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Compatibility of Guar Gum-Based Fracturing Fluid and Breaker Due to Residue and Proppant Carrying Performance

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Abstract: Hydraulic fracturing is a method to improve reservoir permeability by injecting high-viscosity fluid (polymer) to allow fractures to occur in the formation and fill it with proppant. One factor that influences the success of hydraulic fracturing is the selection of fracturing fluid and its additives. A good fracturing fluid must have a high viscosity to conduct fractures and carry the proppant. In addition, the use of fracturing fluids containing polymers and crosslinkers is used to increase the viscosity, in order to be able to fracture reservoir rocks. However, the polymer contained in the fracturing fluid must be decomposed so as not to leave a residue in the reservoir that can cause clogging of the rock pores and reduce the permeability of the fracture. This research was conducted using a compatibility test between Guar gum-based fracturing fluid with various concentrations of borate crosslinker and two type of breaker. The compatibility tests include residue and proppant carrying performance. There are two types of breakers used in this research, oxidizer and encapsulated breaker. From the results of the analysis, it can be seen that the GF-1A fracturing fluid has the smallest residue of 0.887 gr and the GF-2C fracturing fluid has the best performance of carrying proppant of 0.00012 mm/s.

Keywords: Fracturing Fluid, Additives, Residue, Proppant Carrying Capacity

1. Introduction

Hydraulic Fracturing is one of the stimulation techniques that improve the productivity of low permeability oil and gas reservoirs. Hydraulic fracturing improves reservoir permeability by injecting high-viscosity fluid (polymer) to allow fractures to occur in the formation and fill it with proppant [1, 2]. A good fracturing fluid must have a high viscosity to conduct fractures and carry the proppant. However, the fracturing fluid must be cleaned up after the fracturing process is completed so that the fracturing fluid particles or materials do not clog the new pores which can result in decreasing permeability. Hence, the selection of fracturing fluid and additives become the defining factor of the hydraulic fracturing operation [2, 3].

There are two types of based fracturing fluid in a hydraulic fracturing operation, oil-based and water-based fracturing fluid. The water-based fracturing fluid contains a thickening agent, usually a polymer, and several additives such as crosslinker, buffer, breaker, and clay stabilizer. The common type of water-based fracturing fluid is Guar Gum [1-3]. Besides the price and availability [4], Guar Gum generates good rheology properties for a leak-off control and proppant carrying performance. The rheology can be reached by a low concentration of Guar Gum with the additive of crosslinker. Two types of crosslinkers widely used are metallic and boron crosslinkers. It can be used separately or in a mixture. The other factor that must be concerned is chemical breakage and cleanup characteristic to give high fracture conductivity. Gel Breaker is a chemical additive that reduces the viscosity of fracturing fluid by breaking long-chain molecules into shorter segments. There are two kinds of breakers that are commonly used, oxidizer and encapsulated gel breaker [2, 3, 5]. This paper will conduct a performance of borate as a crosslinker at various concentration added with two types of breakers in Guar gum, related to a produced residue that reflects the imperfect polymer break, and proppant carrying performance due to capability of fracturing fluid to bring proppant.

2. Literature Review

The type of guar gum fracturing fluid and its derivatives has the property of rheological proppant transport and control of leak-off. This rheology can be achieved at low guar gum concentrations with the addition of a crosslinker. There are two types of crosslinkers used, namely boron based and metallic crosslinks. The two types of crosslinks can be used separately or combination [3, 6].

In addition to the rheological property, an important fluid property is being able to break down and clean the polymer after the fracturing fluid reaches the desired depth layer, so that fracture conductivity can be achieved and reduce the plugging effect. Additives that can be used as polymer breakers and cleaners are called break gels or breakers. There are three types of gel breaks that are often used, including enzyme, oxidizer, and acid [1, 7]. The type of breaker oxidizer in the form of solid powder consists of two types, namely bromate and persulfate.

The base-gel fluid that functions as a base fluid with high viscosity is composed of potassium chloride, surfactant, clay stabilizer, gel stabilizer, bactericide, then the sensitivity of the polymer concentration (thickener) is adjusted by 35 ppt, 40 ppt, and 45 ppt. to get optimal properties.

