Optimization of the Rheological Properties of Colloidal Gas Aphron (CGA) Based Drilling Fluid to increase the penetration rate

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Abstract: Aphrons are colloidal dispersions of micro-bubbles with diameter ranging from 10 to 100 µm. An aphron is made up of a core, which is often spherical of an internal phase encapsulated in a thin shell. In the case of a gaseous core, this structure is called colloidal gas aphron (CAG's). A proper designed drilling fluid is highly desired to improve the rate of penetration and at the same time be effective for depleted and high permeability reservoirs. In this work, we have prepared aphron based drilling fluids by using cationic and anionic surfactants and various tests as mud density, rheological and filtration characteristics were carried out on the developed apron based drilling fluids. It was observed that by using aphron based fluid, with an increase in the mud density, apparent viscosity, yield point, and decrease in plastic viscosity of the drilling fluid significantly improved the penetration rate. Further it has been observed that the cationic aphron based fluid shows better results in terms of rheology, filtration loss and stability. This study would be effectively applicable in the field of drilling fluid technology with increase the rate of penetration saving both time and cost.

Keywords: aphron, mud density, rheological characteristics, rate of penetration.

I. INTRODUCTION:

The reduction in a bit's penetration rate with increasing depth of hole has been the subject of many investigations. The factors which influences ROP, can be classified in two main groups: *i)* Controllable Factors, and *ii)* Environmental Factors. The controllable factors can be altered more easily than environmental factors. Because of economical and geological conditions, the variation of environmental factors is impractical or expensive. A number of factors hint at the complexity of the bit/rock interaction, something which is compounded by interdependence and nonlinearity in some of these effects. Since mud properties, such as its type, density, viscosity, etc, are all dependent on formation type and pressure. Hence, mud properties are included in "Environmental Factors". [1]

The rate of penetration achieved with the bit as well as the rate of bit wear, has an obvious and direct bearing on the cost per foot drilled. The most important variables affecting penetration rate that have been identified and studied includes bit type and its hydraulics, along-with its relation with formation characteristic and drilling fluid properties. [2]

The properties of the drilling fluid reported to affect the penetration rate include (i) density, (ii) rheological flow properties, (iii) filtration characteristics, (iv) solids content and size distribution, and (v) chemical composition. Penetration rate tends to decrease with increasing fluid density, viscosity, and solids content, and tends to increase with increasing filtration rate. The density, solids content, and filtration characteristics of drilling mud are necessary control the pressure differential across the zone of crushed rock beneath the bit. The fluid viscosity controls the parasitic frictional losses in the drill string and thus, the hydraulic energy available at the bit jets for cleaning. There is also experimental evidence that increasing viscosity reduces penetration rate even when the bit is perfectly clean. The chemical composition of the fluid has an effect on penetration rate, such that the hydration rate and bit balling tendency of some clays are affected by the chemical composition of the fluid.

Aphron based drilling fluid:

Aphron based drilling fluids are highly shear thinning water-based fluids containing stabilized air-filled bubbles (aphrons). Aphrons are colloidal dispersions of micro-bubbles with diameters ranging from 10 to 100 µm. An aphron is made up of a core, which is often spherical of an internal phase encapsulated in a thin shell. In the case of a gaseous core, this structure is called colloidal gas aphron [3]. Likewise, when the internal core is a liquid (normally oil) it is called colloidal liquid aphron [4]. Finally, aphrons with cores formed of a water-in-oil emulsion are called colloidal emulsion aphrons [5].

