used in this study. In this machine, the drilling mud was transferred via a centrifugal pump with 2-100 L/min to outlet pipes and then was stored in the bottom of the storage tank to transfer again. To apply different shear stresses, there were three different pipes with 0.75, 0.50, and 0.25 inch of diameter for applied nozzles. In this machine, there

Figure 1. Scheme of circulation mud machine, used in this study.

were 3 safety valves (V.1, 2, 3) to get samples from three different points.

In the experiments using the mud circulation method, 1.5Kg of the mud was used in 20L distilled water. In both systems (mixing and circulating) enough time was given to the reaction to ensure that homogeneity was obtained. Samples were kept in water for one week to swell. Swell ratio was calculated by equation (1):

$$\text{Swell Ratio} = \frac{W_s}{W_d} \quad (1)$$

In the equation (1), W_s is the swelled hydrogel weight, and W_d is the dry hydrogel weight.

In radiation method, a UV crosslinker (CL-1000M model, wavelength: 302 nm) was applied to generate radiation waves.

2.5 Rheological study

A rotatory viscometer having 6 rotation speeds 3, 6, 100, 200, 300, and 600 rpm (Fann Co., V.G 35A model) was used to measure rheological properties such as apparent and plastic viscosities of prepared samples. Offset angle was measured in related speed and it is represented by the Θ symbol. Finally, rheological properties were obtained by equations (2-6).

$$\text{Apparent viscosity (cP)} = 0.5 \times \Theta_{300} \quad (2)$$

$$\text{Plastic viscosity (cP)} = PV = \Theta_{600} - \Theta_{300} \quad (3)$$

$$\text{Yield point (lbf/100ft}^2\text{)} = \Theta_{\omega} - PV \quad (4)$$

$$\text{Gel}_i = \Theta_{\max} \text{ (after 10 sec)} \quad (5)$$

$$\text{Gel}_i = \Theta_{\max} \text{ (after 10 min)} \quad (6)$$

In equations (2-6), Θ_{300} is the offset angle at 300 rpm, Θ_{600} is the offset angle at 600 rpm, Θ_{ω} is the offset angle in (ω) rpm, and $\Theta_{\max}$ represents the maximum of offset angle in a specific time.

In addition, the yield in hydrogel obtained by crosslinking was calculated with the relationship described by equation (7):

$$\eta(\%) = \left(\frac{m_h}{m_r} \right) \times 100\% \quad (7)$$

Where, η is yield of crosslinking reaction; m_r is weight of reactants introduced into the reaction; m_h is weight of hydrogel obtained after crosslinking.

3. RESULTS AND DISCUSSIONS

3.1 Rheological properties

It was expected that mixer type and mixing time would affect the rheological characteristics of mud. Figures 2 and 3 show the rheological properties of drilling mud versus mixing time (I_6 sample-base mud) using the mixer system and circulation machine, respectively. It is interesting to point that this sample, including the high radiation dose and the normal monomer concentration, was selected to show the effects of irradiation dose and monomer concentration. As presented in the Figure 2, with increase in mixing time, apparent viscosity and yield point increased up to the 40 minute mark and then remained constant. Conversely, plastic viscosity remained constant up to 30 minutes of mixing time, then, increasing considerably during the additional 60 minutes and, after this time, approaching its final value. As presented in the Figure 3, with an increase in mixing time, apparent viscosity and yield point increased up to 160 minute with high slope and then remained constant. On the other hand, initially, plastic viscosity remained constant up to 60 minutes of mixing time and, then, increased considerably for additional 100 minutes, after this time approaching its final value.

Comparing the results presented for rheological properties, Figures 2 and 3 show that increments of the properties occur in longer time for the circulation system than that of the mixer system, while final increment of the properties is higher in mixer system than that of the circulation machine. In other words, comparisons of yield point, apparent, and plastic viscosities of samples prepared in the mixer system and circulation machine show that, for both samples, these parameters increase considerably, but the final

Figure 2. Rheological properties of the modified mud versus mixing time in the mixer system for I₆ sample.

