EFFECT OF FLY ASH ON THE RHEOLOGICAL AND FILTRATION PROPERTIES OF WATER BASED DRILLING FLUIDS

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Abstract

An experimental investigation was carried out to study the effect of fly ash on the rheological and filtration properties of water based drilling fluids with the objective of the development of environmentally acceptable non-damaging and inhibitive drilling fluid system to drill sensitive formations. Initially, different drilling fluids combinations were prepared using carboxy methyl cellulose (low viscosity grade), polyanionic cellulose, xanthan gum, and potassium chloride. The rheological properties as well as filtration properties of these drilling fluids were measured by API recommended methods. These drilling fluids show very good rheological behavior but poor filtration loss characteristics. When fly ash was added in these drilling fluid combinations, a nanoparticles fluid system was established which has better control on filtration properties without affecting the rheological properties and has good potential for the drilling of sensitive formations.

Index Terms: Filtrate Loss Properties, Rheological Properties, Wellbore Instability, Inhibitive Drilling Fluid, Nanoparticles, Shale.

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1. INTRODUCTION

The appropriate selection of the drilling fluids and the variation in their properties when subjected to the borehole conditions are the major concern of the drilling engineers and operators [1] [2]. The drilling of sensitive formations like shales, shaly sandstones, fractured and unconsolidated reservoirs causes borehole hydration and dispersion of cuttings which may lead to wellbore instability, additional reaming, inadequate logging, pipe sticking, high torque, pipe suck-up [3] [4]. The various forms of hole instability result from the interaction of drilling fluid with sensitive formations which are related to hydration, swelling and dispersion of the sensitive formations. Water is adsorbed on clays by two phenomena: surface hydration and osmotic swelling. Crystalline swelling is exhibited by all clays and the later one can be seen in certain clays of the smectite group [5].

Normally, non-aqueous drilling fluids are acceptable due to their high performance as they are less sensitive to the borehole environment; provide high lubricity and deliver better drilling efficiency. But, environmental considerations regarding the fluid disposal and miscellaneous costs are the factors which limit their applications [6] [7]. However, Water based drilling fluids don't have these unwanted issues associated with their application in drilling a well. But, they are highly sensitive to formation characteristics and a single fluid can't be used to drill all wells [8]. Water based drilling fluids are generally considered to be more environmentally acceptable than oil-based mud or synthetic based fluids. These drilling fluids facilitate clay hydration and swelling which can increase the well construction costs significantly [9].

Smectite clays are frequently encountered by the operators while exploiting any reservoir. Clay minerals have different types of exchangeable cations which affect the amount of swelling. They compete with water molecules for the available reactive sites in the clay structure. Clay with low valence exchangeable cations has high tendency to swell than those with high valences. Understanding of the basic mechanism of clay swelling is essential for developing a mud system. Clay inhibitors are used to inhibit swelling tendency of the clays but the use of some inhibitors is retarded by the increasingly strict environmental guidelines especially in densely populated areas [5].

Selection of the drilling fluid is based on the desired rheological parameters and filtration properties by the engineer keeping in view the borehole conditions. The high yield point/plastic viscosity ratio indicates that it is a shear thinning mud which is desirable for drilling fluid as it sets to a gel, which is sufficient to suspend the cuttings when circulation is stopped and which breaks up quickly to a thin fluid when it is agitated by continuation of drilling [10]. Formation damage due to invasion of drilling fluids filtrate is well known problem in the drilling of oil & gas wells. This is caused by the differential pressure between the hydrostatic mud column and formation pressure.

Fly ash is the industrial waste product that is obtained after the burning of coal in factories and thermal power plants. Fly ash can be considered as the world's fifth largest raw material resource. Currently, the energy sector in India generates over 130 Mt of Fly Ash annually and this amount will increase as annual coal consumption increases by 2.2% [11]. The large-scale storage of wet fly ash in ponds takes up much valuable agricultural land approximately (113 million m^2), and may result in severe environmental degradation in the near future, which would be disastrous for India. Fly ash is generally grey in colour, abrasive, mostly alkaline, and refractory in nature. The chemical composition of fly ash has high percentage of silica (60–65%), alumina (25–30%), magnetite, Fe_2O_3 (6–15%) [12].

