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Rheological properties of water based slurry under turbulent flow condition

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Abstract

In previous researches the testing of additives had been performed under laminar flow conditions where as in this paper, results are taken under turbulence flow condition. So the results that are getting from this research may be varying from other that had been performed under laminar flow condition. This paper presents the effect of different additives on rheological properties of water- bentonite slurry by studying the rheological behaviour of additives. This work present the results to relate the turbulent flow condition of any fluid flow. In the present investigation, 19 different samples have been prepared by varying concentration of additives. The variation of shear stress and shear rate has been plotted and on the basis of this behaviour of fluids has been explained. The value of k and n are calculated by using Power law.

Keywords: Rheological Properties, Drilling Fluid, Turbulence Flow, Additives, Apparent Viscosity.

Introduction

Bentonite has been used as drilling fluid additive in world[1,2]. The bentonite is used to increase the viscosity of the mud and to reduce the fluid loss. By investigating the rheological and thermal properties of bentonite for water base drilling fluids. It was found that all bentonite samples exhibit two weight loss events on heating[3]. The yield point, plastic viscosity, apparent viscosity and Gel strength of drilling mud increased with increase in bentonite and nano clay contents[4]. Drilling mud rheological property is important because it can distinguish various properties of mud like well cleaning, erosion preservation, removal of cutting material and hydraulic calculation of pump[5]. It is found from laboratory and field tests that the rheology has a greater effect on the combination of drilling fluid and rate of penetration in the rotary drilling process. The type of drilling fluid could be different for each drilling operation.

Various additives are added to the drilling fluid for particular purposes. Sometimes their uses are contradictory, for example, mud has to be viscous so that it is able to lift the cuttings to the surface, but viscosity must not be too high so as to minimize the friction pressure loss. Additives are like viscosifiers (clays, bentonite, asbestos, polymers as PAC, HEC, xanthan gum, guar), weighting agents (barytine, carbonate, barite, iron oxide, calcium carbonate, saline, galena), filtrate reducers (Carboxy Methyl Cellulose, resins starch, polyanionic cellulose, acrylate, bentonite), clays swelling inhibitors (KCl, glycol Fibbers, cement slurry, corns, flaked), Viscosity reducer (Phosphates, sodium polyacrylate, tannates, lignins) and plugging agent for mud losses. In the petroleum-drilling field, water base polymers are purposely added to drilling mud in order to perform very specific functions, like fluid-loss control, modification of rheological properties, shale stabilization, lubrication, etc.[6]. The polymers can be generally classified as natural polymer such as tamarind gum[7], xanthan gum[8] or carboxy methyl cellulose (CMC)[9]. The rheology and filtration properties of drilling muds with water soluble polymers change considerably under severe operating conditions (high temperature and high salinity conditions)[10]. It was observed that addition of KCl/polymer to the drilling fluid has affected the rheological model and caused a variation in model parameter, consistency index, and flow behavior index[11]. Tragacanth gum acts as a good viscosifiers and fluid loss control agent. The drilling fluid filtrate also has reduced the effect on formation damage[7].

In this present study, the various additives are added to water based slurry which are examined from the rheological point of view. The effects of water soluble polymer (carboxy methyl cellulose (CMC) and babool gum, sodium carbonate and viscosifying agent bentonite) on water based slurry are investigated.

Materials and methods

Sample preparation: The samples are prepared by adding Bentonite, Carboxy-methyl cellulose (CMC), Babool gum and Sodium carbonate (Na_2CO_3) to distilled water. Bentonite is added to water in order to: i. increase the hole cleaning properties; ii. reduce water seepage or filtration; iii. form a thin filter cake; iv. promote hole-stability and v. overcome loss of circulation. Babool gum is used as a viscosifying agent. CMC used as a filtrate reducer and effectiveness of it decreases as salt concentration increases. (Na_2CO_3) is used for removal of soluble calcium salts from makeup waters and mud and some use in clay beneficiation. Nineteen different water based samples are prepared by varying the concentrations of CMC, Babool gum and Na_2CO_3. Compositions of the prepared samples are given below in Table-1.

Table-1: Composition of ingredients (remaining amount is water)

Sample No	Composition of ingredients (remaining amount is water)				
	Bentonite	Babool tree gum	Sodium carbonate (Na_2CO_3)	Carboxy-methyl cellulose (CMC)	Measured density (kg/m^3)
1	--	--	--	--	980
2	2% wt/wt (150μm)	--	--	--	981.7
3	4% wt/wt (150μm)	--	--	--	983.33
4	6% wt/wt (150μm)	--	--	--	984.91
5	6% wt/wt (150μm)	4.8 g / 100 g bentonite	--	--	987.9
6	6% wt/wt (150μm)	7.2 g / 100 g bentonite	--	--	989.39
7	6% wt/wt (150μm)	7.2 g / 100 g bentonite	3.2 g / 100 g bentonite	--	994
8	6% wt/wt (150μm)	7.2 g / 100 g bentonite	3.2 g / 100 g bentonite	0.833 g / 100 g bentonite	994.74
9	6% wt/wt (150μm)	7.2 g / 100 g bentonite	3.2 g / 100 g bentonite	1.67 g / 100 g bentonite	995.5
10	4% wt/wt (600μm)	--	--	--	1029
11	4 % wt/wt (600μm)	4.8 g / 100 g bentonite	--	--	1031
12	4% wt/wt (600μm)	7.2 g / 100 g bentonite	--	--	1032
13	4% wt/wt (600μm)	7.2 g / 100 g bentonite	3.2 g / 100 g bentonite	--	1035.17
14	4% wt/wt (600μm)	7.2 g / 100 g bentonite	3.2 g / 100 g bentonite	0.833 g / 100 g bentonite	1035.69
15	6% wt/wt (600μm)	--	--	--	1052.12
16	6% wt/wt (600μm)	4.8 g / 100 g bentonite	--	--	1055.11
17	6 % wt/wt (600μm)	7.2 g / 100 g bentonite	--	--	1056.606
18	6% wt/wt (600μm)	7.2 g / 100 g bentonite	3.2 g / 100 g bentonite	--	1061.21
19	6% wt/wt (600μm)	7.2 g / 100 g bentonite	3.2 g / 100 g bentonite	0.833 g / 100 g bentonite	1062.96

