EXPERIMENTAL STUDY OF POLYMER AND SURFACTANT CONCENTRATION EFFECT ON YIELD AND STABILITY OF APHRON FLUIDS

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ABSTRACT: *Colloidal Gas Aphron (CGA) drilling fluid is a micro bubble system wherein the bubbles are multilayer and are created by mixing a certain concentration of polymer and surfactant in an aqueous medium. The function of surfactant in this system is to perform surface tension for containing the Aphron as it is formed and creating multilayer bubble wall .Polymer is used as a viscosity agent and stabilizing the Aphron. By entering the air into system which is a consequence of adding surfactant to viscous fluid system, a drilling fluid system will be prepared with a lower density than other typical drilling fluids. CGA drilling fluid system is a relatively new approach in oil drilling and completion operations especially in depleted reservoirs which have low pore pressure. By using Aphron drilling fluids, lost circulation to formation will be minimized and by providing a flexible seal on formation openings and micro fractures, formation damage will be neglected. The advantage of Aphron system is that Aphrons can be removed easily after starting production. As the Aphrons are supposed to have a sufficient stability for sealing the formation pores, hence having a good stability and longevity are important factors for this fluid system. An important parameter affects Aphron stability is type and concentration of surfactant and polymer. In this study the effect of polymer and surfactant concentration on Aphron stability and longevity is investigated. In addition in different concentrations of polymer and surfactant, yield and bubble's percent of Aphron system are measured to recognize how polymer and surfactant concentrations can control yield and entrained air percent to the Aphron systems. The output of this study can be helpful in designing stable Aphron system.*

Keywords: Colloidal Gas Aphron, Stability, Yield, Drainage test, Polymer, Surfactant

1-Introduction

Many gas and oil reservoirs are spending their mature period which due to production, their pressure is drawn down. As these formations generally are located between intervals with higher pore pressure, during drilling through these formations using regular drilling fluids, due to high differential pressure creation in low pressure interval, a considerable volume of drilling fluid invades to the formation and causes formation damage [1]. In high invasion rates especially in formations with higher permeability, differential sticking may occur. Aphron drilling fluid system is a relatively new approach in oil drilling and completion operations in order to reduce formation damage in vertical and horizontal wells especially for depleted wells, where overbalance drilling occasion high invasion or may fracture the formation by forcing the drilling fluid into the formation and causing formation damage. Aphron drilling fluids have been successfully used in oilfields to drill through depleted reservoirs or formations which had experienced problems such as uncontrollable losses [2]. In addition another advantage of Aphron drilling fluid system is that the Aphron can eliminate differential sticking by improving near wellbore pressure drop [3]. Aphron drilling fluids by providing a flexible seal on formation openings and micro fractures can balance the differential pressure between the formation and borehole. The main materials in Aphron formulation are polymer and surfactant. A polymer need to be considered in the formulation of Aphron as a viscosifire and stabilizer which controls the rheological properties and helps in stabilization of bubbles by limiting the growth of bubble size over time [4]. Surfactant is added for reducing surface tension and micro bubble generation.

Aphron bubble sizes are approximately 10 to 100 microns in diameter. Like regular foams, Colloidal Gas Aphrons are generally comprised of an air core but unlike foams, CGA's have a thin aqueous protective shell. CGA is comprised of an inner shell as well as an outer shell. Structure of the Aphron on a molecular level is shown in figure1.
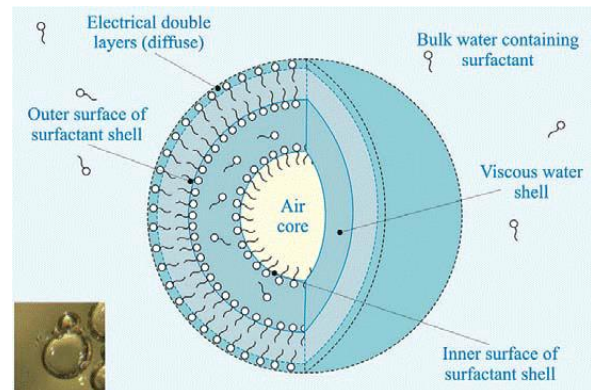