The filtration properties of a drilling fluid system are highly influenced by the use of fly ash in the developed mud system [13]. Fly ash is eco-friendly and doesn't raise any environmental issues as it is quite compatible with the soil. Even, fly ash improves the physical properties and nutrients of the soil, making it more fertile and beneficial for the growth of plants [14]. Hence, adding fly ash to drilling fluid will not raise any sort of burden on disposal of the fluids after drilling and there is much scope of utilization of this industrial waste in the drilling of oil & Gas wells.

This experimental work consists of the development of ecofriendly inhibitive and non-damaging water based drilling fluid system by using xanthan gum as viscosifier, polyanionic cellulose as fluid loss control agent, potassium chloride as shale inhibitor and fly ash as bridging agent for the control of filtration properties of the drilling fluids. Compared to other particulate bridging agents, used in drilling fluids such as calcium carbonate (CaCO3), fly ash has advantage of being cheaper and lighter. As density of calcium carbonate is 2.7 g/cc and density of fly ash is 2.2 g/cc [15].

2. Experimental work

2.1 Materials used:

Low viscosity grade carboxy methyl cellulose, potassium chloride were purchased from Central Drug House (P) Ltd. (CDH), India and low viscosity grade polyanionic cellulose, xanthan gum, octanol were purchased from Sigma-Aldrich, India , fly ash was collected from an 10MW operational thermal power plant located in Jharia division.

2.2 Experimental procedure:

Firstly, the powdered form of drilling fluid additives were weighed and mixed with water in the Hamilton Beach stirrer. The powder samples were added one by one; at first potassium chloride was added and allowed to mix thoroughly. Xanthan gum which acts as a viscofier was added and mixed thoroughly. After complete mixing, low viscosity grade carboxy methyl cellulose & polyanionic cellulose which act as a fluid loss control additives were added slowly. Also, 2-3 drops of octanol were put in the solution which acts as a defoamer.

Fann V-G meter 35SA model (Fann Instrument Company, Houston, Texas) was used to measure the dial readings which were further empirically correlated to determine rheological properties like plastic viscosity, apparent viscosity, yield point; and also the initial and 10 minutes gel strength of the prepared homogenous solutions. API (American Petroleum Institute) Filter press apparatus was used to measure the filtration properties of the different solutions.

Rheological and filtration properties were again measured by adding different concentrations of fly ash which acted as an effective bridging agent in the developed mud system. Fly ash was collected directly from a thermal power plant of 10MW instead of the pond so as to get better results. Effect of adding different concentrations of fly ash on the density of the solutions is also analyzed by Fann mud balance model 140. Particle size distribution of the developed drilling fluid systems is analyzed by using Zetasizer Nano S90 model (Malvern Instruments Ltd, UK). Finally, optimum concentrations were obtained which satisfy the criteria of non-damaging drilling fluid.

3. RESULTS AND DISCUSSION

Bentonite clay is used most commonly for the preparation of water based drilling fluids. The organic polymers are added in bentonite water suspension to improve its rheological properties and to control filtration loss properties [16]. In this study bentonite clay is not used as it causes permeability reduction in the petroleum formations [17] and it contains many exchangeable ionic sites, which is not desired for drilling sensitive formations. Hence, bentonite free drilling fluid system is established by varying concentrations of the bio-polymers and semi-synthetic polymers. The developed systems are inhibited by potassium chloride. Instead of bentonite viscosity is imparted by non-ionic polymer xanthan gum as it provides very high viscosity at lower concentrations and it is quite compatible with the other polymers used in the system. Low viscosity grade carboxy methyl cellulose and polyanionic cellulose are used to control filtration as they have good temperature stability of 121^0 C and 149^0 C respectively

[16]. Carboxy methyl cellulose also helps in maintaining the rheology of the fluid inside the wellbore when dispersion of cutting takes place while drilling clay formations especially on plastic viscosity and apparent viscosity. Initially, optimized base fluid systems are developed at different concentrations as shown in Table 1, and the rheological and filtration properties of these fluid systems are shown in Table 2. The developed systems have high yield point and plastic viscosity ratio which is the essential part and the sign of the shear thinning fluid, required for good suspension ability of cuttings when drilling is stopped and thereby enhances the drilling efficiency of the drilling fluid [10]. On increasing the amount of xanthan gum rheological parameters were increased sharply. Also, plastic viscosity is low which results in high rate of penetration. Apparent viscosity is in moderate range as desired which imparts low viscosity inside the pipe where shear rates are high and high viscosity in the annulus to lift out the drilled cuttings prevailing to low shear rate conditions.