Figure 3. Rheological properties of the modified mud versus mixing time in the circulation machine for I₆ sample.

increment is higher for samples prepared by the mixer system. Also, the increments of the parameters happen in much less time for sample prepared by the mixer system. It is interesting to point out that apparent viscosity and yield point of the muds increased in initial mixing time and remained constant in the rest of time. This happened because the stress of the mixing action resulted in an increased fluidized resistance.

However, regarding to plastic viscosity definition, the friction of some layers is virgin against existed stresses in initial time. After the mixing progress, all layers missed their friction resistance and they could not sustain any stress.

Figure 4 shows the effects of adding hydrogels prepared by radiation and thermal methods, XC, and CMC polymers to the plastic viscosity of drilling mud. The experiment used H₂ and I₁ samples due to

Figure 4. Concentration (ppm) effect of XC, CMC and prepared hydrogels on plastic viscosity (cP).

the presence of little crosslinker agents and irradiation dose to show the addition concentration to drilling mud. This figure shows that effects of CMC and XC polymers and hydrogels on plastic viscosity are comparable at low concentrations (e.g. less than 10%). The prepared radiation and thermal hydrogels increase significantly plastic viscosity of mud, more than CMC and XC polymers at concentrations higher than 10% and 30%, respectively. However, this increment is more pronounced in the radiation prepared hydrogels. In spite of XC and CMC polymers, it is observed that thermal and radiation prepared hydrogels in higher concentrations show the most significant effects. Also, the effects of adding radiation prepared samples are by far higher than thermal prepared samples.

Plastic viscosity is a part of fluid resistance against the flow which generates mechanical friction. The solid interaction with itself or with the liquid around of its particles and the friction occurred in fluid layers are some of the factors which generate plastic viscosity. Adding polymer increases the concentration of solid and liquid materials. As a result, plastic viscosity increases. In samples prepared by thermal method, the effect of adding hydrogel on plastic viscosity is lower than the effect of linear polymer CMC and higher than that of XC polymer. This occurs due to the fact that powder particles of hydrogel build a larger molecular structure as they absorb more water and

clay; this, in turn, decreases active surface and the number of particles. As a consequence, the friction between surfaces decreases and, therefore, it maintains plastic viscosity. Coagulation results in plastic viscosity reduction. As for the hydrogels obtained by gamma radiation, the high water absorption capacity of the particles results in high mixture concentration; fluid layer friction also increases highly and neutralizes the mentioned effect. This function increases plastic viscosity as compared to the non-crosslinking polymers. On the other hand, the reason for low plastic viscosity of mud in the mixing system is linked to the low dynamics and the cutting forces of the nozzles of the circulation machine.

Tables 4 and 5 show the crosslinker density and monomer concentration effects upon plastic viscosity (cP) in thermal prepared samples. As presented in the Tables 4 and 5, plastic viscosity increases with formaldehyde crosslinker volume and monomer concentration.

Tables 6 and 7 display radiation doses and N-Iso propylacrylamide monomer concentration effects on plastic viscosity for radiation prepared samples. Clearly, there is a direct correlation between radiation dose and monomer concentration upon plastic viscosity.

Figures 5 and 6 show yield point and apparent viscosity of CMC and XC modified mud at different concentrations and the hydrogels modified muds

Table 4. Crosslinker density effect on plastic viscosity (cP) in heating prepared samples.

System	Plastic Viscosity (cP)			
	Base mud	H ₂ (30 ppm)	H ₃ (30 ppm)	H ₄ (30 ppm)
*MS	3.0	6.5	9.2	14.1
**CM	3.0	6.8	9.0	14.2

*MS - mixer system **CM - circulation mud machine

Table 5. Monomer concentration effect on plastic viscosity (cP) in heating prepared samples.

System	Plastic Viscosity (cP)			
	Base mud	H ₈ (10 ppm)	H ₁₀ (40 ppm)	H ₁₂ (60 ppm)
MS	3.0	3.5	5.5	7.0
CM	3.0	3.6	5.2	7.0

Table 6. Radiation dose effect upon plastic viscosity (cP) in radiation prepared samples.

System	Plastic Viscosity (cP)			
	Base mud	I ₄ (30 ppm)	I ₅ (30 ppm)	I ₆ (30 ppm)
MS	3.0	22.4	26.0	55.4
CM	3.0	21.2	27.0	49.8

Table 7. Monomer concentration effect upon plastic viscosity (cP) in radiation prepared samples.