Equipment and procedure: Figure-1 shows the schematic of the mini pilot plant test loop experimental setup developed for the present pressure drop measurement. This is fairly simple set up comprising of the 1 hp centrifugal self priming (Kirloskar make) mono-block pump. The test loop was made to conduct the pressure drop studies for slurries at different concentrations at different velocities with and without the addition of additives. The primary components of pilot plant test loop are pipeline, concentric annulus with inner cylinder free to rotate, slurry tank, flow measuring tank, pressure gauges, flow control valves flexible pipe. The centrifugal mud pump is installed on the pump base of 2.5 ft, 2.5 ft and 3 ft length, breadth and height respectively. A MS pipe of 8 meter length and 38.1 mm diameter connection is done in between the pump and mixing tank. Pressure gauge tapping were kept 4 m length apart for a significant pressure drop measurement. In the return line, the flow is passed through the concentric annulus pipe. Inner diameter of the annulus is 12 mm and outer diameter of the annulus is 63.5 cm. The distance between the pressure trappings was kept apart for 1.5 m. The inner pipe of the concentric annulus was attached with the ½ hp motor for the rotation of the inner diameter of the annulus. The pressure gauges of 1 to 2 bar capacity with 0.025 bar accuracy were used for the pressure measurement at the desired locations. The slurry tank (mixing tank) is made of 0.715 meter diameter with 0.50 meter height with a capacity of 200 litres. The flow measuring tank was calibrated for the measurement of the successive volume. This was used for the measurement of flow rate and thus for the calculation of velocity of flow in combination with the time measurement devices.

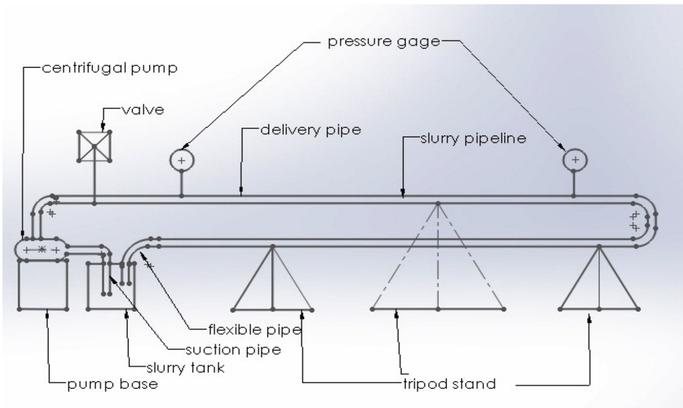

Figure-1: Schematic diagram of pilot plant test loop.

This complete arrangement is shown in the Figure-1, as line diagram. The lists of the various samples run in the test are shown in the Table-1.

Results and discussion

Physical and chemical properties of drilling fluid are important because they are directly related to the cost of drilling operation. Therefore the selection of right additives play important role in drilling well completion. The experiments were conducted for particulate slurries at different concentration with and without additives. Babool gum of 4.8 and 7.2 g per 100g of bentonite were added to the fluids. Sodium carbonates of 3.2 g per 100g of bentonite are added. CMC 0.833g and 1.67 g per 100g bentonite are added. The experiments are conducted for three flow condition first pipe flow, second annular flow without rotation and third annular flow with rotation. Experiments are conducted for 2%, 4% and 6% concentration of bentonite with 150 micron and 600 micron particle size based on these values of curves are plotted The data collected from experiments are used for calculating rheological parameters such as stress, strain rate and apparent viscosity of different slurries.

Stress Vs Strain curve – Samples are prepared by adding different concentrations of additives to water-bentonite slurry. The variation between shear rate and shear stress of samples 2 to 9 are plotted in Figures-2, 3 and 4 for different flow conditions. For different flow conditions, the stress vs strain rate curves are different. From the figure it is clear that curves having maximum value of shear stress for pipe flow and minimum for annular flow with rotation. As the additives are added to the bentonite fluids, the values of shear stress decreases in sample of pipe flow (Figure-2) whereas in sample of annular flow (Figure-3 and 4) it is increased. Curves of Figure-3 and 4 have minimum values of stress and strain rate as compare to Figure-2. In Figure-3, as additives are added to the solution, the values of shear stress increase.

In Figure-4, samples 2, 3, 5, 6 and 8 are showing curves of similar pattern which are become constant after reaching pick point. Sample 7 shows linear curve between stress and strain rate. Sample 9 shows the higher value of stress as compare to other samples.