Table-1: Composition of the developed Mud System

Mud System	Composition (w/v %)			
	Xanthan Gum	Polyanionic Cellulose-LVG	Carboxy Methyl Cellulose-LVG	Potassium chloride
1	0.3	0.4	0.4	5
2	0.3	0.6	0.6	5
3	0.5	0.6	0.6	5
4	0.3	0.8	0.8	5
5	0.3	0.8	0.6	5

Filtration is the important phenomenon that can be seen in the wellbore due to pressure exerted by the hydrostatic column of the mud. Invasion of filtrate inside the formation accelerates ionic diffusion which results in severe problems leading to wellbore instability and sometime to wellbore failure [18] [19]. Swelling pressure is a strong function of the ionic diffusion at clay sites. Also, it has been observed that when water invasion proceeds at millimetres a day; ions will diffuse over centimetres in a day and pressure will diffuse over decimetres a day [18].

Filtration properties of the base fluid systems reported in table 2 are high and will raise many issues regarding hole stability. Cake thickness is also high which is not desirable. Sometimes removal of higher cake thickness needs extra operations like back flushing but this operation too have certain limitations and will increase drilling costs & time [20]. Also, high cake thickness may result in decrease production and may demand for work over jobs. Fluid loss is decreased with the increase in the concentrations of carboxy methyl cellulose and polyanionic cellulose which are fluid loss additives.

To account for all these severe issues fly ash which acted as a bridging agent is used. The effect of fly ash on the filtration properties is shown by gradually increasing the fly ash concentration starting from 1%. The effect of 1% fly ash on filtrate loss can be seen in Table 3. The filtrate loss and the cake thickness are reduced. By increasing the concentration to 2% as reported in Table 4 the filtrate loss and cake thickness are further reduced. At last on addition of 3% of fly ash the filtration properties are improved further as shown in Table 5. The reason for this behaviour of the fluid is due to the availability of very fine size particles of fly ash in the solutions which settles very quickly to form a very thin impermeable filter cake.

Table-2: Rheological and Filtration properties of the developed mud system

Mud System	Plastic Viscosity (cp)	Apparent Viscosity (cp)	Yield Point, lbf/100 ft^2	Initial Gel Strength, lb/100ft^2	10 minutes Gel Strength, lb/100ft^2	API, Filtrate loss in ml	Cake thickness (mm)
1	12	20	16	4	7	16	0.8
2	13.5	22	17	5	8	15	0.8
3	15	30.5	31	9	16	13	0.55
4	18	29	22	5	9	12	0.55
5	15	25	20	4.5	8	14	0.6

Table-3: Rheological and Filtration Properties of the developed mud system with 1% TPFA

Mud System	Plastic Viscosity (cp)	Apparent Viscosity (cp)	Yield Point, lbf/100 ft^2	Initial Gel Strength, lb/100ft^2	10 minutes Gel Strength, lb/100ft^2	API, Filtrate loss in ml	Cake thickness (mm)
1	12	20	16	4	7	12	0.55
2	13.5	22	17	5	8	10	0.5
3	15	30.5	31	9	16	9	0.4
4	18	29	22	5	9	9	0.4
5	15	25	20	4.5	8	10	0.5

Table-4: Rheological and Filtration Properties of the developed mud system with 2% TPFA