The on-fly fluid consists of a cross-link/activator as a chemical catalyst that affects the speed of polymer activation (crown time) so that its viscosity increases to the desired viscosity at the specified time. A breaker as a chemical catalyst that is able to break down the polymer so that its viscosity decreases over time called break time. Buffer (pH control) as an additive to stabilize pH so that the fly-on fluid can work optimally. Crosslink sensitivity is 0.2%, 0.4%, and 0.6%. As for the size of the proppant are 16/20 mesh, 20/40 mesh and 30/50 mesh.

2.1. Residue

The residue is one of the factors that need to be considered in designing the type of fracturing fluid to be used. Currently, one of the most commonly used types of fracturing fluid is guar based. But in many cases, the use of guar will produce residues that can cause formation damage. According to Ming Hua, L. Y. 2016 [9, 10], particles in fracturing fluid residues generally measure about 74.77 μm which is greater when compared to the magnitude of the pore throat diameter which is about 0.04 - 2.34 μm. If the residue is left in the fracture, it can affect proppant conductivity.

Based on research conducted by Hai, Q et. al. 2018 [5, 7] regarding success in the application of clean fracturing fluid replacing guar-based fracturing fluid. The results of the test in the laboratory show that after gel-breaking, the residue produced when using guar-based fluid is greater than clean-based fluid. The amount of residue produced will have an impact on the damage to fracture conductivity and matrix permeability [8].

This test calculates the residue caused by mixing the fracturing fluid with the breaker, so that it can be seen the ability of the breaker to break down the polymer contained in the fracturing fluid. This test is done by mixing the fracturing fluid with a certain composition with various types of breakers with a certain concentration as well. The test method is by inserting a number of fracturing fluid samples into a thermostatic water bath at a temperature of 80C and adding a breaker. After the fluid break, enter the fluid mixture into the centrifuge and rotate it at a speed of 3000 r/min for 30 minutes. Observe the presence of sediment that occurs and separate the precipitate, then dry it in the oven and weigh the residue.

2.2. Proppant Carrying Performance

In addition to the residue, proppant carrying performance is also a factor to consider in designing the type of fracturing fluid. One of the success parameters of the hydraulic fracturing process is when proppant can be delivered up to the formation. According to Zhao, G. 2018 [11] the parameter that needs to be evaluated when designing proppant carrying performance is settling velocity. The standard of proppant carrying performance based on Hai, Q. 2018 [5] is $8x10^{-3}$ mm/s.

This test will record the deposition time of the proppant in the fracturing fluid with a sensitivity that has been made previously. This test is done by mixing proppant with a certain mesh and a certain volume (maximum 40% sand ratio - volume ratio) into the fracturing fluid solution. Then the mixture is stirred at a certain speed and put into a measuring cup. Then measure the volume of proppant that settles against the overnight time of 24 and 48 hours.

3. Materials and Methods

3.1. Materials and Equipment

Guar Gum-based with value 40 pptg/1000 mL is a system of fracturing fluid used in this research. This fracturing fluid consists of Guar Gum, clay stabilizer, bactericide, surfactant, mutual solvent, and crosslinker, as shows in Table 1. A borate crosslinker was added to the formula using a concentration of 0.2%, 0.4%, and 0.6%. The additive consists of two types of breakers; oxidizer and encapsulated breaker. The compositions of the additives show in Table 2. The six formula of guar gum fracturing fluid is shown in Table 3, where 20/40 mesh of proppant is used in proppant carrying performance. The equipment used in this experiment are HP/HT rheometer, agitator, centrifuge, filter press, oven, timer, and scale.

Table 1. *Compositions of fracturing fluid.*

Chemical	Laboratory Concentration
Gelling Agent (Guar Gum)	4.8 gr
KCl Clay Stabilizer	20 gr
Bactericide	1 mL
Surfactant	2 mL
Borate Crosslinker	0.2; 0.4; and 0.6 mL

Table 2. *Additive compositions.*

Additive	Concentration
Oxidizer Gel Breaker	0.4 mL
Encapsulated Gel Breaker	0.24 gr