The potential of aphrons as components of drilling fluids rests in-their ability to form a solid free, tough, and elastic internal bridge in pore networks or fractures to minimize deep invasion by means of air micro-bubbles. The use of CGA's as a drilling/completion fluid presents several advantages as high carrying capacity, minimum amount of fluid placed in the formation, and excellent fluid recovery after treatment. [6]
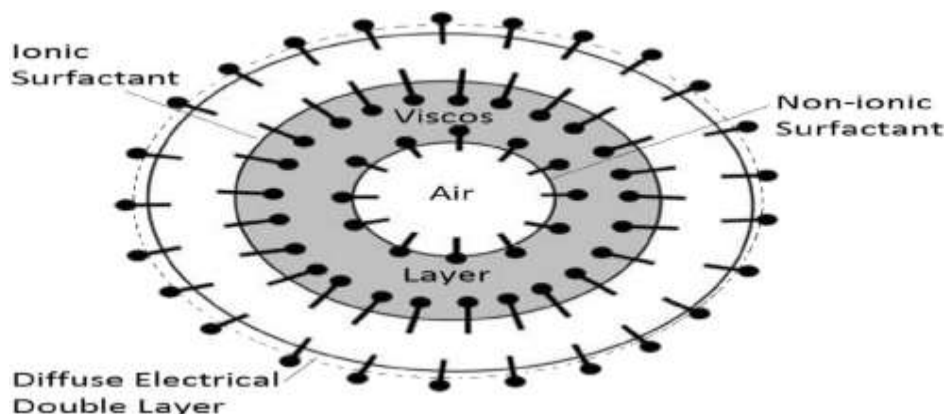
Figure 1: Aphron Structure (Sebba's Suggestion)

Unlike conventional foam bubbles, aphrons have the structure of ''one core, two layer, and three membranes''. The gas core of aphron is encapsulated by an aqueous protective shell. This tough, impermeable shell helps to prevent leakage of air from the core, and allows the aphrons to survive downhole pressures. In fact, the shell is surfactant tri-layer. The outer surfactant layer is thought to be hydrophilic, making the aphrons compatible with the surrounding water-based fluid, and produces an effective barrier against coalescence with adjacent aphrons. So, they show little affinity for each other. However, the aphrons can attract one another to form complex aggregates, which behave in the same manner as the individual aphron.[7] In contrast to conventional bubbles, which do not survive long past a few hundred psi, aphrons have been found to survive compression to at least 4000 psig for significant periods of time.

II. METHODOLOGY

Potassium chloride (KCl) was used for the preparation of base fluid with the primary purpose of shale inhibition as potassium chloride is very effective stabilizing agent in shale sensitive formation [8]. After that weighed amount of xanthum gum was added to this to make the desired weight percentage. Xanthum gum was used after potassium chloride as it had been observed, if xanthum was used before potassium chloride the viscosity of the solution increases and then it inhibits the solubility of potassium chloride. Then the mixture was transferred to a conical flask and it was stirred for 10 minutes in the Hamilton mixer at low speed for proper mixing. After proper mixing was achieved carboxy methyl cellulose (CMC) was mixed in the solution in a proper calculated percentage. Care was taken while mixing CMC as it was observed that too fast mixing caused formation of solid crystals in the solution, which in turn hampered proper mixing of the solution. Finally, the rest of the chemicals (calcium carbonate and starch cellulose, as mentioned in the table 2) were mixed in the solution with appropriate precaution and proper weight percentage. Then it was subjected to the Hamilton mixer for 30 more minutes at high speed for achieving proper mixture without formation of solid crystals.

Apparent viscosity, yield point, initial gel strength, 10 minutes' gel strength, plastic viscosity, filtration loss, mud density was calculated with the help of fan VG meter, filter press and mud balance.

After a stable base fluid was prepared, next step was preparation of aphronized fluid. For that purpose, two different types of surfactants were used:

1. Cetrimonium bromide [$(C_{16}H_{33})$ $N(CH_3)_3$] Br: Cationic Surfactant

2. Sodium dodecyl sulfate $CH_3(CH_2)_{11}SO_4Na$: Anionic Surfactant

Cetrimonium bromide was added to the base fluid and then mixed properly for around 30-45 minutes in the Hamilton mixture and thus, Aphron based fluid was prepared. The sample was then transferred for different tests for determination of rheology and other purposes. Then Sodium Dodecyl sulfate was added in similar manner and then the sample was transferred for different test for determination of rheology and other purposes.