Mud System	Plastic Viscosity (cp)	Apparent Viscosity (cp)	Yield Point, lbf/100 ft^2	Initial Gel Strength, lb/100ft^2	10 minutes Gel Strength, lb/100ft^2	API, Filtrate loss in ml	Cake thickness (mm)
1	12	20	16	4	7	11	0.5
2	13.5	22	17	5	8	9	0.5
3	15	30.5	31	9	16	8	0.4
4	18	29	22	5	9	7	0.3
5	15	25	20	4.5	8	8	0.4

Table-5: Rheological and Filtration properties of the developed mud systems with 3 % TPFA

Mud System	Plastic Viscosity (cp)	Apparent Viscosity (cp)	Yield Point, lbf/100 ft^2	Initial Gel Strength, lb/100ft^2	10 minutes Gel Strength, lb/100ft^2	API, Filtrate loss in ml	Cake thickness (mm)
1	12	20	16	4	7	10	0.5
2	13	21.75	17.5	5	8	8	0.4
3	15	30.5	31	9	16	8	0.4
4	17.5	28.75	22.5	5	9	6	0.3
5	15	25	20	4.5	8	7	0.35

The bridging effect of fly ash particles further results in very poor filtration loss. The major advantages of using fly ash as bridging agent is that it is less denser than calcium carbonate, being the waste product it is very cheap & easily available, and due to nutritive value of the fly ash to the soil it is environmentally acceptable. By analyzing results as shown in the tables the effect of adding fly ash on the rheological properties is very negligible. Hence, adding of fly ash to the prepared homogenous solution will not alter the rheological parameters significantly. There is not any significant effect of fly ash on the density of the fluid systems. The pH of the developed system was in range of 8.5-9.0. The developed drilling fluid systems need to be inhibited and must control the swelling pressure hence 5 % KCL is added to the developed drilling fluids which is the normal concentration used in development of inhibited drilling in most of the fields [13].

The drill-in fluid should contain bridging solids of a specific particle size distribution (PSD) that is able to cope with the natural heterogeneity encountered in a formation. This plays a critical role in the rapid formation of the filter cake. In order to improve filtration properties for better performance there must be smaller particles that should bridge the formation pores [13].Particle size distribution of the different base polymer systems can be seen in the Fig. 1 to 5. It is very clear from the results that larger the amount of the smaller size particles and lesser the value of Z-average better will be the filtration and rheological properties. Also, the spurt loss which is defined as the invasion of filtrate or fluid loss that passes through the filter medium before a filter cake is formed is also the strong function of the particle size of the bridging agent. If particles are not bridging quickly to form the filter cake then spurt loss will be high which will damage the formation.

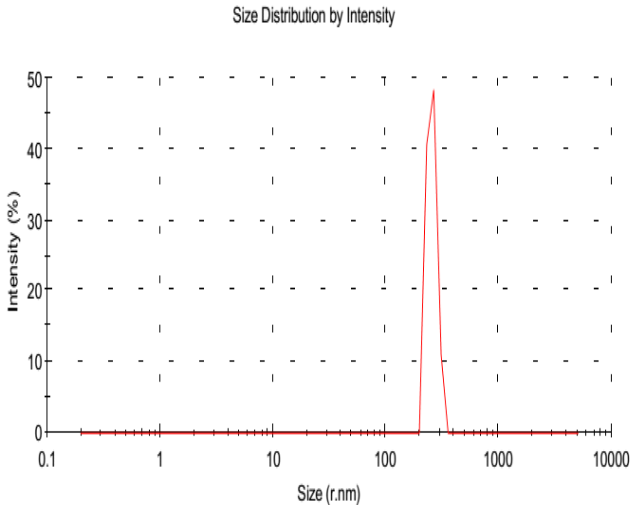

Fig-1: Particle size distribution of the mud system 1 (Z average (r.nm) = 1287)