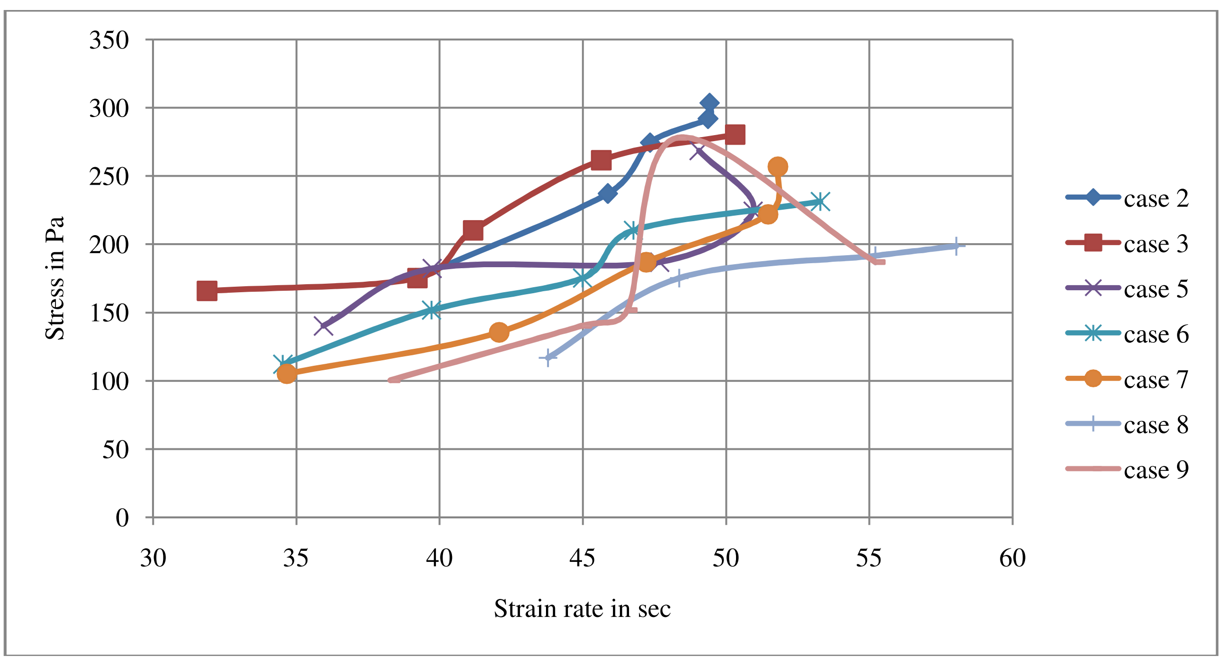

Figure-2: Stress Vs Strain curve for pipe flow.

