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MODELING THE EFFECT OF KCL INHIBITION ON THE RHEOLOGICAL PROPERTIES OF SHALE CONTAMINATED WATER BASED MUD

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Abstract

Water based muds are the most extensively used drilling muds. Their use is however limited, especially in shaley formations where it results to various degrees of wellbore instability. In such formations, oil based muds are often utilized due to their possession of superior shale stabilization properties. The recent emphasis on environmental protection, high cost of formulation and disposal after use, amongst other factors however, present huge challenges to the use of oil based muds thereby resulting to a pressing need for the design of water based muds that can be adapted to suit the drilling of such problematic formations. Use of potassium based (i.e. KCl) inhibition has been found to be successful in areas where inhibition is required to limit chemical alteration of shales, the challenge then becomes the development of efficient means of formulating such mud systems.

In this paper, experimental data is used to establish the fact that rheological properties of a water based mud (plastic viscosity and yield point) are altered when shaley formation is encountered and use of KCl inhibition can correct this problem as it tends to return the properties to their original values. Furthermore, equations which can be used to predict the changes in rheological properties as shale concentration increases and effect of utilizing inhibition are developed using the obtained data with reasonable accuracy.

Keywords: shaley formation; wellbore stability; inhibition; rheological properties; drilling mud.

1. Introduction

Drilling fluid or mud is a mixture of barite, clay and other chemical additives in a liquid phase. It is the life-blood of drilling operations. This is because an oil or gas well cannot be drilled without continuous circulation of the drilling fluid to facilitate drilling operations [6].

Drilling mud performs numerous functions such as removal of drilled cuttings, control of formation pressure, maintenance of wellbore stability and facilitation of proper bit performance.

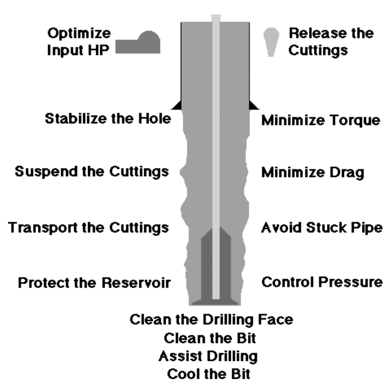

Figure 1 Functions of a drilling fluid

The complex drilling fluids represent 15 to 18% of the total cost (about $1 million) of petroleum well drilling [5]. Their formulation and characterization require various techniques. Use of drilling fluid technology is dependent on performance, economics and environmental concerns [6].

Water based drilling muds are the most extensively used drilling muds according to the Oilfield Market Report (2004). They are generally easy to build, inexpensive to maintain, and can be formulated to overcome most drilling problems. The primary performance criteria for a drilling fluid are its rheology and hydraulics. Water based muds (WBMs) can be further classified into inhibitive, non-inhibitive and polymer.

For the purpose of the study of this paper, KCl-inhibitive type water based mud is utilized. The effect of shale and inhibition on water based mud's rheology is established and subsequently modeled with reference to plastic viscosity and yield point.

Rheology is primarily concerned with the relationship of shear stress and shear rate and the impact these have on flow characteristics inside tubular and annular spaces. In drilling fluids analysis, the flow behavior of the fluid is described using rheological models and equations. The influence of rheological properties of mud in drilling is mostly significant in borehole cleaning, barite suspension and solids separation [10].

2. Model Development

The model was developed through the use of Excel® trendline function. A trendline is used to graphically display trends in data; it goes beyond the actual data to predict future values. A trendline is most accurate when its R-squared value is at or near 1. When a trendline is fit to a data set, Excel® automatically calculates its R-squared value.

3. Results and discussion

The experimental data show that rheological properties of a WBM (plastic viscosity and yield point) are altered when shale formation is encountered and use of KCl inhibition can correct this problem.