Figure 1- Structure of the Aphron proposed by Sebba

The two shells are separated from each other by a viscous water phase. The inner shell is contained surfactant molecules which are hydrophobic inwards. This layer supports and separates the air core from the viscous layer. The outer shell which supports the viscous layer is hydrophobic outwards. As far as this bubble is in contact with the bulk water there is another layer in which the surfactant molecules are hydrophobic inwards. This indicates that there is a region between the Aphron outer shell and the bulk phase layer where a hydrophobic core will be adhered to the Aphron [5]. Therefore as most of the entrained air into system is encapsulated in Aphron shell, Aphron drilling fluids unlike aerated muds will not cause corrosion the drill string.[6]

Aphron stability is determined by the rate of mass transfer between the viscous water layer and the bulk phase. This mass transfer is known as the Marangoni effect [7]. The

Marangoni effect (also called the Gibbs–Marangoni effect) is the mass transfer along an interface between two fluids due to surface tension gradient. If the viscous layer's mass transfer rate is high, Aphrons will lost its stability and longevity. Therefore a viscous fluid is used to have suitable viscosity to minimize the Marangoni effect. Furthermore the concentration of surfactant and polymer plays an important role on mass transfer rate between viscous shell and bulk phase. By viscosifying the water by adding a polymer the rate of mass transfer will reduce to a point where the Aphron structure is stabilized [8]. The other controller factor for CGA stability is the surfactant molecules transfer rate between the viscous water shell and the bulk phase because of gravity drainage and temperature gradients which Marangoni effect counteracts this deformation. The viscosified shell can help to minimize the surfactant molecules transfer rate. Usually for adjusting the shell viscosity a biopolymer is added to fluid system [9-10].

Already the effect of polymer and surfactant on Aphron bubble size is investigated by Shivhare which is mentioned that surfactant concentration has no significant effect on bubble size and by increasing polymer concentration bubble size will decrease in addition by increasing mixing rpm the average bubble size will decrease [11].

2- MATERIAL AND METHODS
2-1-Material
In this study, AS surfactant and AG polymer were used for investigation of yield and stability of Aphron. The used polymer is a high molecular weight natural biopolymer which provides viscosity and rheology control even in a wide range of brines, drilling and fracturing fluids. A schematic of this polymer chemical structure is shown in figure 2. It is a Hetropolysacharide associated with a primary structure which is consist of repetitive Pentasaccharide units and are formed by two units of glucose, mannose units and one unit of glucuronic acid (a carboxylic acid similar to glucose). It is considered non-hazardous and suitable for use in environmentally sensitive locations and applications. This polymer is a highly dispersible powder which can be used in oil and water based drilling fluids and provides adequate Cutting transport capacity. The solutions which are made by AS polymer have a non-Newtonian rheology behavior and by increasing shear rate, apparent viscosity decreases. In addition these polymer solutions create an initial resistant to flow (yield stress) which must be overcome to flow. For Aphron systems in this study, AS polymer is used in different concentrations (1 lb/bbl,1.5 lb/bbl,2 lb/bbl and 3 lb/bbl) to stabilize the Aphron bubbles and Aphron's longevity. It is desired to find out which concentration in terms of stabilizing the Aphron system is suitable .

As an Aphron generator, a surfactant will be added to the fluid system. Labour has used three types of surfactants (anionic, cationic and non-ionic surfactants) for Aphron generation and founds that anionic surfactants are suitable for Aphron generation [12]. Hence in this study an anionic surfactant (AG) is used in 4 concentrations (0.25 lb/bbl, 0.5 lb/bbl, 0.75 lb/bbl and 1 lb/bbl) which these concentrations are above CMC. The surfactant formula is C12H25SO4N and consists of an organosulfate and a 12-carbon tail attached to a sulfate group. The chemical structure of this surfactant is shown in figure 3.
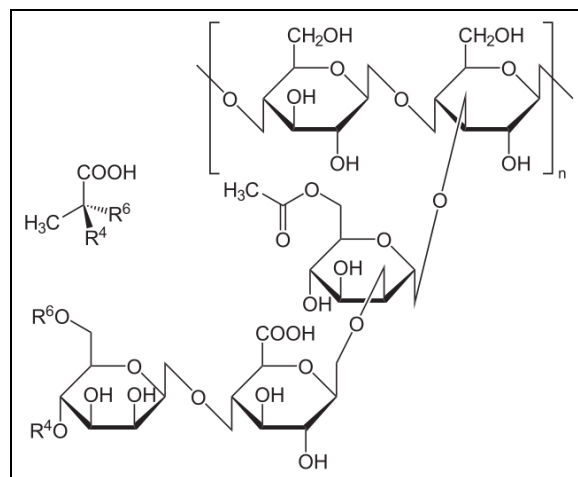

