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Influence of Polymer on the Performance of Bentonite as a Drilling Fluid

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Abstract— Drilling fluids play a vital role in stabilizing the excavation side walls before concreting and to prevent the formation of sludgy layers at the base of excavation by suspending debris to the ground surface. Although bentonite drilling fluid offers borehole stability, cake formation and working space can limit its usage. In the present study, Polymer fluids have been used to prevent the borehole collapse in sandy soil and to bring out the influence of polymer on the performance of bentonite as a drilling fluid which is of great significance in determining the performance of bored piles. A model pile of 50mm diameter with l/d ratio of 5 is casted with M_{20} grade of concrete and kept under seven days saturation. The pull out test is conducted on the model pile casted with different interface types such as bentonite slurry, PolyAnionic Cellulose polymer (PAC) solution, Partially Hydrolysed PolyAcrylamide polymer (PHPA) solution and PAC polymer mixed with bentonite slurry in the proportions of 0.1%, 0.2%, and 0.3% by weight. The improvement in the pull out capacity is studied by varying the slurry interface. It is observed that, frictional factor (β) is higher for pile formed with 0.1% PAC polymer mixed bentonite slurry interface. This addition of polymer increases the viscosity of slurry and helped in the reduction of fluid loss. The thinner cake formation and uniform surface with no honey comb formation except at the pile base is observed for pile formed with polymer slurry interface when comparing to bentonite slurry interface.

Index Terms— Bentonite, Polymer, Viscosity, Uplift Capacity.

1 Introduction

Drillng fluids is the foremost important requirements including the support for excavation face walls in unstable strata prior to concreting [7] as well as at the time of cuttings to the ground surface, providing power to the cutter, controlling formation pressure (barrier), buoyancy and lubrication. For this purpose, bentonite clay slurry has been the optimal for excavation projects around the world as support fluids since the pioneering work of Veder in the early 1950s [7], [5], [6], [8]. Bored piles and diaphragm walls have been regularly constructed using bentonite slurry (drill mud) to prevent the collapse of side walls of the bore hole as well as heaving at the base [11]. The construction industry uses bentonite slurry in the construction of Diaphragm walls, piling and drilled shafts. The slurry-displacement method is used where soil conditions are such that caving or excessive deformation will occur when a hole is excavated. The slurry is then displaced by concrete which is placed through a tremie. The bentonite slurry is able to stabilize the excavation, preventing bulging or wall collapse through the formation of a filter cake. The polymers are added to develop viscosity and reduction water loss [2]. A viable partly hydrolyzed polyacrylamide (PHPA) known as Shore Pac was used to prepare the test slurry [9].

The mechanisms by which a seal is formed at the soil surface causing filter-cake development were Surface filtration and deep filtration. In surface filtration, very little bentonite penetrates the soil and lodges the pore spaces lead to the growth of filter cake on the soil surface. Deep filtration is a more intricate mechanism of filter-cake development than surface filtration. During deep filtration, the slurry penetrates the soil several millimeters and the seal is not formed as quickly as in surface filtration and thus filter-cake development is slower. This filter cake is shielded by layer of bentonite particles called as bentonite cake. It shows that the use of bentonite fluids can increase the risk of 'soft toe' and concrete contamination due to the settling of suspended soil particles [4]. Thus, the amount of time between completion of the excavation and the placement of the concrete influences the filter-cake thickness. The longer the slurry remains in an excavation, the thicker the filter cake which affects the load capacity of pile. Hence the drilling fluid system requires alternate fluid so that the thickness of bentonite cake is reduced. Polymer as a single product would be similar to treating all clay slurries, such as bentonite, attapulgite, kaolin, and native clay as if they were all equal [3].

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2 Methodology

For the experimental studies, the model pile of 50mm diameter and 250mm length is constructed under bentonite slurry, polymer solution and also mixture of bentonite and polymer solution as interface types in a cylindrical steel tank of diameter 500mm and depth of 600mm. The basic properties of selected bentonite, bentonite slurry and polymer solution are studied. The load displacement response of model piles are studied and compared with the piles constructed under different drilling fluids. The soil sample collected is medium sand and materials used are sodium bentonite, PolyAnionic Cellulose (PAC) Polymer and Polyacrylamide polymer. The Pull out response of piles are studied by casting the piles under bentonite with 0.1%, 0.2% and 0.3% PAC and the results are compared with the model piles constructed under bentonite slurry and polymer solution.