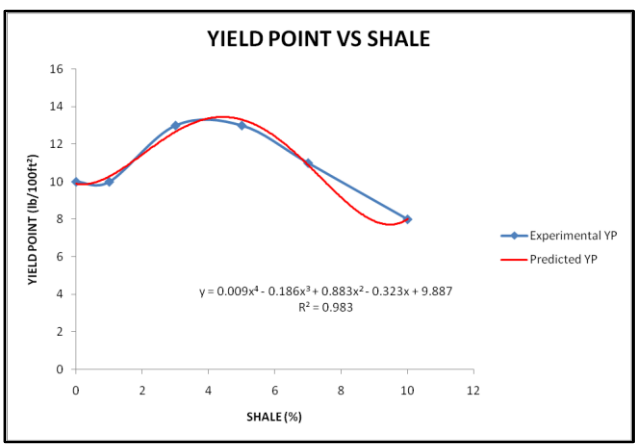

Figure 2 Yield point vs shale concentration profile

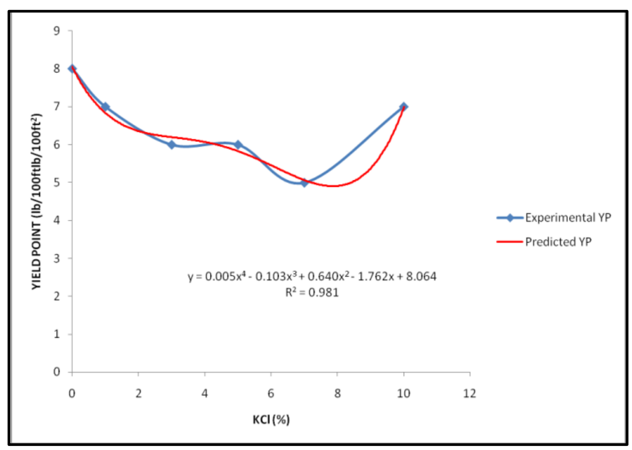

Figure 3 Yield Point vs KCl concentration profile,

Figure 2 shows that there is a non-linear relationship between yield point and shale concentration. The yield point is seen to be steadily increasing until a shale concentration of about 4% after which it starts decreasing. The R-squared value shows that the model is a good fit to the experimental values.

Figure 3 shows that there is a non-linear relationship between yield point and KCl concentration. The yield point is seen to be steadily decreasing until a KCl concentration of about 9% after which it starts increasing as expected. The initial decrease probably signifies the period in which the inhibition effect is overcoming the effect of shale in the system before becoming visibly active and the increase, which is the expected trend, shows that the inhibition is overcoming the effect of shale in the system. The R-squared value shows that the model is a good fit to the experimental values.

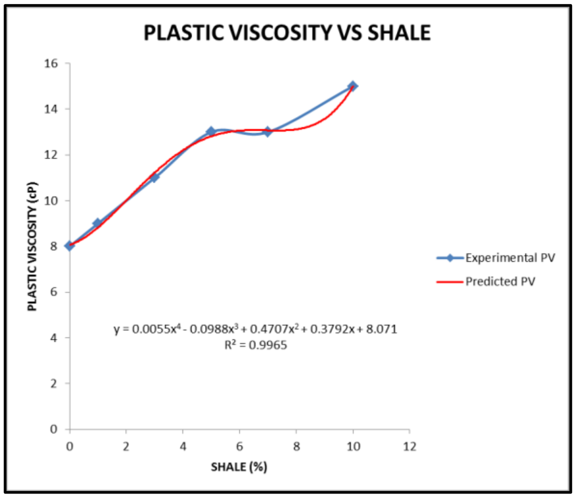

Figure 4 Plastic viscosity vs shale concentration profile

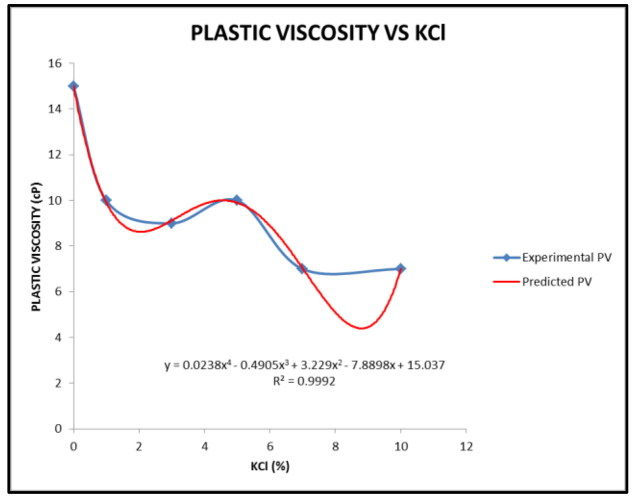

Figure 5 Plastic viscosity vs KCl concentration profile

Figure 4 shows that there is a non-linear relationship between plastic viscosity and shale concentration. The plastic viscosity is seen to be steadily increasing in an almost linear, except for shale concentration of about 6-8% where it remains fairly stable.