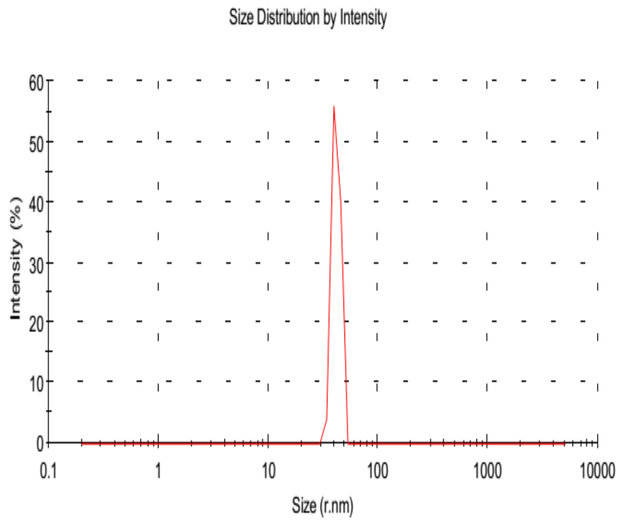

Fig-2: Particle size distribution of the mud system 2 (Z average (r.nm) = 1572)

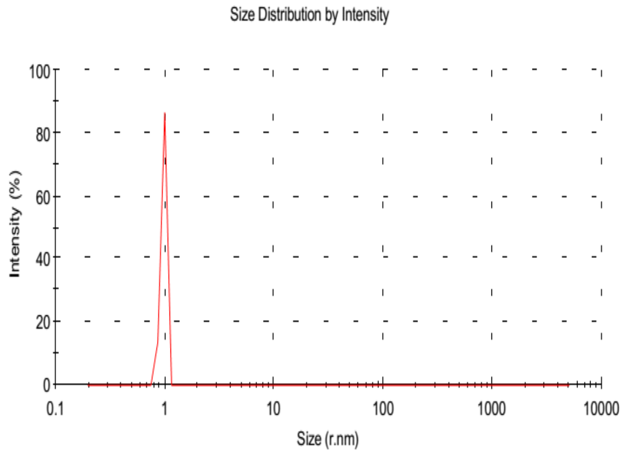

Fig-3: Particle size distribution of the mud system 3 (Z average (r.nm) = 8465)

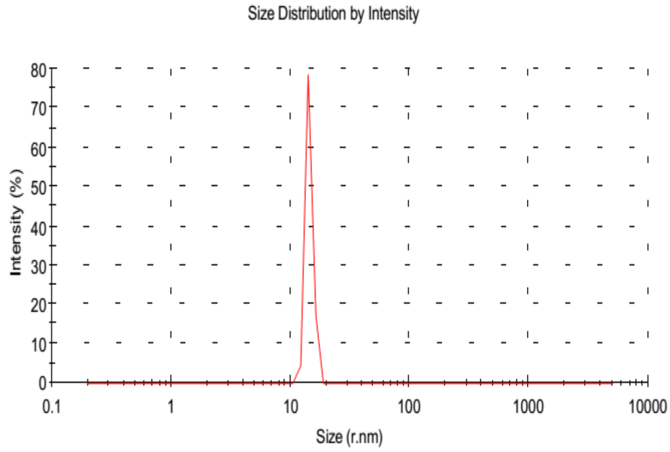

Fig-4: Particle size distribution of the mud system 4 (Z average (r.nm) = 7139)

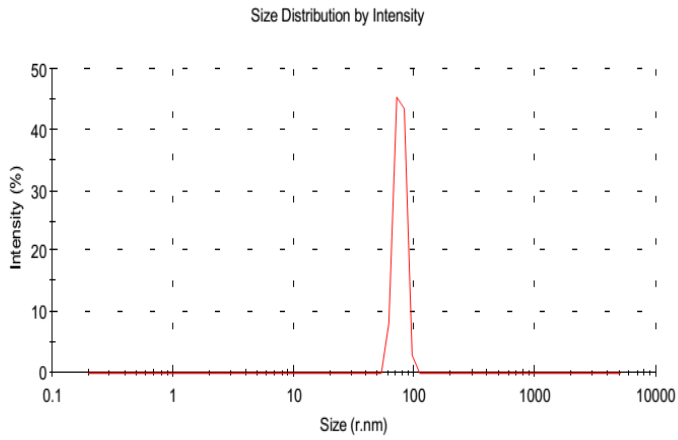

Fig-5: Particle size distribution of the mud system 5 (Z average (r.nm) = 1269)

In our case with fly ash the spurt loss was negligible and the filter cake was formed very quickly thereby minimizing the fluid loss with increase in the concentration of the fly ash.
Also, effect of fly ash on the PSD (Particle Size Distribution) is shown with one mud system by gradually increasing the quantity of fly ash. Mud system 3 is selected to analyze the effect of fly ash on the particle size of the developed mud system. In Fig.6 the mud system which is incorporated by 1% of fly ash has radius of around 85 % particles in 100 nanometre range and Z-average size is around 1026.