III. RESULTS AND DISCUSSIONS

1. Test Conducted for Stable Base Fluid using different concentrations of Polymers:

SAMPLES	WATER (ml)	KCL (wt%)	XANTHUM GUM	XANTHUM GUM	CMC (wt%)	STARCH (wt%)	CALCIUM CARBONATE

		(wt%)	(MORE VISCOUS) (wt%)			(wt%)
1	450	3%	0.4%		0.4%	
2	450	3%	0.8%		0.4%	
3	450	3%	0.8%		0.8%	
4	450	3%		0.2%	0.4%	
5	450	3%		0.4%	0.4%	
6	450	3%		0.4%	0.4%	1%
7	450	3%		0.4%	0.4%	1% 3%

Table 1: Different Concentrations of the Polymers.

SAMPLES	$\emptyset_{600}$ (RPM)	$\emptyset_{300}$ (RPM)	Gel$_{10\,sec}$ Strength (lb/100 ft^2)	Gel$_{10\,min}$ Strength (lb/100 ft^2)	PV (Plastic Viscosity, Pa-s)	AV (Apparent Viscosity, Pa-s)	YP (Yield Point, lb/100 ft^2)	YP/ PV	Fluid Loss (ml)
1	6.5	3.5	1.5	1.5	3	3.25	0.5	0.167	-
2	11	6	1.5	1.5	5	5.5	1	0.2	-
3	17	10	1.5	1.5	7	7.5	3	0.428	-
4	29	19	4	5	10	14.5	9	0.9	-
5	47	35	8	12	12	23.5	23	1.916	50
6	53	37	10	15	16	26.5	21	1.4	25
7	450	33	7	12	12	27	21	1.75	20

Table 2: Results Obtained for base fluid.

Rheology:

By comparing the results obtained with the desired optimized result we can observe that the results from the first three test (TEST 1, TEST 2, TEST 3) were not satisfactory as the value of apparent viscosity and YP/PV was very low. But after addition of more viscous xanthum gum there was a drastic increase in the values of apparent viscosity and YP/PV as we can infer from the graph. From the graph we can also observe that after addition of CMC 2 (TEST 5), which is more viscous than the previous CMC, there was a steady increase in the values of apparent viscosity and YP/PV values and the value of plastic viscosity was satisfactory as well, however the amount of fluid loss was very high which is undesirable.

Fluid loss:

From the table 4, it can be seen that the fluid loss of the Cationic aphron based fluid is less than that of the anionic aphron based fluid. Penetration rate generally decreases as the circulation loss decreases. Also too much circulation loss can cause formation damage. So, the fluid loss should be preferably below 10 ml. Also a comparison has been made between the circulation loss of the aphron based fluid and stable base. From that it can be seen that the circulation loss for the base fluid (without the surfactant) was 20 ml but after the addition of surfactants it reduced significantly.
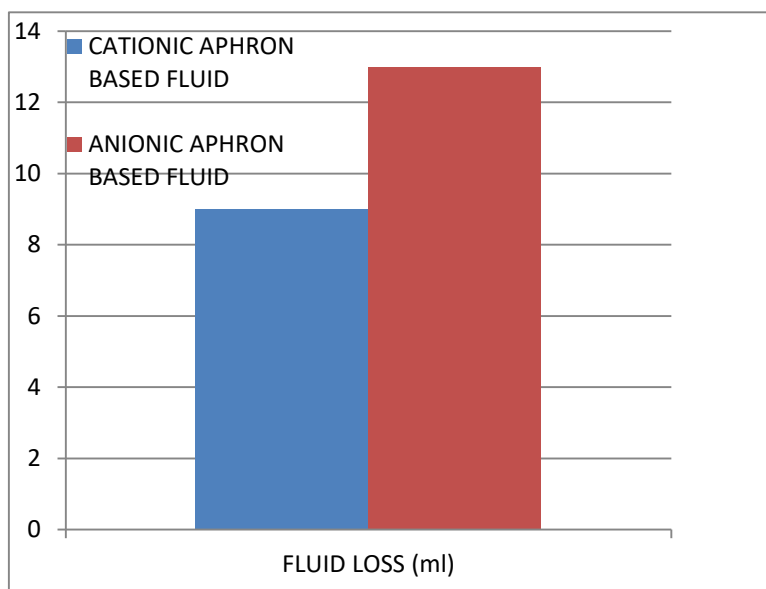
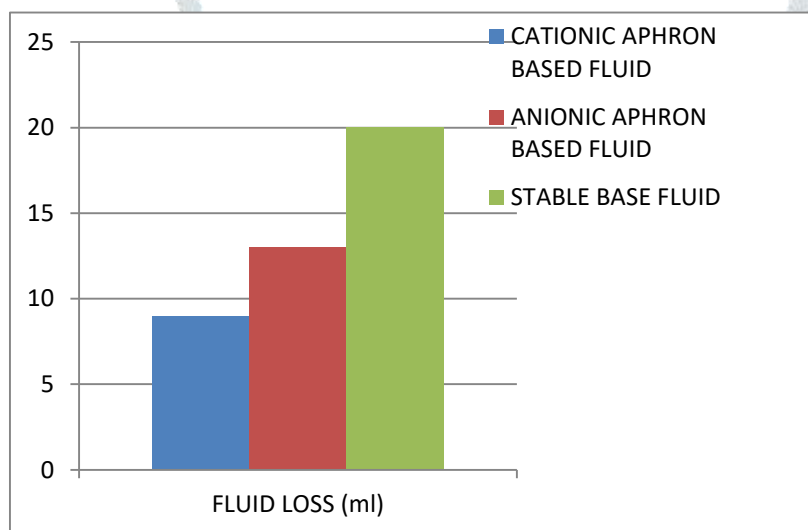**Figure 2:** Filtration Loss of Aphron Drilling Fluids

Figure 3: Comparison of fluid loss of aphron based fluid and stable base fluid.

Density:

SAMPLES	DENSITY(g/cm^3)
ANIONIC APHRON FLUID	1.054
CATIONIC APHRON FLUID	0.41

Table 3: Density of Aphron Based fluid

The density of anionic aphron based fluid is more than the cationic aphron based fluid. Penetration rate generally increases with decrease in mud density. However too low mud density may result in collapse and fill problems, while too high mud weight may result in mud losses or pipe sticking.
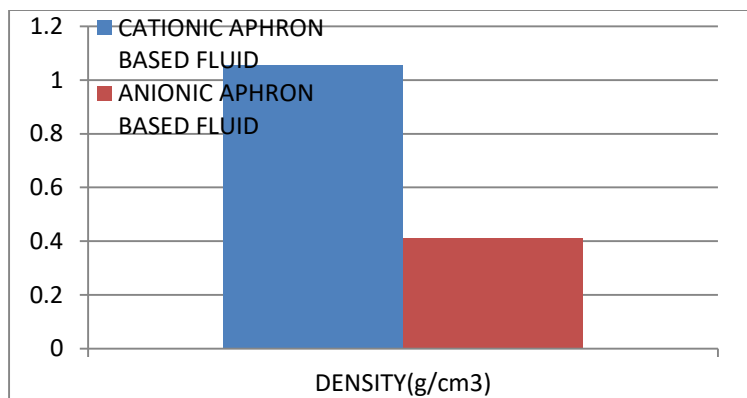
Figure 4: Density of Aphron Drilling Fluid

Stability:

	ANIONIC APHRON DRILLIND FLUID	CATIONIC APHRON DRILLING FLUID
V_I	430 ml	430 ml
$V_{10\ min}$	430 ml	430 ml
V_{30min}	430 ml	430 ml
V_{1hr}	425 ml	430 ml
V_{2hr}	420 ml	425 ml
V_{4hr}	410 ml	420 ml
V_{8hr}	390 ml	415 ml

Table 4: Stability of Aphron Drilling Fluids

The stability of micro-bubbles with time is also an important factor for determining the ability of the aphron to block rock pores. For the cationic aphron based fluid it was observed that the reduction in volume of the sample was slower than the anionic aphron based fluid. The volume remained approximately constant for the first one hour.