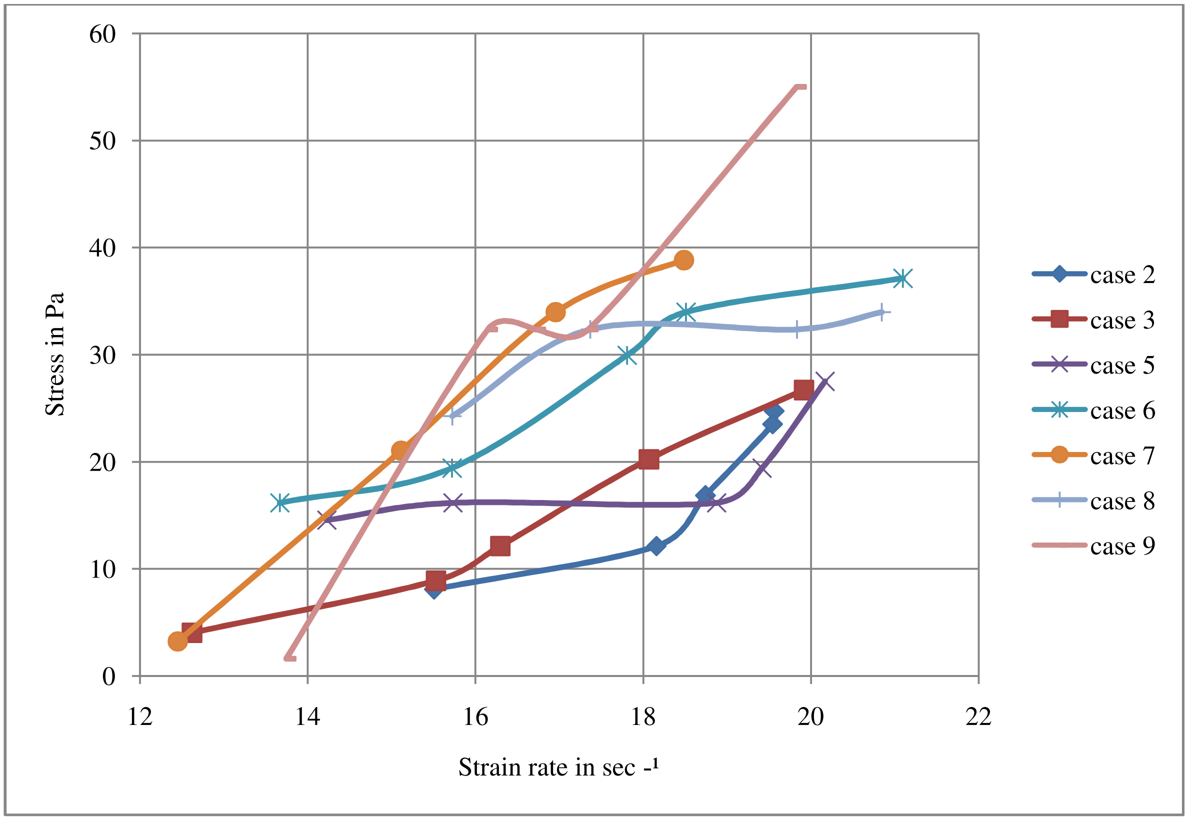

Figure-3: Stress Vs Strain curve for annular flow without rotation.

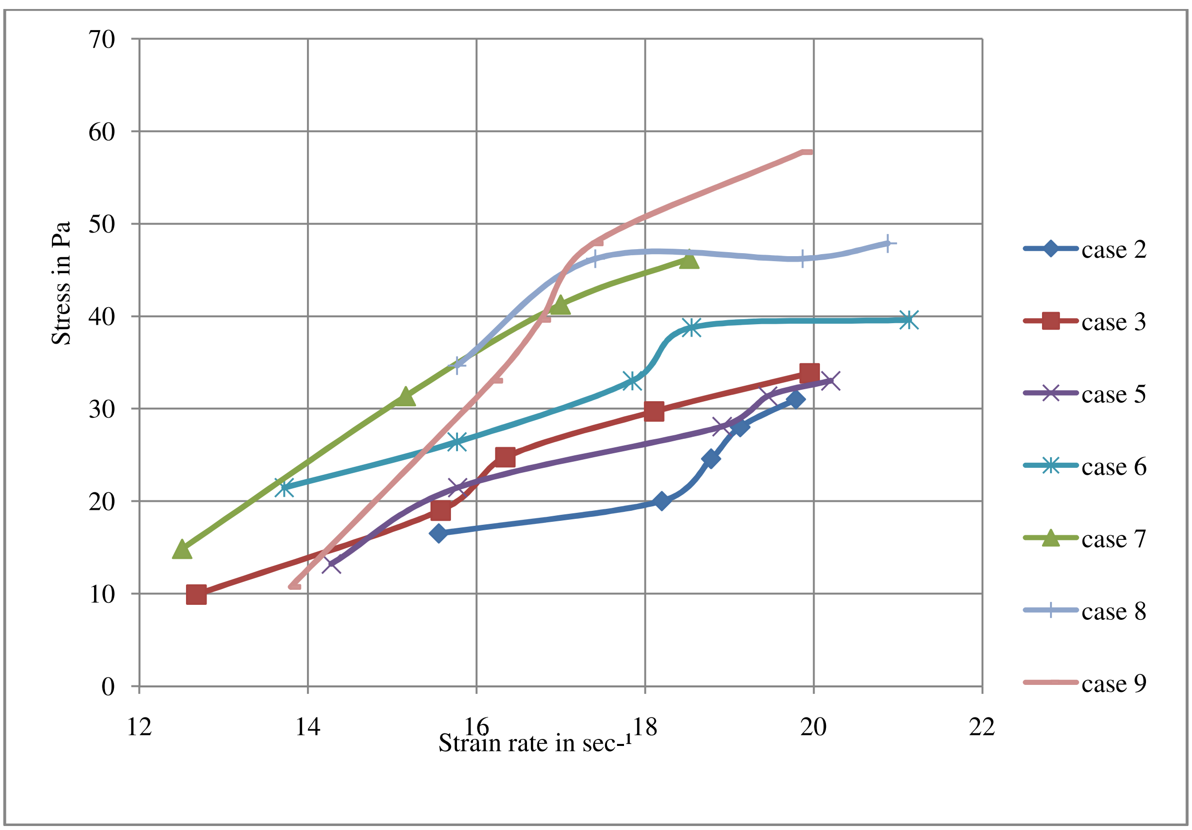

Figure-4: Stress Vs Strain curve for annular flow with rotation.

Apparent viscosity: Figure-5 and 6 representing the relationship of shear stress, strain rate and apparent viscosity in a plot for samples 5 to 8 having 6% concentration of bentonite with 150 micron particle size. Apparent viscosity of each sample shows the similar linear curve between shear stress and strain rate. With increase in strain rate there is an increase in apparent viscosity. Samples show the shear-thickening behaviour. In Figure-5, sample no. 7 (containing 7.2 g of Babool gum and 3.2 g of sodium carbonate) is having highest apparent viscosity in pipe flow as well as for annular flow with rotation in Figure-6.

Effect of concentration: In Table-2, results are concluded for some selected samples no. 2, 3, 8, 10, 14, 15 and 19 for three flow conditions: pipe flow, annular flow without rotation and annular flow with rotation. From the Table-2, the value of k decreases and n increases for sample 2, 3, 10, 14 and 19. The value of k increases and n decreases for sample 8 and 15.