3 Index Properties

To study the effect of mixing Polymer with bentonite, laboratory tests were conducted for the index properties such as liquid limit, plastic limit and shrinkage limit. PolyAnionic Cellulose polymer (PAC) and Partially Hydrolysed PolyAcrylamide (PHPA) polymer are mixed with bentonite in the proportions of 0.1%, 0.2%, 0.3% by weight. The index properties of bentonite, bentonite with polymer mixed are presented in Table.1.

TABLE 1

INDEX PROPERTIES

PARAMETERS	Bentonite	Bentonite + PAC Polymer			Bentonite + PHPA Polymer		
		0.1 %	0.2 %	0.3 %	0.1 %	0.2 %	0.3 %
Liquid Limit %	408	412	419	426	396	408	413
Plastic Limit %	48.5	52.34	61.89	70.80	60.34	68.87	70.57
Plasticity Index %	359.5	359.66	357.11	355.2	335.66	339.13	342.43
Shrinkage Limit %	9.52	12.36	15.74	20.92	12.11	14.92	18.36

4 FLOW RESPONSE OF DRILLING FLUID

Rheology is the study of the deformation of fluids and flow of matter. Its importance is recognized in the analysis of fluid viscosity (marsh funnel viscosity) and borehole cleaning. Rheological properties (such as density, viscosity etc.) are the basis to assess the functionality of the mud system in the drilling operations. The viscosity property is analyzed for the bentonite slurry, polymer solution using Marsh funnel viscosity test.

4.1 Properties of Bentonite Slurry

The relation between specific gravity of bentonite slurry versus time clearly depicts that the Marsh cone viscosity increases with specific gravity of bentonite slurry and it increases exponentially beyond the specific gravity of 1.04 shown in table. 2. In this project specific gravity of 1.05 has been adopted in experimental studies as the low specific gravity will not offer adequate strength shown in fig. 1.

TABLE 2

SPECIFIC GRAVITY, MARSH FLOW AND PH OF BENTONITE SUSPENSION

Specific Gravity	Slurry composition Water	Bentonite	Marsh Flow (sec)	pH
1.01	99.5%	0.5%	26	7.84
1.02	99%	1.0%	26	8.13
1.03	98%	2.0%	26.5	8.81
1.04	97.5%	2.5%	28	9.21
1.05	97%	3.0%	30	9.62
1.06	96.5%	3.5%	31	10.01
1.07	96%	4.0%	32	10.38
1.08	95%	5.0%	34	10.79

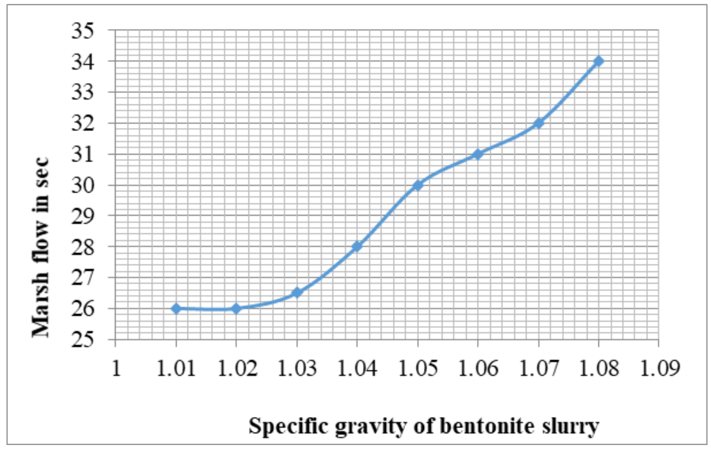


Fig. 1. Relation between specific gravity of bentonite suspension and Marsh flow in seconds

4.2 Properties of PAC Polymer Solution

The Marsh funnel tests were conducted for the PolyAnionic-Cellulose polymer solution by varying concentration from 0.7 to 2.9gm/l with an increment of 0.2gm/l as the normal concentration of PAC polymer ranges from 0.71 to 2.85gm/l. From the marsh cone flow test, the viscosity of fluid is measured in terms of flow time and is listed in the Table. 2.1 for various concentration of polymer solution along with respective pH values. It was found to be that the Marsh cone viscosity increases with the increase in PAC concentration. Relation between various concentration of PAC solution, Marsh flow and pH are plotted in Figure. 1.1.