It debased to 420 ml within four hours. Finally, by the end of 8 hours it reduced to 415 ml due to breaking of the bubbles. From this we can infer that the stability of the cationic aphron based is more stable than the anionic aphron based fluid.
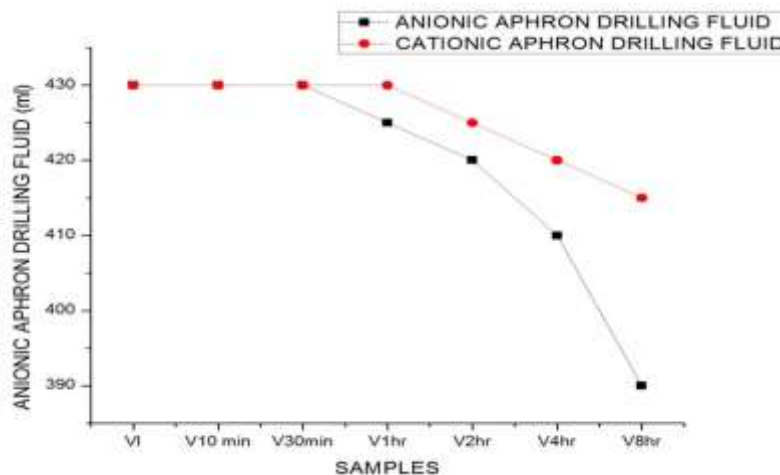

Figure 5: Stability of Aphron Based Fluids.

Effects of surfactant concentration on the rheology:

SAMPLES	WEIGHT%	Gel$_{10\ sec}$ Strength (lb/100 ft^2	Gel$_{10\ sec}$ Strength (lb/100 ft^2	PV (Plastic Viscosity, Pa-s	AV (Apparent Viscosity, Pa-s)	YP (Yield Point,lb/100 ft^2)	YP/ PV
Anionic	0.1%	10	14	15	25.5	21	1.4
Aphron	0.2%	16	20	15	32.5	35	2.33
Fluid	0.3%	5	5	14	23.5	19	1.36
Cationic	0.1%	11	20	17	33.5	33	1.94
Aphron	0.2%	17	26	16	37.5	43	2.68
Fluid	0.3%	7	11	14	30.5	33	2.357

Table 6: Rheology of Aphron Based Drilling Fluid

From the table 7 we observe that as the weight percent of the anionic aphron based drilling fluid (using sodium do-decyl sulfate) was increased to 0.2 wt% (0.9g), there was a positive effect on the apparent viscosity and YP/PV value. There was no change in plastic viscosity. The ratio of initial gel strength to the final gel strength also approximately remained the same.