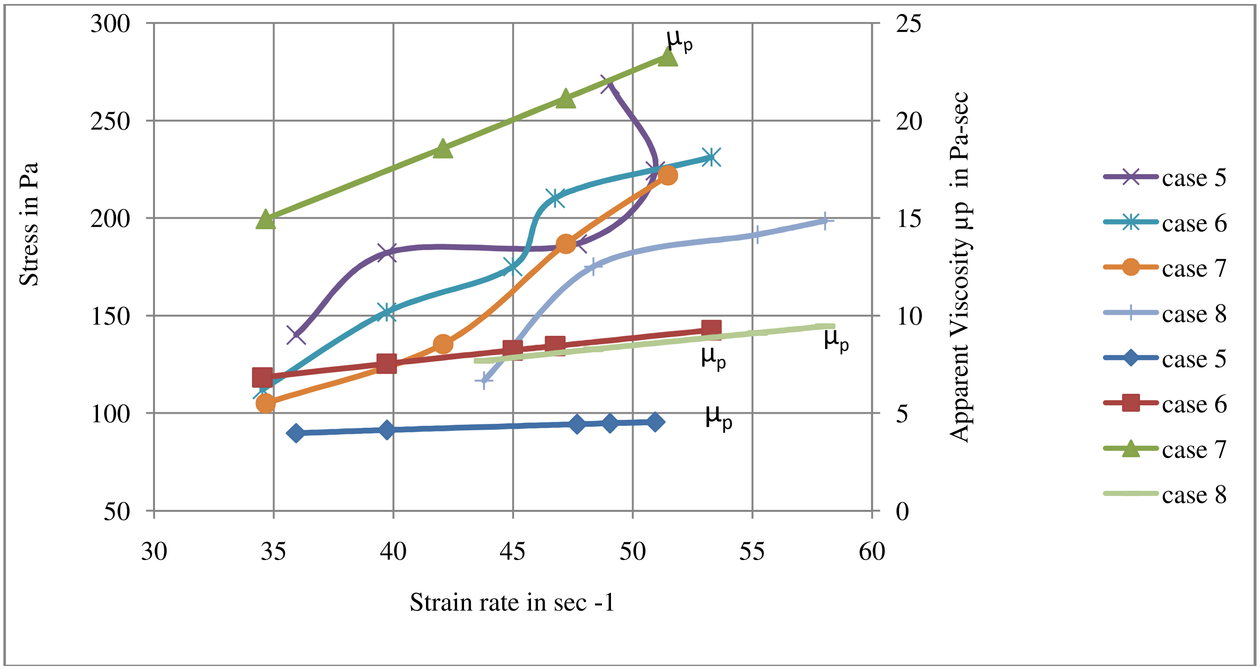

Figure-5: Representation of stress, strain rate and apparent viscosity (μ_p) for pipe flow.

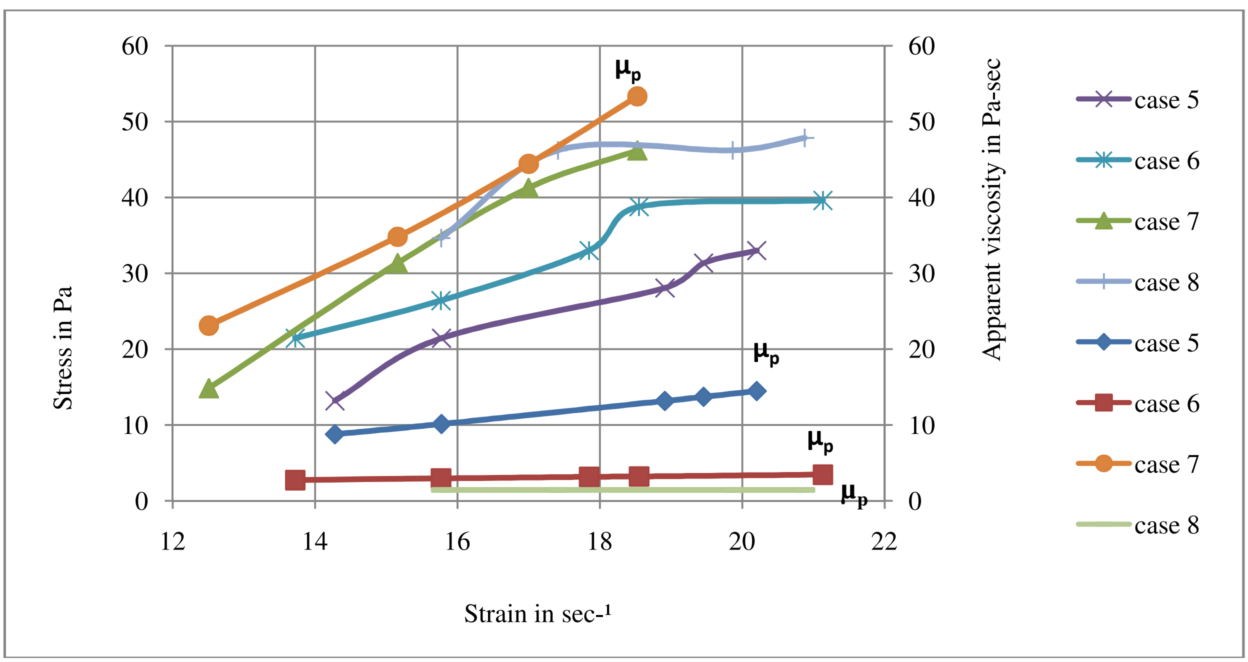

Figure-6: Representation of stress, strain rate and apparent viscosity (μ_p) for annular flow with rotation.