System	Plastic Viscosity (cP)			
	Base mud	I ₇ (10 ppm)	I ₉ (40 ppm)	I ₁₀ (60 ppm)
MS	3.0	4.2	5.8	24.0
CM	3.0	4.2	5.9	25.2

prepared by radiation and thermal processes. These figures show that, at low concentrations, CMC and XC increase yield point and apparent viscosity slightly more than hydrogel samples, while at high concentrations hydrogels increase these parameters much more than CMC and XC; phenomena that is pronounced in radiation prepared hydrogels.

Tables 8 and 9 depict the effects of the crosslinker density and monomer concentration for heating prepared samples. According to Table 8, the initial and final gel strength increase with the increase in crosslinker density for heating samples. The increment of final gel strength is higher than increment of initial gel strength for both mixing systems in order to fully shape the drilling fluid. As presented in Table 9, also, the gel strength

property enhances with the addition of the monomer used in drilling fluid. Similarly to the data presented in Table 8, the increment of final gel strength is higher for both mixing systems.

Tables 10 and 11 show the effects of radiation dose and monomer concentration for radiation prepared samples. According to Tables 10 and 11, initial and final gel strengths increase with the increase in radiation dose and monomer concentration for irradiation samples and the increment of both gel strength properties are considerable.

Finally, Table 12 shows the effects of monomer concentration for CMC and XC polymers on the primary and final gel strengths. Generally speaking, in all cases, adding a polymer increases gel strength. The effect of initial gel strength increases

Figure 5. Concentration (ppm) effect of prepared hydrogels, CMC, and XC polymers upon yield point (lbf/100ft²).

Figure 6. Concentration (ppm) effect of prepared hydrogels, CMC, and XC polymers upon apparent viscosity (cp).

by adding polymers according to the following order classification: first radiation prepared hydrogels, then CMC and XC polymers, and, at last, thermal prepared hydrogels. As for the final gel strength, the order classification is as follows: radiation prepared hydrogels, CMC polymer, thermal prepared hydrogels, and XC polymer. On the other hand, initial gel strength has higher amounts in the mixer system whereas final gel

strength has higher amounts in the circulation system. Since thermal prepared hydrogels are dispersed in mud, they will not have high water absorption. Thus, linear polymers are considered poor when it comes to their ability of increasing its water absorption property.

Table 8. Crosslinker density effect upon gel strength (lbf/100ft²) in heating prepared samples.

System	Properties	Base mud	H ₂ (30 ppm)	H ₃ (30 ppm)	H ₄ (30 ppm)
MS	Initial Gel	6.0	11.2	24.4	26.6
CM	Strength	5.0	10.0	25.2	27.0
MS	Final Gel	10.0	17.1	36.3	50.0
CM	Strength	10.0	19.0	38.2	51.2

Table 9. Monomer concentration effect upon gel strength (lbf/100ft²) in heating prepared samples.

System	Properties	Base mud	H ₈ (10 ppm)	H ₁₀ (40 ppm)	H ₁₂ (60 ppm)
MS	Initial Gel	6.0	8.2	18.2	22.2
CM	Strengthen	5.0	6.0	17.2	26.3
MS	Final Gel	10.0	11.0	25.2	45.0
CM	Strengthen	10.0	13.2	26.0	46.2

Table 10. Radiation dose effect upon gel strength (lbf/100ft²) in radiation prepared samples.

System	Properties	Base mud	I ₄ (30 ppm)	I ₅ (30 ppm)	I ₆ (30 ppm)
MS	Initial Gel	6.0	16.1	34.0	40.2
CM	Strengthen	5.0	14.0	31.2	38.0
MS	Final Gel	10.0	23.3	57.5	80.2
CM	Strengthen	10.0	25.0	59.1	82.3

Table 11. Monomer concentration effect upon gel strength (lbf/100ft²) in radiation prepared samples.