As it was again increased to 0.3 wt % (1.35g) there was a negative effect on the apparent viscosity, yield point and YP value. The plastic viscosity almost remained the same. The initial gel strength was equal to the final gel strength suggesting that the sample does not have the ability to suspend solid particles when the circulation is ceased.
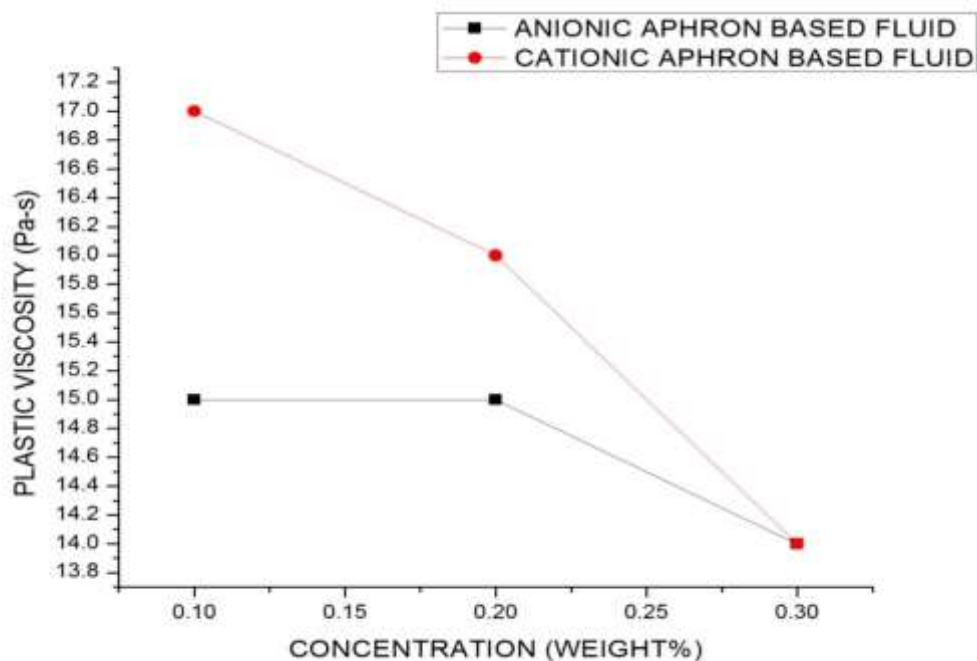

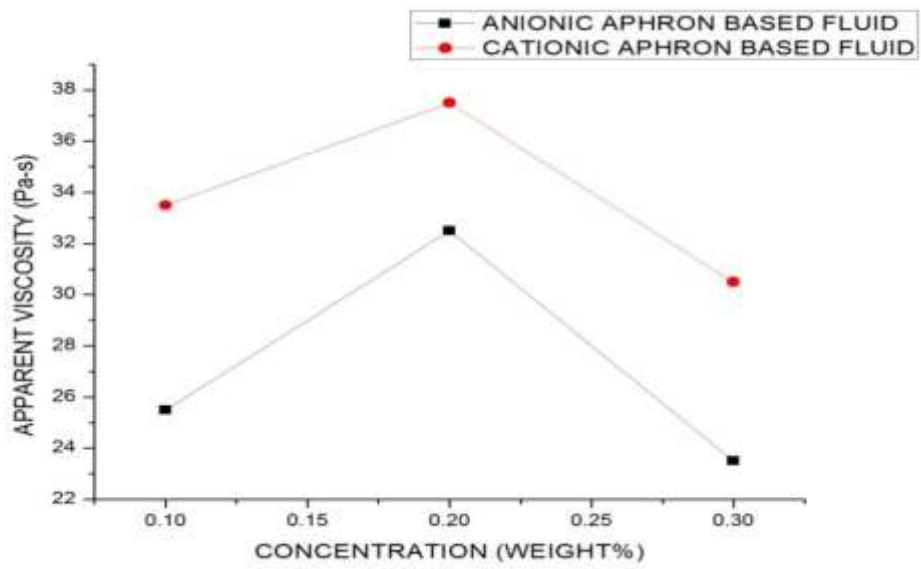**Figure 7**: Plastic viscosity Vs concentration.