Table-2: Effect of concentration.

Sample No	Composition	Density	Rheological Data			
			Pipe flow		Annular flow with rotation	
		(ρ) in kg/m^3	*k*	*n*	*k*	*n*
2	2% Wt/wt Bentonite (150 micron Particle size).	981.7	0.23814	2.3059	0.098865	2.928
3	4% Wt/wt Bentonite (150 micron Particle size).	983.33	1.268886	1.2625	0.128993	2.787
8	6% Wt/wt Bentonite (150 micron Particle size). 7.2 gms gum / 100 gms bentonite, 3.2 gms / 100 gm bentonite, 0.833gm / 100 gms bentonite.	994.74	0.47607	1.736	1.462285	0.994
10	4% Wt/wt Bentonite (600 micron Particle size).	1029	1.48231	1.3287	0.052866	3.42
14	4% Wt/wt Bentonite (600 micron Particle size). 7.2 gms gum / 100 gms bentonite, 3.2 gms / 100 gm bentonite, 0.833gm / 100 gms bentonite.	1035.69	0.16046	2.5452	0.008189	4.867
15	6% Wt/wt Bentonite (600 micron Particle size).	1052.12	0.41008	1.8622	1.2789	1.008
19	6% Wt/wt Bentonite (600 micron Particle size). 7.2 gms gum / 100 gm bentonite, 3.2 gms / 100 gm bentonite, 0.833 gm / 100gms bentonite.	1061.96	1.28018	1.3759	0.10614	2.905

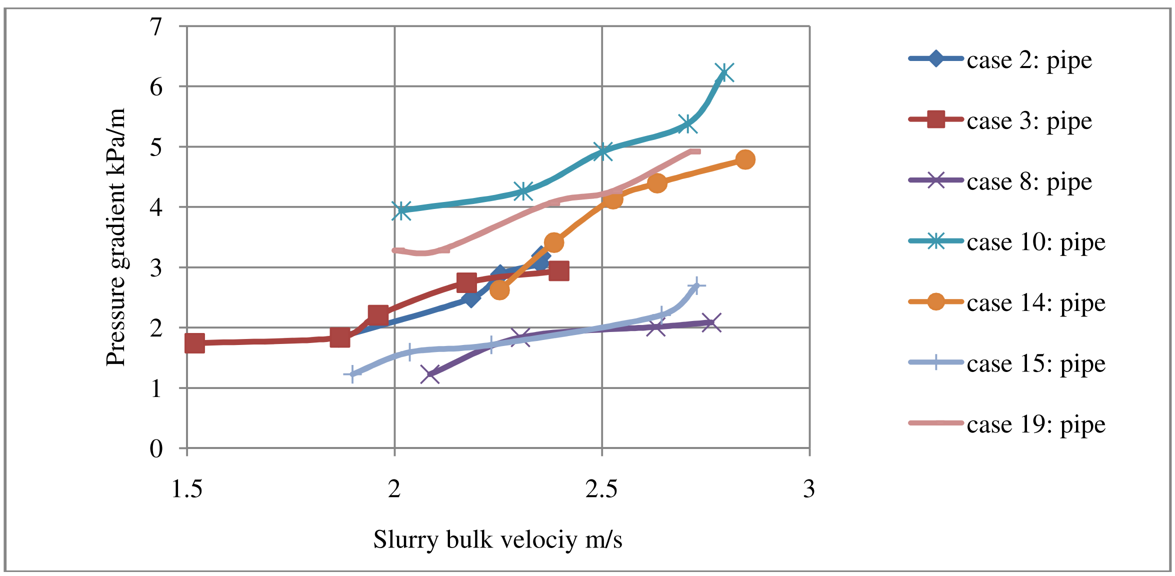

Figure-7: Showing variation between pressure gradient and slurry bulk velocity for pipe flow.

Results are concluded for some selected samples. From Figure-7 for pipe flow, it can be concluded that for sample no 2 (2% conc., 150 micron) and sample no 3 (4% conc., 150 micron) pressure gradient increases with increase in slurry bulk velocity and it has linear profile. For Sample 3 the curve has lower value of slurry bulk velocity as compare to all the samples. For sample 8 (6% conc., 150 micron) curve shows the similar linear profile with additives but has low values of pressure gradient as compare to other samples. For sample 10 (4% conc., 600 micron), the curve has higher value of pressure gradient as compare to other samples so it can concluded that the particle size has greater impact on pressure gradient. For sample 14 (4% conc., 600 micron) with additive shows similar curve as of sample 8 but has high values of pressure drop as compare to it. Sample 15(6% conc., 600micron) shows similar values as sample 8. Sample 19(6% conc., 600 micron) shows similar curve as that of sample 10 but has slightly less value of pressure drop as compare to it.

From Figure-8 for annular flow without rotation it can be concluded that for the all samples pressure drop increases with increase in bulk velocity.

From Figure-9 for annular flow without rotation it can be concluded that for all samples pressure drop increases with increase in bulk velocity but has high value pressure drop because of friction due to rotation.

Effect of additives: From Figure-7 and 8, it is clear that additives have greater impact on water- bentonite suspension as compare e.g., sample no 8 has low value of pressure drop as compare to other samples. Sample no 14 and 19 have higher value of pressure gradient as compare to other.