Table 3. *The formula of guar gum fracturing fluid.*

No	Fluid Types	Formula
1	GF-1A	4.8 gr gelling agent + 0.2 gr crosslinker + 20 gr KCl + 1 mL bactericide + 2 mL surfactant + 25 mL mutual solvent + 0.4 mL oxidizer breaker
2	GF-1B	4.8 gr gelling agent + 0.4 gr crosslinker + 20 gr KCl + 1 mL bactericide + 2 mL surfactant + 25 mL mutual solvent + 0.4 mL oxidizer breaker
3	GF-1C	4.8 gr gelling agent + 0.6 gr crosslinker + 20 gr KCl + 1 mL bactericide + 2 mL surfactant + 25 mL mutual solvent + 0.4 mL oxidizer breaker
4	GF-2A	4.8 gr gelling agent + 0.2 gr crosslinker + 20 gr KCl + 1 mL bactericide + 2 mL surfactant + 25 mL mutual solvent + 0.24 gr encapsulated breaker
5	GF-2B	4.8 gr gelling agent + 0.4 gr crosslinker + 20 gr KCl + 1 mL bactericide + 2 mL surfactant + 25 mL mutual solvent + 0.24 gr encapsulated breaker
6	GF-2C	4.8 gr gelling agent + 0.6 gr crosslinker + 20 gr KCl + 1 mL bactericide + 2 mL surfactant + 25 mL mutual solvent + 0.24 gr encapsulated breaker

3.2. Fluid Preparation

The based gel is prepared with 4.8 gr of guar gum added with 1000 mL of tap water. Add the other chemical; clay stabilizer, bactericide, surfactant, and mutual solvent. The fluid was mixed using an agitator at 1000 RPM. Check the viscosity of the base gel at 300 rpm with a viscosity range of 35 - 50 cp. Recommended viscosity of 50 cP to prevent screen out [4].

In the residue test, take 100 mL of the gel-based solution then add the crosslinker and breaker according to the desired formula mentioned above. Allow the solution to break in the water bath. After a complete break, put the solution into a centrifuge tube and rotate it for 30 minutes at a speed of 3000 RPM. Filter the residue and weigh the wet weight, the residue is then dried and the dry weight is weighed.

In the proppant carrying performance test, a 200 mL-based gel fracturing fluid solution is needed, then add a crosslinker and a breaker according to the desired formula. Mix proppant with a size of 20/40 mesh with a ratio of 40% by volume. Then observe and record the rate of deposition of the proppant.

Table 4. *Rheology of based gel fracturing fluid.*

The Concentration of Base Gel	Viscosity Room Temperature (cP) at a Certain Shear Rate (RPM)						Power Law		SG
	600	300	200	100	6	3	n'	k'	
40 pptg	48	37	30	20	4	2	0,94265	0,00114	1

4. Results and Discussion

4.1. Fracturing Fluid Rheology Test

Table 4, shows the results of viscosity measurements at 40 system-based gel fracturing fluid at a certain shear rate. The viscosity of the based gel is 37 at 300 RPM and it fulfills the standard. After viscosity measurement, the fluid is mixed with a crosslinker, and measure the viscosity using HP/HT rheometer. By using HP/HT rheometer [3, 12], the viscosity of the cross-linked fluid can be determined at a specified shear rate at a specified temperature. Figure 1 shows the viscosity of fracturing fluid. The viscosity of the fracturing fluid will decrease with time due to the influence of temperature. From this graph, it can be found the viscosity of the fracturing fluid at the end of the injection. From the plotting results, the viscosity of the fracturing fluid is around 400 cP at injection time. Hence, it is compatible when used because the viscosity of the fracturing fluid is above 300 cP which is the standard of the service company.

From Figure 2, it can be seen that power law index (n') and consistency index (k') are the behavior of the power law fluid with respect to temperature, time, and shear rate. From the test of forty (40) systems fracturing fluid, the crown time for 12 seconds, the release time for 15 seconds, and the break time of about 120 minutes to produce a fluid with a viscosity of 37 cP at 180°F.