TABLE 2.1

SPECIFIC GRAVITY, MARSH FLOW AND PH FOR VARIOUS CONCENTRATION OF PAC SOLUTION

PAC (gm/l)	Marsh Flow (sec)	pH
0.9	26.5	8.39
1.1	29	8.48
1.3	30	8.56
1.5	31	8.60
1.7	32.5	8.66
1.9	34	8.72
2.1	37	8.77
2.3	38.5	8.89
2.5	42	8.95

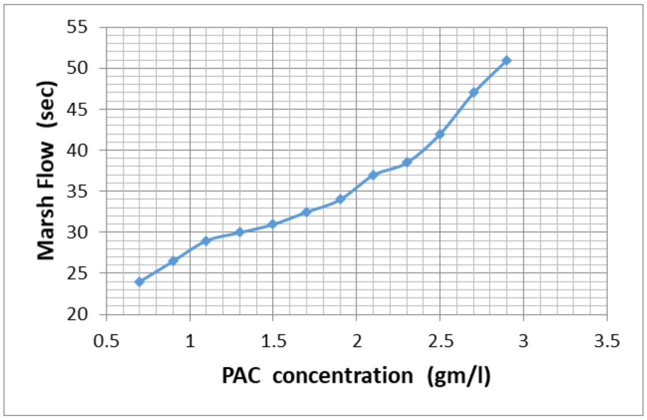


Fig. 1.1. Relation between PAC concentration and Marsh flow

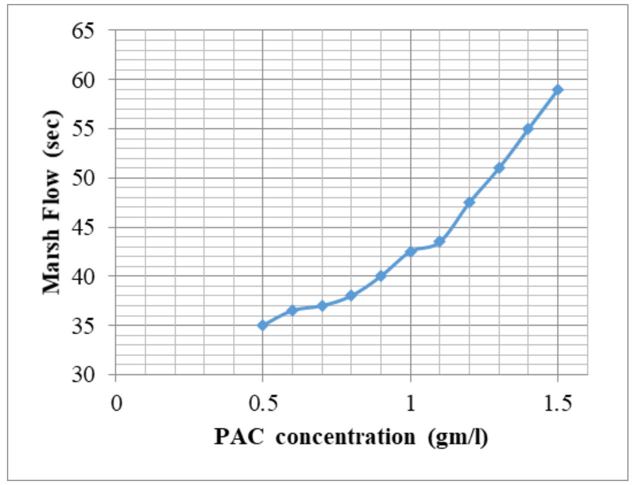


Fig. 1.2 Relation between polyacrylamide concentrations and Marsh flow

4.3 Properties of Polyacrylamide Polymer Solution

The Marsh funnel test and pH test (Plate 4.3) were conducted for the PolyAcrylamide polymer solution by varying concentration from 0.5gm/l to 1.5gm/l with an increment of 0.1gm/l. From the marsh cone flow test, the viscosity of fluid is measured in terms of flow time and is listed in the Table. 2.2 for various concentration of polymer solution along with respective pH values. It was found that the Marsh cone viscosity increases with the increase in PA concentration. Relation between various concentration of PA polymer solution, Marsh flow and pH are plotted in Figure. 1.2.

TABLE 2.2

MARSH FLOW AND PH FOR VARIOUS CONCENTRATIONS OF POLYACRYLAMIDE POLYMER SOLUTION

Polyacrylamide polymer concentration (gm/l)	Marsh Flow (sec)	pH
0.5	35	8.18
0.6	36.5	8.28
0.7	37	8.39
0.8	38	8.55
0.9	40	8.62
1.0	42.5	8.66
1.1	43.5	8.73
1.2	47.5	8.81
1.3	51	8.89
1.4	55	8.95
1.5	59	9.03

4.4 Bentonite Slurry Mixed With PAC Polymer

The bentonite slurry of specific gravity 1.03, 1.04, 1.05 and 1.06 are mixed with different concentrations of PAC polymer. Marsh funnel tests are conducted on them and the results are furnished in the Table. 2.3 and the relation between Marsh flow and the bentonite slurry mixed with PAC polymer are presented in the Figure 1. It can be seen from the curves presented in the figure. 1.3 that the marsh cone viscosity increases with increase in percentage of polymer mixed bentonite slurry. However, the rate of increase in viscosity is higher for bentonite slurry having specific gravity of 1.06.