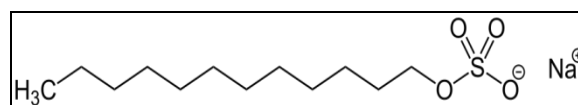**Figure 2-Chemical structure of AS Polymer**

Figure 3- Chemical structure of AG Surfactant

An important property of surfactant is its critical micelle concentration (CMC). Surfactants that are used for Aphrons generation must have a concentration above the CMC [13]. Using the surfactant concentrations below the CMC will not form a stable Aphron dispersion and at concentrations above the CMC, addition of surfactant has a negligible effect, because the supernumerary surfactant molecules will remain suspended in the fluid film surrounding the CGAs[14] .

Through this study, Drainage rate for these concentrations of polymer and surfactant is recorded. Furthermore the effect of increase of polymer concentration on Aphron generated volume (yield of Aphron) is investigated.

2-2- Experimental Procedure
The experimental procedure in this study consists of three main steps:
2-2-1- Preparation of the Aphronized fluids.
2-2-2- Measurement of the yield of base and Aphronized fluid and entrained air percent.
2-2-3- Measurement of the drained viscous layer volume of Aphron during the time (static drainage test).

2-2-1-preparation of the testing fluids
Fresh water was used for preparing the base fluid. The base fluid was generated by mixing the different concentrations of polymer (1 lb/bbl, 1.5 lb/bbl ,2 lb/bbl and 3 lb/bbl) in 350 cc fresh water. The Hamilton-Beach overhead malt mixer was used to mix the fluid at 10,000 rpm for 20 minutes. A picture of Hamilton beach mixer is shown in figure 4.

Figure 4- Hamilton Beach Mixer

Prepared base fluid was allowed to cool down to room temperature, between 20 and 24°C. This was done to prevent Aphrons against destabilization at high temperatures. The Aphron system is expected to become destablized at temperatures more than 40°C [15]. For Aphron generation, the base fluids and surfactant were mixed for 5 minutes at a speed of 8000 rpm to make a uniform distribution of micro bubbles through the liquid phase. For this study four concentrations of AG surfactant were used (0.25 lb/bbl ,0.5 lb/bbl ,0.75 lb/bbl,1 lb/bbl). Hence 16 Aphron fluid samples were prepared which were consisting of different concentration of AG and AS .

2-2-2- Measurement of yield of base and Aphronized fluid and entrained air percent

The term yield is used for evaluation how much is the Aphronized fluid volume after Aphron generation. Surfactant and polymer concentrations have a significant effect on the Aphronized fluid generated volume. In fact, yield of Aphronized fluid is related to entrained air percent in the base fluid and by increasing air percentage, the yield will increase. To investigate how concentration of polymer and surfactant change Aphron's yield, all samples volume recorded after Aphron generation using a large graduated cylinder and by means of their density measurement, this amount correlated to a more accurate value. In addition entrained air percent has been calculated by means of calculation of base fluid density before and after Aphron generation.

2-2-3- Measurement of the drained viscous layer volume of Aphron during time (Static drainage test)

Stability of CGAs plays an important role for application of micro bubbles for effective blocking ability during drilling operation. Stability of CGAs is investigated by analyzing drainage rate measurement under static conditions during time. All the experiments are done under room condition. To conduct static drainage tests, initially, 100 ml of the freshly prepared CGA based fluid is poured into a graduated cylinder. By passage of the time, base fluid (which forms Aphron's viscous layer) will drain out of the CGAs structure and drained volume will form at the bottom of the cylinder. The height of the drained volume is recorded during the time. A picture of sample during drainage test is shown in figure 5.
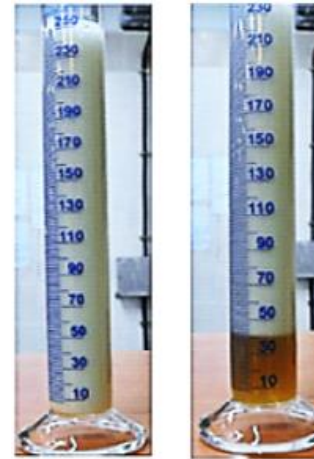

Figure 5- Samples before and after drainage test

In this study the results are recorded at 4, 12 and 24 hours' time intervals. Draining of Aphron's viscous layer leads to thinning viscous layer of CGAs, growth of Aphron bubble size and finally Aphron instability. The longer the CGA resists to drain viscous layer in other word less drained viscous layer, the more stable the CGA is.