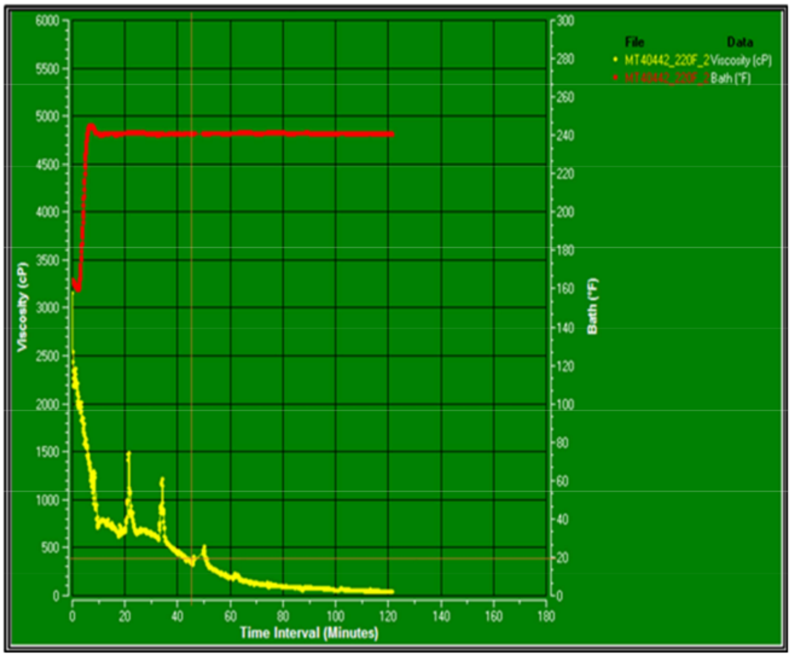

Figure 1. *Viscosity of cross-linked fluid 40 pptg system viscometer chandler HPHT.*

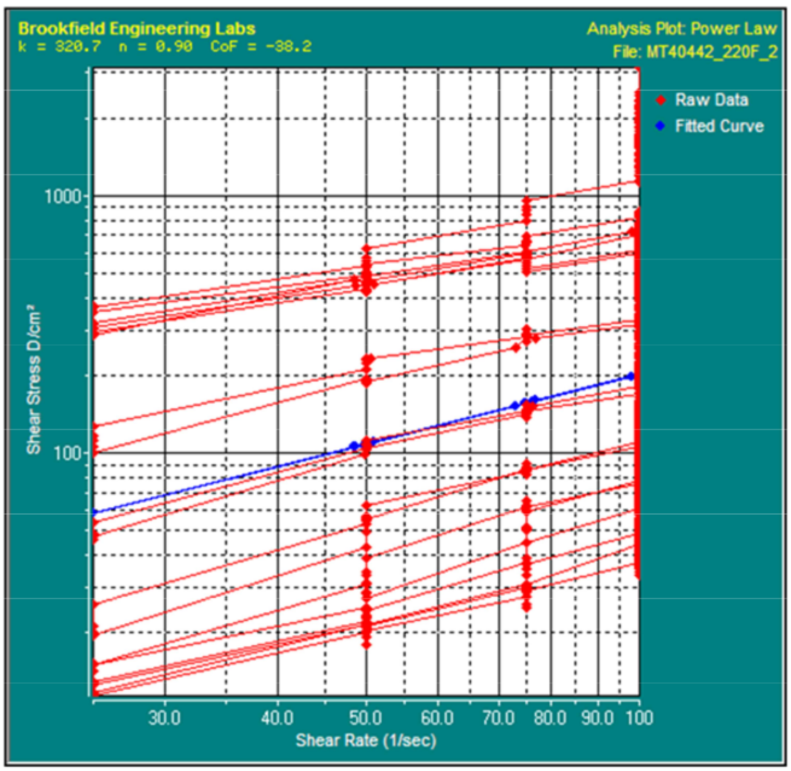

Figure 2. *Power law index (n') and consistency index (k') cross-linked fluid of 40 system.*

4.2. Residue Test Results

Figure 3 and Figure 4, shows the separation of residue from the fracturing fluid after it breaks completely. Figure 3 shows the separation process using measuring cup after its keep at room temperature. Figure 4 shows the separation after the fracturing fluid was rotated in the centrifuge. After separation was completed, the residue was filtered by a filter press, and dried using oven. The weighing process is done at wet and dry conditions. Table 5 shows the smallest dry residue produced by fluid type GF-1A of 0.887 gr, but in wet condition type GF-1B has the smallest residue. The highest residue was found in fluid type GF-2C for both wet and dry conditions, 3.96 gr in wet condition and 0.985 gr in dry condition. In general, the residue produced by fluid type GF-1A is less than fluid type GF-1B. The higher the crosslink concentration, the more residues are produced. It can be concluded that 40 system guar gum-based fracturing fluid was compatible with 0.2% of borate crosslinker and 0.4% of oxidizer breaker.