From Figure-8 for annular flow without rotation it is concluded that for sample 8 pressure drop has higher value as compare to others. Except sample 8 all the samples show the similar profile. Similarly, for Figure-9 it is concluded that from the entire samples, sample 8 has higher values pressure drop. So it means additives greatly affect the flow of pipe.

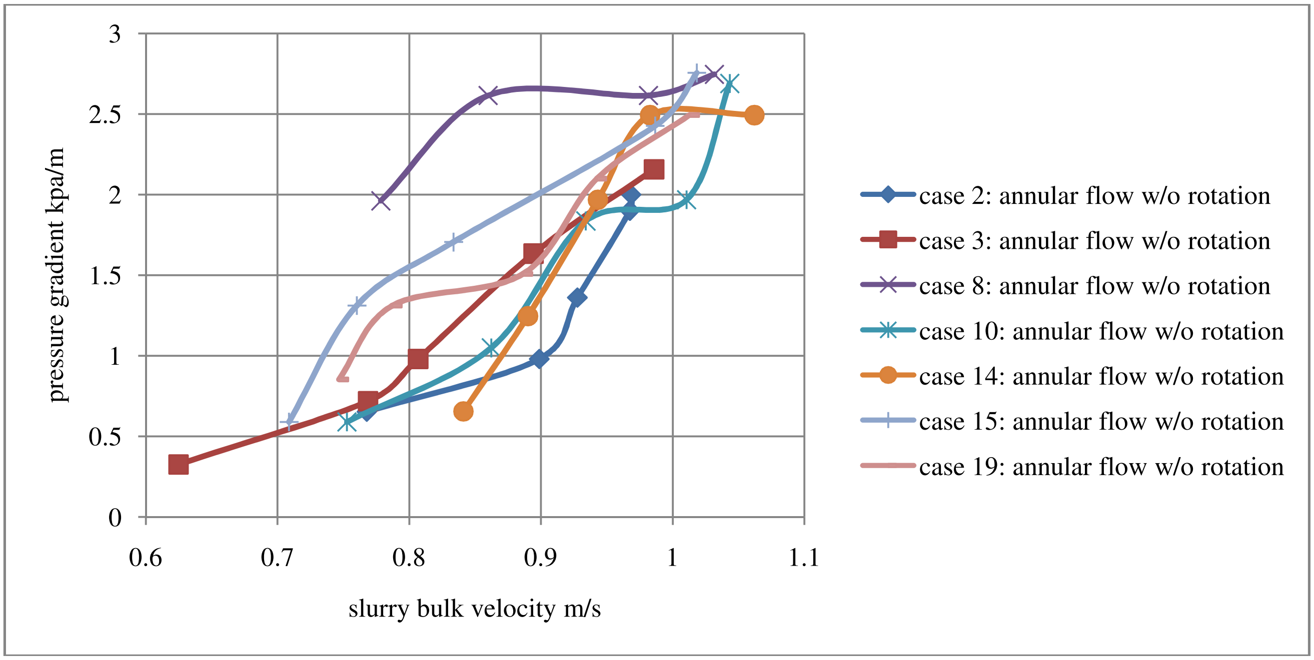

Figure-8: Showing variation between pressure gradient and slurry bulk velocity for annular flow without rotation.