3-RESULTS AND DISCUSSION

3-1- Yield and entrained air percent

The variation of the yield with polymer and surfactant concentration is shown in Figures 6 and 7. As it is shown in figure 6, by increasing surfactant concentration from 0.25 lb/bbl to 1 lb/bbl for each constant polymer concentration, yield of Aphron increases. The reason is increasing in concentration of surfactant leads to decrease surface and
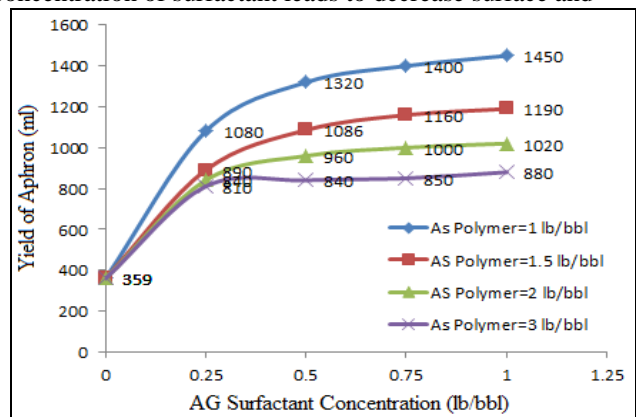

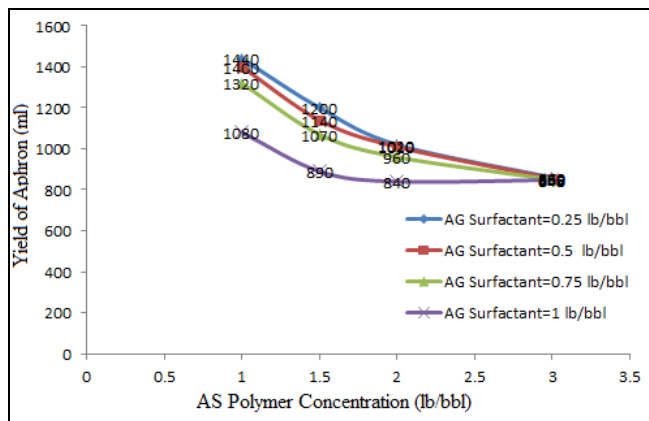**Figure 6- Effect of Polymer Concentration on Yield of Aphron**

Figure 7-Figure 7_Effect of Polymer Concentration on Yield of Aphron

Figure 8- Entried air Percent (%) After Aphron Generation

3-2- Static Drainage test

Interfacial tension more and allows more air to enter to the base fluid. Contrariwise increasing polymer concentration leads to reduce the yield. In fact by increasing polymer concentration, as viscosity is increased, lead to be a barrier to enter more air into system. Therefore Aphron systems with higher concentration of polymer can involve less air into their base fluid. As it is shown in Fig 6 for higher polymer concentration, by increasing surfactant, the yield variation rate will decrease. based on Fig 6 after concentration of 2 lb/bbl polymer, the yield variation rate start to become smooth and for concentration of 3 lb/bbl for all surfactant concentrations, the yield values have a very close together volume and varied between 840 and 880 and shown a smooth variation curve.

Based on the results which are shown in fig 7, yield of Aphron using surfactant concentrations 0.75 and 1 lb/bbl for polymer concentration between 1.5 to 2 lb/bbl are very close together and after concentration of 2 lb/bbl of polymer, variation curves for surfactant concentration of 0.75 lb/bbl is matched completely on variation curve for surfactant 1 lb/bbl. By increasing polymer concentration from 2 lb/bbl, the obtained yield using all of surfactant concentration are going to be closed to each other. As a consequence, the polymer concentration is a controller factor for yield of Aphron and by increasing polymer concentration, rate of yield increment will decrease. Therefor in concentrations of above 2 lb/bbl of polymer, the Aphron for all surfactant concentrations, in terms of volume variations showed a more stable behavior .