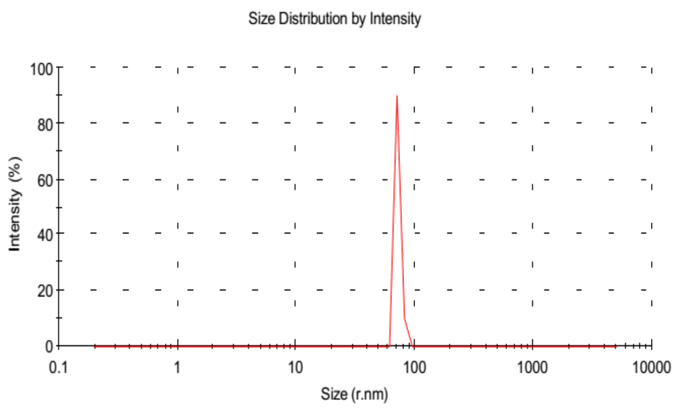

Fig-6: Particle size distribution of mud system 3 with 1% fly ash (Z average (r.nm) = 1026)

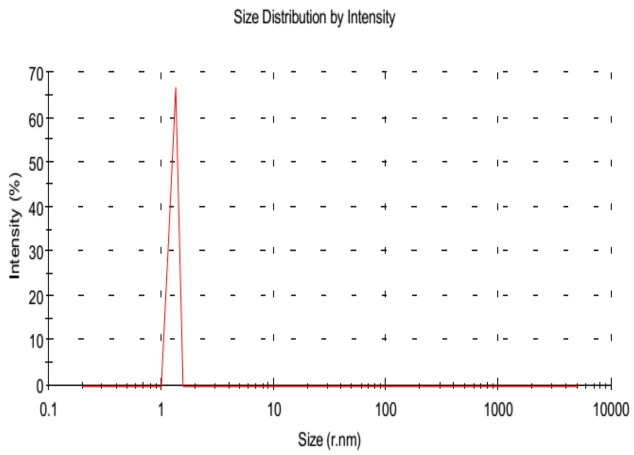

Fig-7: Particle size distribution of mud system 3 with 2% fly ash (Z-average (r.nm) = 876.7)

. Again, in Fig.7 by increasing fly ash concentration to 2% the mud system have around 65% of the particles radius in 1 to 2 nanometre range and also reduced Z-average size which is around 867.7. So, by increasing the concentration of fly ash the particles size reduces and hence improves the filtration properties of the drilling fluids significantly. Systems with the nanoparticles has better control on filtration properties and are advantageous in controlling fluid invasion to the formations. Also nanoparticles based drilling fluid system helps in wellbore strengthening while drilling shale reservoirs as they can penetrate the formation pores easily and thereby bridging the formation [19]. The results that were obtained and shown in this paper state that presence of nanoparticles in the developed system has improve the filtration properties significantly.

CONCLUSIONS

Following conclusions are drawn from the present experimental work:

1. The filtration properties were improved with the increase in concentration of the fly ash. As the availability of smaller size particles has increased in the developed drilling fluid system, which resulted in better bridging effect of the particles therefore reducing the cake thickness and filter loss.
2. The particles size got reduced after the addition of the fly ash in the developed drilling fluid system.
3. Presence of nanoparticles in the system improves the properties of the developed drilling fluid system.
4. Sequence of adding and mixing of the polymers is very crucial and should be done very carefully in order to prepare homogenous solutions.
5. Effect of fly ash on the rheological properties is very negligible.
6. Fly ash may compete with other bridging agent due to its better efficiency, availability, better environmental effects, and low cost factor. It should be utilized at best as it is the waste product of the industries in huge amount.

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BIOGRAPHIES

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