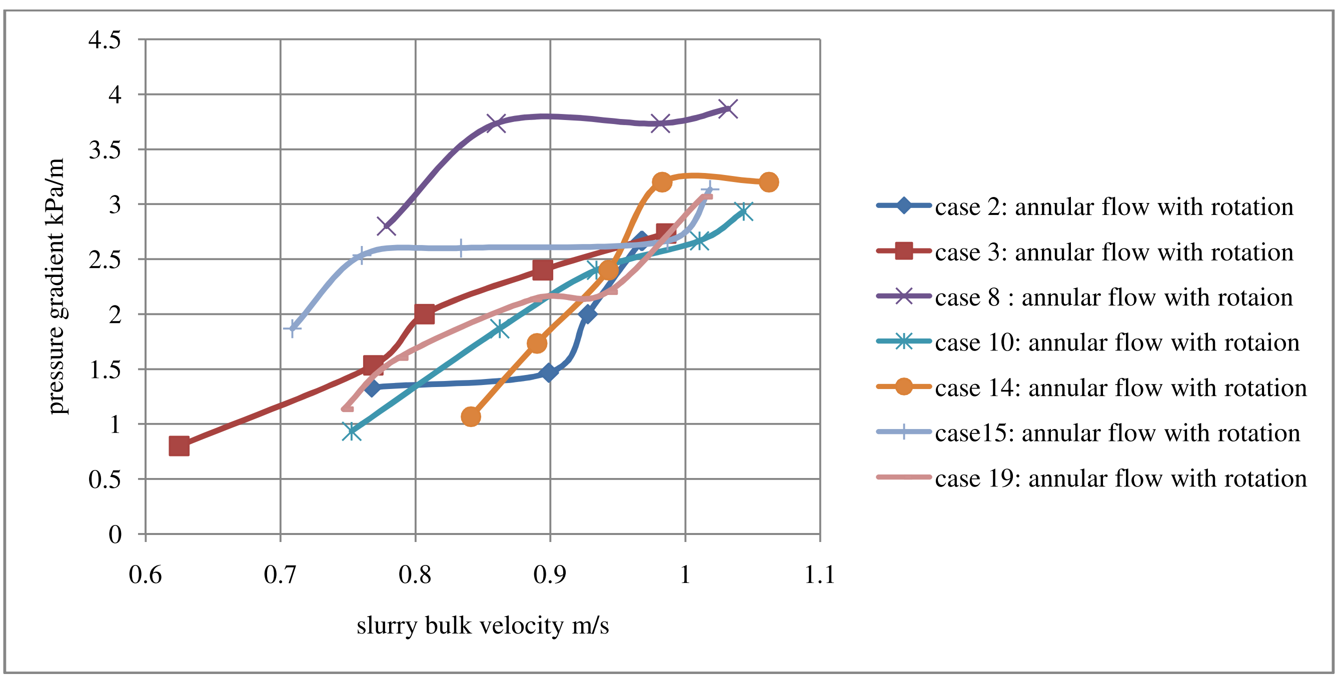

Figure-9: Showing variation between pressure gradient and slurry bulk velocity for annular flow with rotation.

Effect of particles size: From Figure-7 for pipe, it is concluded that for sample 2 and sample 3 (150 micron particle size) pressure gradient increases with increase in slurry bulk velocity and it has linear profile. For Sample 3 the curve has lower value of slurry bulk velocity as compare to all other samples. For sample 8 (with additives), curve shows the similar linear profile but has low values of pressure gradient as compare to other samples. For 600 micron, the curve for sample 10 has higher value of pressure gradient as compare to other samples so it is concluded that the particle size has greater impact on pressure gradient and flow parameter. For sample 14 (with additive) shows similar curve as that of sample 8 but have high value of pressure drop as compare to it. Sample 15 shows similar values as that of sample 8. Sample 19 shows similar curve as that of sample 10 but has less value of pressure drop as compare to it.

Conclusion

The present work shows the results from the experiments that are conducting under the different flow condition i.e., pipe flow, annular flow without rotation and annular flow with rotation. The experiments are conducted for particulate slurries at different concentration at different velocities with and without additives. From the (Figure 5 and 6) relationship between shear stress, strain rate and apparent viscosity, the values of apparent viscosity are increasing with increasing strain rate. Each sample shows the shear thickening behaviour. Graphs between pressure gradient and slurry bulk velocity for pipe flow, annular flow with rotation and annular flow without rotation are plotted for selected samples. Pressure gradient increases with increase in slurry bulk velocity and it has linear profile. Sample with additives has low value of pressure gradient as compare to other samples like sample 8 (6% conc., 150 micron). For sample 10 (4% conc., 600 micron), the curve has higher value of pressure gradient as compare to other samples so it can concluded that the particle size has greater impact on pressure gradient. It is concluded from above results that the rheological properties of water based slurry are showing different results under different flow condition.

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References

1. Abdou M.I., Al Sabagh A.M. and Dardir M.M. (2013). Evaluation of Egyptian bentonite and nano-bentonite as drilling mud. *Egyptian Journal of Petroleum*, 22(1), 53–59.
2. Vipulanandan C. and Mohammed A.S. (2014). Hyperbolic rheological model with shear stress limit for acrylamide polymer modified bentonite drilling muds. *Petroleum Science and Engineering*, 122, 38–47.
3. Kok M.V. (2004). Determination of rheological models for drilling fluids (a statistical approach). *Energy Sources*, 26(2), 153-165.
4. Vipulanandan C. and Mohammed A. (2015). Effect of nano-clay on the electrical resistivity and rheological properties of smart and sensing bentonite drilling muds. *Journal of Petroleum Science and Engineering*, 130, 86–95.
5. National Iranian Oil Company (2002). Drilling formation. Department of drilling chemistry, Ahwaz, Iran.
6. Yan J.N. (2001). Drilling Fluid Technology. *The Press of University of Petroleum, Dongying*, 358-359.
7. Mahto V. and Sharma V.P. (2004). Rheological study of a water based oil well drilling fluid. *Journal of Petroleum Science and Engineering*, 45(1), 123-128.
8. Garcıa-Ochoa F., Santos V.E., Casas J.A., Gomez E. (2000). Xanthan gum: production, recovery, and properties. *Biotechnology Advances*, 18(7), 549-579.
9. Benchabane A. and Bekkour K. (2008). Rheological properties of carboxy-methyl cellulose (CMC) solutions. *Colloid and Polymer Science*, 286(10), 1173-1180.
10. Esther Vermolen, Menno Van Haasterecht J.T., Shehadeh Masalmeh K., Marinus Faber J., Diederik Michiel Boersma, Marc Gruenenfelder A. (2011). Pushing the envelope for polymer flooding towards high-temperature and high-salinity reservoirs with polyacrylamide based terpolymers. *Society of Petroleum Engineering*, 141497.
11. Kok M.V. and Alikaya T. (2005). Effect of Polymers on the Rheological Properties of KCl/Polymer Type Drilling Fluids. *Energy Sources*, 27(5), 405-415.
12. Chilingarian G.V. and Vorabutr P. (1983). Drilling and drilling fluids. *Elsevier Science Pub. Co., Inc., New York, NY*.
13. Darley H.C.H. and George Gray R. (1988). Composition and properties of drilling and completion fluids. fifth edition, Gulf Professional Publishing, Texas.