TABLE 2.3

MARSH FLOW FOR DIFFERENT CONCENTRATIONS OF PAC POLYMER

PAC concentration (%)	**Marsh Flow 's'**			
	γ =1.03	**γ =1.04**	**γ =1.05**	**γ =1.06**
0	26.5	28	29	30
0.1	27	28.5	31	34.5
0.2	27.5	30.5	35.5	39
0.3	30	34	39	45
0.4	33.5	37.5	44	49.5
0.5	36	43.5	47.5	53

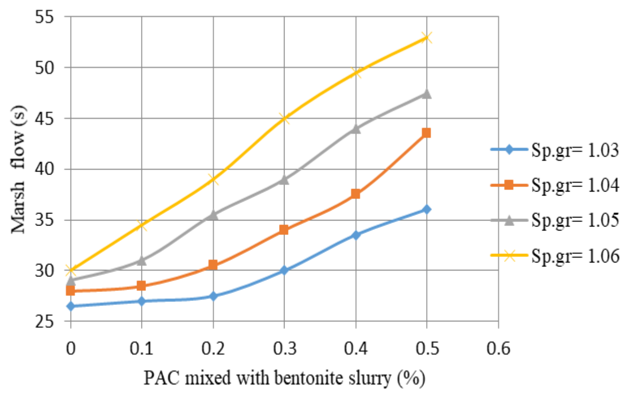


Fig. 1.3. Relation between PAC concentration to Marsh flow for four different specific gravity of bentonite slurry (1.03, 1.04, 1.05 and 1.06)

5 EXPERIMENTAL STUDY

The pull out test is conducted on the model pile casted with different interface types such as bentonite slurry, PolyAnionic Cellulose polymer (PAC), Partially Hydrolysed PolyAcrylamide (PHPA) polymer and PAC polymer mixed with bentonite slurry in the proportions of 0.1%, 0.2%, and 0.3% by weight. The model pile was subjected to pullout load to analyze the frictional capacity alone.

5.1 Pullout Response

To improve the performance of bentonite slurry as against reduction in the pile capacity, 0.1%, 0.2% of PAC polymer mixed with bentonite slurry, bentonite slurry alone, and PAC polymer is charged into the pile hole and the model pile was casted and tested for the uplift capacity. The load-displacement relationship obtained from the pull out test conducted on model pile casted under bentonite slurry alone, PAC, and bentonite slurry with 0.1%, 0.2% PAC polymer is shown in the Fig. 2, Fig. 2.1, Fig. 2.2 and Fig. 2.3 respectively.

Fig. 2. Pull out response of model pile with bentonite slurry of 1.05 specific gravity

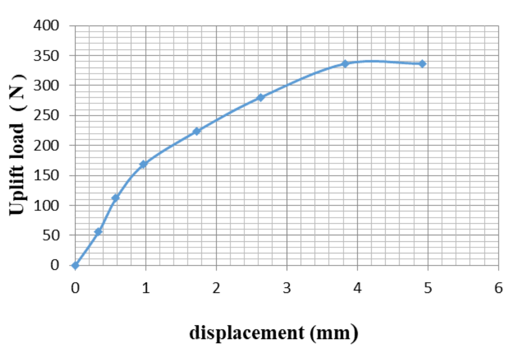


Fig. 2. Pull out response of model pile with bentonite slurry of 1.05 specific gravity

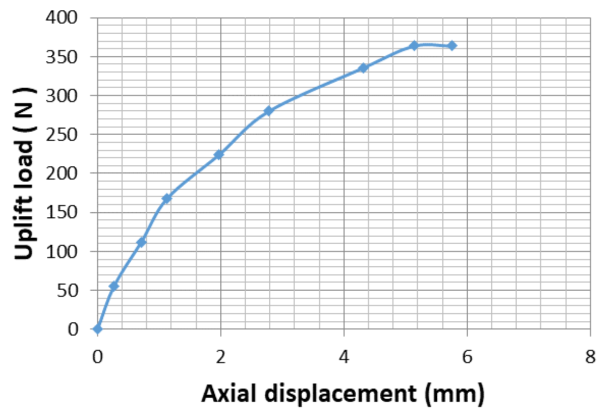


Fig. 2.1 Pull out response of model pile with PAC polymer solution of 1.78gm/l concentration