System	Properties	Base mud	I ₇ (10 ppm)	I ₉ (40 ppm)	I ₁₀ (60 ppm)
MS	Initial Gel	6.0	10.0	20.0	38.2
CM	Strengthen	5.0	8.2	20.0	35.3
MS	Final Gel	10.0	13.0	30.2	69.0
CM	Strengthen	10.0	15.2	33.1	70.0

Table 12. Monomer concentration effect upon gel strength (lbf/100ft²) for XC and CMC.

Properties	Additives & System	Concentration			
		Base mud	10 ppm	40 ppm	60 ppm
Initial Gel Strength	CMC (Mixer)	6.0	9.1	19.2	31.3
	CMC (Cycle)	5.0	7.5	18.0	33.2
	XC (Mixer)	6.0	8.9	19.0	26.4
	XC (Cycle)	5.0	6.8	17.4	28.3
Final Gel Strength	CMC (Mixer)	10.0	12.2	27.9	53.0
	CMC (Cycle)	10.0	15.0	28.5	65.1
	XC (Mixer)	10.0	8.4	19.5	39.4
	XC (Cycle)	10.0	12.9	27.0	37.4

3.2 Swelling behavior of Chitosan N-Iso propylacrylamide Hydrogel

Swell test was done after extraction and purification of samples in ambient temperature. Swell ratio versus the reaction yield are shown in Figure 7. This curve relates to the samples from I₁ to I₆ and I₁₁. Yield path enhances swell ratio and

corresponds to the increasing of yields exponentially. Yield increasing enhances crosslinking reaction and produces a precursor that can absorb high amount of water. This property was observed only in samples made that used the radiation method. Because crosslinking density did not fully prevent water absorption, crosslinkings were increased to make stronger hydrogels. As the

Figure 7. Swelling ratio vs. reaction yield for radiation prepared samples (I_1 - I_6 and I_{11}).

Figure 8. Swelling ratio vs. monomer concentration for radiation prepared samples (I_6 - I_{10}).

result, crosslinking samples gained the property of water absorption. In the case of radiation dose increasing and reaching the crosslinking critical value, with the increase in radiation the adsorbent value decreased in the samples.

Figure 8 shows swell ratio versus monomer concentration for radiation prepared samples (I_6 - I_{10}). The reason for increasing swell ratio with N-Isopropylacrylamide concentration is the need for increase in monomers in order to change the grafting yield.

According to the above results, the hydrogel is a high absorbent and, in some cases, it can absorb up

to 20 times more than its weight.

In the next experiment, swell ratio versus crosslinking agent density are shown in Figure 9 for H_1 to H_4 samples. Swell ratio decreases with the increase in the amount of both crosslinking agents because of producing an impacted structure in order to crosslinking branches.

Figure 10 shows the swell ratio versus the monomer concentration for heating prepared samples (H_8 - H_{12} , and H_2).

Figure 9. a) Swelling ratio vs. formaldehyde density, and b) Swelling ratio vs. MBA density.

Figure 10. Swelling ratio vs. monomer concentration for heating prepared samples (H_8 - H_{12} , and H_2).

According to the condition of the experiments, swell ratio and grafting yield for samples using the radiation method are higher than the other sample ones. Also, with changing the conditions for heating prepared samples, it would be possible to

increase the parameters mentioned above. Crosslinking densities in samples made using the heating process are higher than ones in samples made using the radiation process, in which swell ratio decreased.

4. CONCLUSIONS

Hydrogels of N-Isopropylacrylamide and chitosan have been produced via thermal and radiation preparation processes to modify rheological properties of drilling muds. According to results of this paper, yield point and apparent viscosity increased significantly with a sharp slope during initial mixing time, while the mixing time had no significant effect on plastic viscosity. The effect of initial gel strength increased with the addition of polymers according to the following order classification: first radiation prepared hydrogels, then CMC and XC polymers, and, finally, thermal prepared hydrogels. As for the final gel strength, the order classification was as follows: radiation prepared hydrogels, CMC polymer, thermal prepared hydrogels, and, at last, XC polymer. In addition, XC, and CMC polymers in low concentrations and thermal and radiation prepared hydrogels in high concentrations had more considerable effects on rheological properties. Radiation prepared hydrogels showed more water absorbency than thermal prepared ones, probably due to low crosslinking density and monomer concentration present in the prepared hydrogels.

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