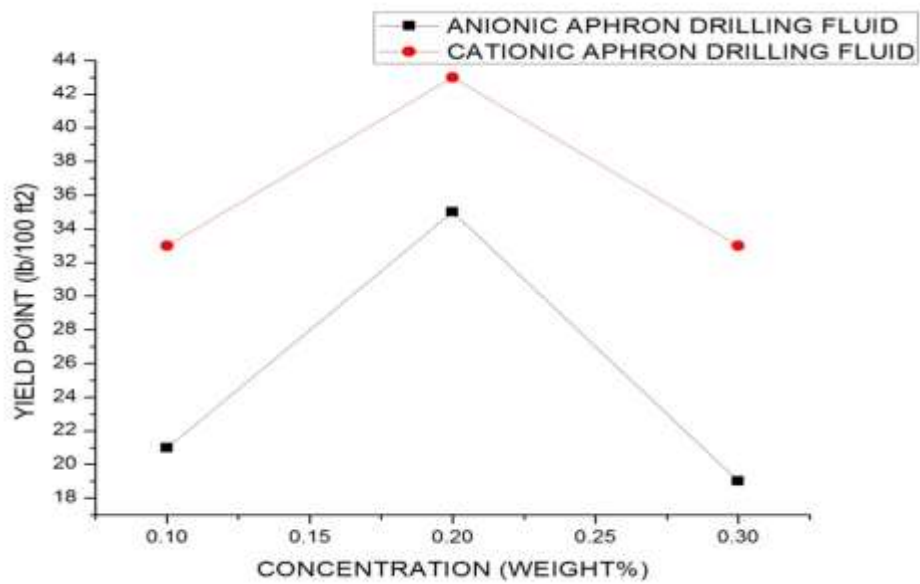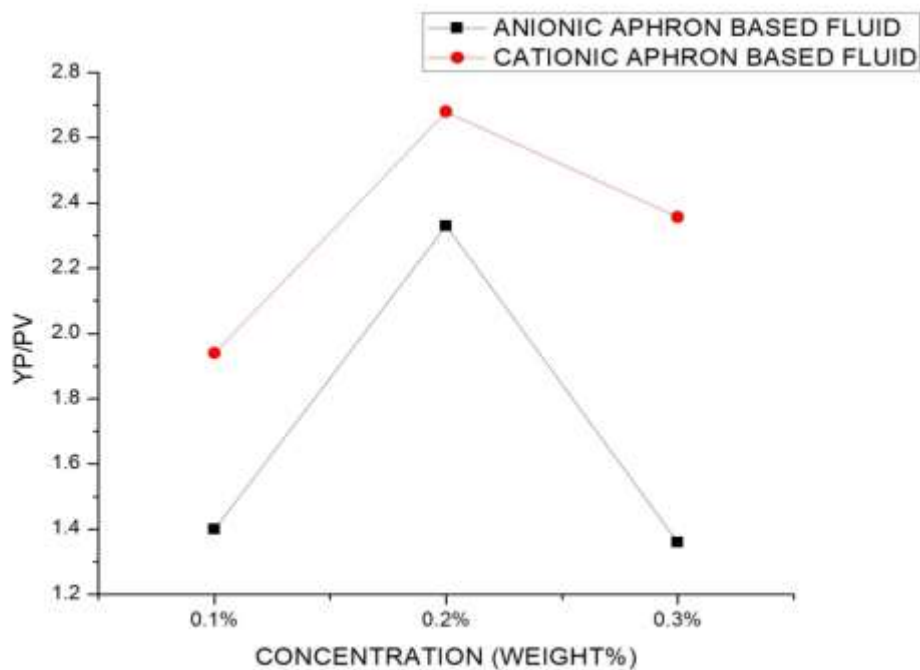**Figure 8:** Apparent Viscosity Vs Concentration.

Figure 9: Yield point Vs Concentration

Figure 10: YP/PV Vs Concentration

IV. CONCLUSION

From this study we concluded that an increase in the mud density, apparent viscosity, YP/PV and decrease in plastic viscosity of the drilling fluid can significantly improve the penetration rate. The use of aphron based drilling fluids with proper base fluid can greatly improve the rate of penetration and at the same time can be effective for depleted reservoirs and high permeability reservoirs. The studies of rheology, stability, effect of different concentrations on rheology, filtration loss and density and their effects, shows that the cationic aphron based fluid gives better results than anionic aphron. Further, to save the time and cost this work would be effectively applicable in the field of drilling fluid technology.

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