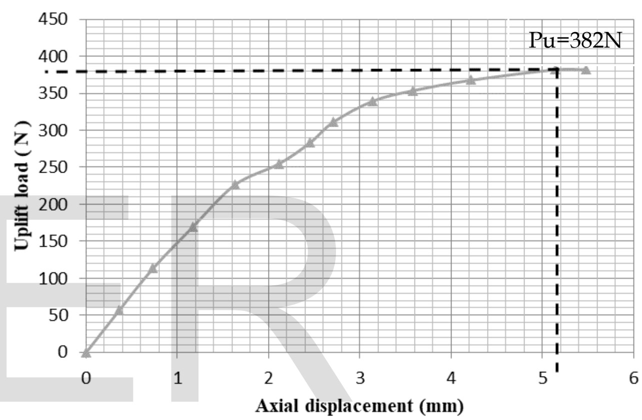


Fig. 2.2. Pull out response of model pile with bentonite + 0.1% PAC polymer interface.

TABLE 3
RESULTS OF EXPERIMENTS OF MODEL PILE WITH DIFFERENT INTERFACE

Pile casting under interface type	Ultimate uplift load (N)	Maximum displacement (mm)	Self-weight of pile (W_p) (N)	Skin friction factor (β= K tan δ)
Bentonite + 0.1% PAC	382	5.14	19.41	2.571
Bentonite + 0.2% PAC	355	4.80	19.82	2.268
Bentonite + 0.3% PAC	345	4.36	18.63	2.235
Polyacrylamide polymer solution	361	5.19	19.66	2.387

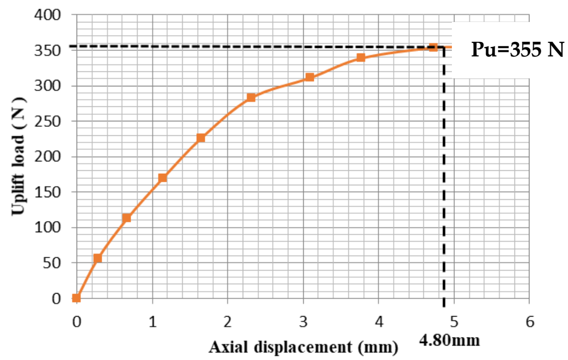
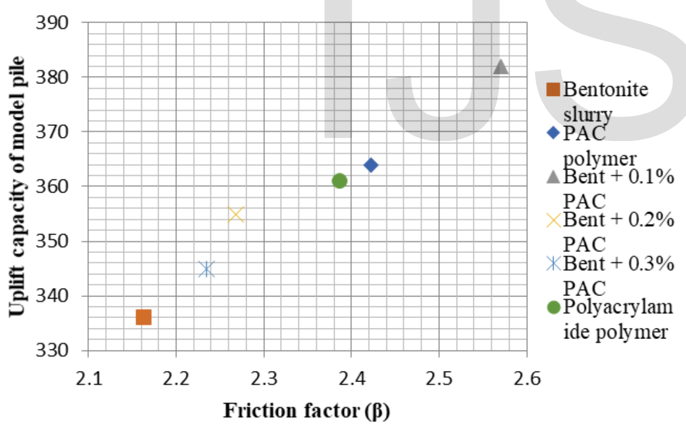


Fig. 2.3. Pull out response of model pile with bentonite + 0.2% PAC polymer interface.

The value of skin friction factor (β) is greater for the model pile with 0.1% PAC polymer mixed bentonite as an interface. This showed that there is less capacity loss when PAC polymer is used as drilling fluid. There is an increase of frictional capacity by 10.70% for polymer interface and 15.87% for 0.1% PAC polymer with bentonite interface over the capacity of pile casted using bentonite slurry as a stabilizing fluid. The frictional factor is compared with the uplift capacity of model pile



for various slurry interfaces and presented in the fig. 2.4.

Fig. 2.4. Uplift capacity vs. frictional factor for piles casted with various drilling fluids.

5.2 Direct Shear

The angle of internal friction was more in the sand which has been taken from the borehole side wall with PHPA polymer solution interface when compared to the sand with bentonite slurry interface. The low value of friction angle in the sand with bentonite slurry interface is due to the presence of fines content in the bentonite slurry that penetrates into the porous granular medium. The angle of internal friction and apparent cohesion are obtained for saturated sand medium with no slurry interface by maintaining the water content of 11 to 13% and is shown in Fig. 2.5 and Fig. 2.6 respectively.