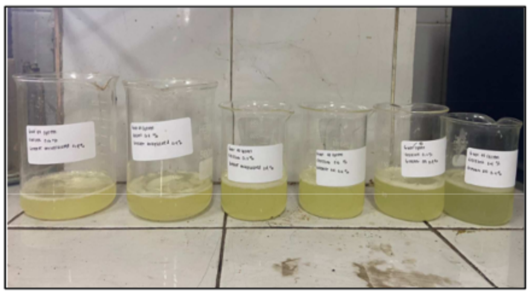

Figure 3. *Aged fracturing fluid until breakage.*

Figure 4. *Fracturing fluid after centrifuge.*

Table 5. *Result of residue at various fluid types.*

No.	Fluid Types	The residue (gr)	
		Wet residue, gr	Dry residue, gr
1	GF-1A	3.84	0.887
2	GF-1B	3.43	0.893
3	GF-1C	3.71	0.894
4	GF-2A	3.81	0.920
5	GF-2B	3.47	0.910
6	GF-2C	3.96	0.985

4.3. Proppant Carrying Performance

Figure 5. *Proppant carrying performance of fracturing fluid.*

Table 6. *Proppant carrying performance for several fluid types of fracturing fluid formula.*

No.	Fluid Types	Time (s)	PCP (mm/s)
1	GF-1A	7200	0.00799
2	GF-1B	21600	0.00046
3	GF-1C	21600	0.00023
4	GF-2A	21600	0.00139
5	GF-2B	21600	0.00035
6	GF-2C	21600	0.00012

Proppant carrying performance was tested by mixing the fracturing fluid and 20/40 mesh proppant 40% by volume. The solution was allowed to stand and the rate of proppant deposition was observed, as shown in Figure 5. The different fluid type has different precipitation time, fluid type GF-1A has the fastest precipitation time, 7200 s, with a precipitation rate of 0.00799 mm/s. The other fluid types have the same precipitation time, 21600 s, but the smallest precipitation time rate is 0.00012 mm/s at fluid type GF-2C. Based on Driweesh, S. M. et al. [3] and Ming, H. et al. [9, 10], the sand natural setting rate is less than 8×10^{-3} mm/s in the static sand suspending experiments for fracturing fluid, the fluid types of GF-1B, GF-1C, GF-2B, and GF-2C have good enough performance.

Table 6, also shows that the higher the crosslink concentration, the better the carrying performance. Generally, fluid type GF-1B has better performance than fluid type GF-1A. It can be said that encapsulated breaker has better performance than the oxidizer breaker.

5. Conclusions

Based on the results of analysis and discussion that has been thoroughly executed, the conclusions can be withdrawal as follows:

1) Forty (40) system of guar gum-based fracturing fluid has satisfied the standard viscosity of 37 cP at 300 RPM.
2) The smallest residue of 0.887 gr is produced by GF-1A with composition 4.8 gr gelling agent + 0.2 gr crosslinker + 20 g KCl + 1 mL bactericide + 2 mL surfactant + 25 mL mutual solvent + 0.4 mL oxidizer breaker.
3) The best proppant carrying performance of 1.2×10^{-4} is GF-2C fluid type with composition 4.8 gr gelling agent + 0.6 gr crosslinker + 20 gr KCl + 1 mL bactericide + 2 mL surfactant + 25 mL mutual solvent + 0.24 gr encapsulated breaker.
4) The fluid types of GF-1B, GF-1C, GF-2B, and GF-2C have good enough performance and fulfill the standard required.

6. Recommendation

This study observes the effect of crosslinker concentration on the resulting residue, as well as the ability of the fracturing fluid to carry proppant. For further research, it is possible to conduct research on the effect of breaker concentration on the resulting residue up to the estimation of the decrease in fracture permeability.

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