The effect of polymer & surfactant concentration on entrained air percent is shown in Fig 8.

As is shown for all surfactant concentration, the solutions which have more polymer concentration resist more to enter the air into the solution. For concentration of 1 lb/bbl of polymer by increasing surfactant from 0.75 to 1,the curve shoes a decrease even less than polymer concentration of 1.5 which it may be due to laboratory measurement errors. The most stable behavior is for concentrations of 2 and 3 of polymer so these concentrations can be suitable choices.
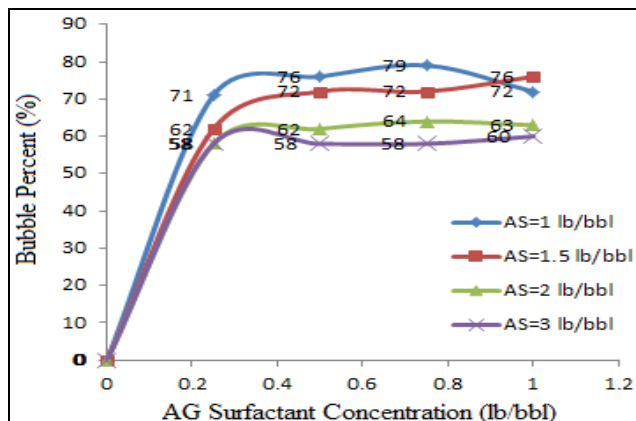
Initial viscous layer volume which is equal to the volume of prepared solution of water and polymer for each of 16 samples are recorded in table 1. For a constant surfactant concentration by increasing polymer concentration, the amount of viscous layer volume which surrounds air is increased which means by increasing polymer concentration, the viscous layer thickness will increase and leads to enhance Aphron stability and longevity. This effect is clearly visible in tables 2-4. After 4 hours, the drained viscous volume for lower polymer concentration is maximum, by increasing polymer concentration to 2, the drained percent changes to 0. After 12 hours for polymer concentration of 1 almost all the viscous layer drained and Aphron structure was completely destroyed. Polymer concentration of 1.5 shows an unstable Aphron too but for polymer concentration above 2, almost a stable Aphron will form which the concentration of 3 formed the most stable Aphron. Hence the concentration of polymer controls the mass transfer rate between viscous shell and bulk space and is the more important controller factor.As a consequence by increasing polymer concentration, mass transfer rate will decrease. The most stable Aphron is created by polymer concentration of 3 lb/bbl with a high longevity more than 24 hours.

Table 1- Initial Viscous layer volume (ml)

		Surfactant Concentration (lb/bbl)			
		0.25	0.5	0.75	1
Polymer Concentration (lb/bbl)	1	30	24	23	28
	1.5	39	36	29	25
	2	44	37	35	35
	3	46	42	43	39

Table 2-Percent of drained viscos layer (%) after 4 hours

		Surfactant Concentration (lb/bbl)			
		0.25	0.5	0.75	1
Polymer Concentration (lb/bbl)	1	53	79	74	57
	1.5	13	11	13	8
	2	0	0	0	0
	3	0	0	0	0

Table 3- Percent of drained viscous layer (%) after 12 hours

		Surfactant Concentration (lb/bbl)			
		0.25	0.5	0.75	1
Polymer Concentration (lb/bbl)	1	96	100	100	98
	1.5	59	55	72	80
	2	6	14	7	20
	3	0	0	0	0

Table 4- Percent of drained viscous layer (%) after 24 hours

		Surfactant Concentration (lb/bbl)			
		0.25	0.5	0.75	1
Polymer Concentration (lb/bbl)	1	100	100	100	100
	1.5	97	93	100	100
	2	45	57	60	63
	3	7	4	6	5

4-CONCLUSION

- Polymer and surfactant concentrations are important factors in Aphron stability and yield. By increasing polymer concentration the stability of Aphron increases. Hence polymer concentration is a major controller parameter to minimize Marangoni effect.
- Increasing polymer concentration is a barrier and controller factor against increase in yield of Aphron.
- Most important factor on Aphron stability is Polymer concentration and the polymer concentrations more than 2 lb/bbl will form a stable Aphron.
- By increasing surfactant concentration for each constant polymer concentration, the entrained air percent to the system increases and as a consequence lead to increase the yield of Aphron.
- Lower polymer concentrations allow more air to be entered to system.

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