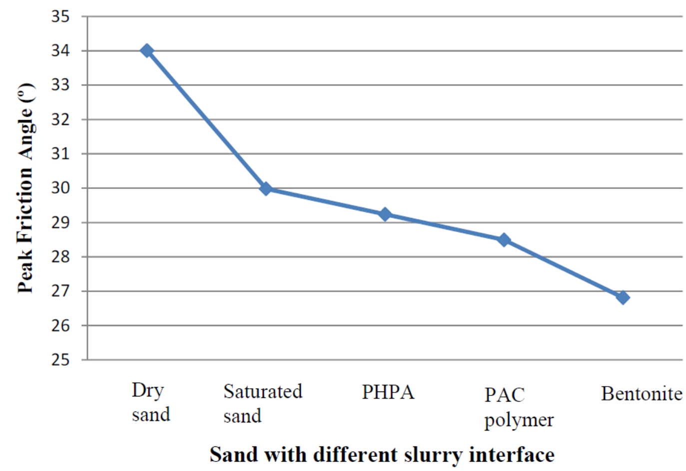


Fig. 2.5. Variation of Peak friction angle of sand for different slurry interface

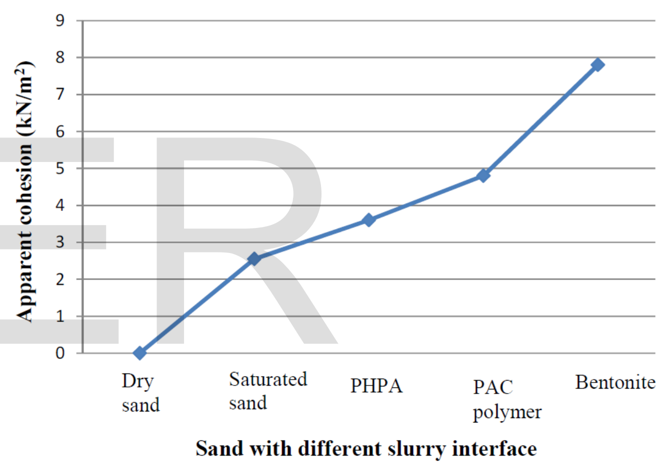


Fig. 2.6. Variation of Apparent cohesion of sand for different slurry interface

TABLE 3.2
DIRECT SHEAR TEST RESULT

Slurry Interface	Peak Friction Angle	Apparent Cohesion
Dry sand (No slurry)	34°	-
Saturated sand (No slurry)	29.98°	2.55 kN/m²
PHPA Polymer	29.235°	3.6 kN/m²
PAC polymer	28.489°	4.8 kN/m²
Bentonite slurry	26.81°	7.8 kN/m²

5.3 Fluid Loss Characteristics for Different Types of Slurry

The quantity of slurry discharged into the pile hole is measured for the different types of slurry. The bentonite slurry occupies the volume of pile hole and seems to get infiltrated into the surrounding sand medium. The fluid loss in the pile hole for bentonite slurry and polymer solution is measured and presented in the Table. 3.3.

TABLE 3.3
FLUID LOSS CHARACTERISTICS

Types of slurry	Quantity of slurry discharged into the pile hole (ml)	Fluid loss (ml)
Bentonite	1964	1473
PAC polymer	602	111
Bentonite + 0.1% PAC	711	220
Bentonite + 0.2% PAC	702	211
Bentonite + 0.3% PAC	688	197
Polyacrylamide polymer	693	202

As the bentonite slurry gets infiltrated, the slurry is again charged into the pile hole and maintained for less than 4 hours. The volume of pile hole is 491 cm^3.There is a drastic reduction in fluid loss in the hole for PAC polymer solution compared to bentonite slurry.

6 CONCLUSION

The "K tan δ" value for polyacrylamide polymer interface is 2.387. The increase in frictional capacity is 9.4% for PA polymer solution interface as compared with the bentonite slurry interface. The "K tan δ" value for PAC polymer interface is 2.422. The increase in frictional capacity is 10.7% for PAC polymer solution interface as compared with the bentonite slurry interface. There is an improvement on friction resistance of pile by the addition of PolyAnionic Cellulose (PAC) polymer [10] to bentonite slurry. The improvement is 5.17% for the PAC polymer additive concentration of 0.1% compared with PAC polymer interface alone. The low value of friction angle in the sand with bentonite slurry interface is due to the presence of fines content in the bentonite slurry that penetrates into the porous granular medium. There is a drastical reduction in fluid loss in the hole for PAC polymer solution compared to bentonite slurry.

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