Figure 5 shows that there is a non-linear relationship between plastic viscosity and KCl concentration. The plastic viscosity is seen to be steadily decreasing until a KCl concentration of about 2% where it tends to attain stability, before decreasing again. The decrease indicates that the inhibition is overcoming the effect of shale in the system. The R-squared value shows that the model is a good fit to the experimental values.

Table 1 Rheological properties of shale contaminated mud

RPM	Mud + 0% Shale	Mud + 1% Shale	Mud + 3% Shale	Mud + 5% Shale	Mud + 7% Shale	Mud + 10% Shale
	(cp)	(cp)	(cp)	(cp)	(cp)	(cp)
600	26	28	35	39	37	38
300	18	19	24	26	24	23
200	14	13	17	20	17	15
100	9	11	12	14	11	10
6	3	3	3	4	2	2
3	2	2	2	2	1	1
10 sec gel ($lb/100ft^2$)	1	1	1	1	1	1
10 min gel ($Ib/100ft^2$)	2	2	2	2	2	2
PV (cP)	8	9	11	13	13	15
YP ($Ib/100ft^2$)	10	10	13	13	11	8

In general, the experimental data show that rheological properties of a WBM are altered when shaley formation is encountered. Yield point tends to decrease and plastic viscosity mainly increases, with increasing shale concentration. Use of KCl inhibition can correct this problem; in all cases (both YP and PV), the result of increasing KCl inhibition was a reversal of the trend observed during the addition of shale.

The model developed using the experimental data obtained from the laboratory procedures presents a new and unique way of predicting the effect of shale and inhibition on WBM's rheological properties. It requires only the concentrations of shale and concentrations of KCl in the mud as input. The model-derived equations can predict changes in these properties for various concentrations of shale and KCl with reasonable accuracy as indicated by the R-squared values. The model is specifically useful for surface conditions due to the shale concentrations utilized in its development. It can be modified to suit lower depths by incorporating higher shale concentrations and consideration of subsurface conditions into the model development.

Table 2 Rheological properties of shale contaminated mud and potassium chloride (KCl)

RPM	Mud + Shale + 1% KCl	Mud + Shale + 3% KCl	Mud + Shale + 5% KCl	Mud + Shale + 7% KCl	Mud + Shale +10% KCl
	(cp)	(cp)	(cp)	(cp)	(cp)
600	27	24	26	20	21
300	17	15	16	13	14
200	14	13	13	10	11
100	10	8	8	7	7
6	2	2	2	2	2
3	1	1	1	1	1
10 sec gel (Ib/100ft^2)	1	1	1	1	1
10 min gel (Ib/100ft^2)	1	2	2	2	2
PV (cP)	10	9	10	7	7
YP(Ib/100ft^2)	7	6	6	5	7

The model developed using the experimental data obtained from the laboratory procedures, presents a new and unique way of predicting the effect of shale and inhibition on WBM's rheological properties. The model derived- equations can predict changes in these properties for various concentrations of shale and KCl with reasonable accuracy as indicated by the R^2 values.

4. Conclusion and Recommendation

(1) The mathematical model should be used for inhibitive WBM design; this will reduce the time and money spent in the experimental design of such muds, it will also prevent additional drilling expenses due to mud change over.

(2) Excel trendline is a very simple modeling tool; other more enhanced software will probably create better models.

(3) The concentrations of shale and potassium chloride inhibition used for the modeling is small compared to those encountered in reality, this limits the accuracy of the model which is dependent on the amount of data incorporated in its formulation. Hence, it is has potential of becoming a viable tool for minimizing shale instability issues.

(4) Further work should be done on developing inhibitive WBM models so as to curtail costs due to lost non-productive time spent in mud changeover when shaley formation is encountered.

Nomenclature

WBM	*Water Based Mud*
KCl	*Potassium Chloride*
PV	*Plastic Viscosity (cp)*
YP	*Yield Point (lb/100ft^2)*
Θ600	*600 Reading of viscometer (rpm)*
Θ300	*300 Reading of viscometer (rpm)*

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