A New Approach to Improve Cutting Transport in Horizontal and Inclined Wells using MR (Magneterheological) fluid

by

Gurbandurdy Arbadov

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

MAY 2012

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan.

CERTIFICATION OF APPROVAL

A New Approach to Improve Cutting Transport in Horizontal and Inclined Wells using MR (Magneterheological) fluid

by

Gurbandurdy Arbadov

A project dissertation submitted to the

Chemical Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfillment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(CHEMICAL ENGINEERING)

Approved by,

(IR Abd Aziz Omar)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and the original work contained herein have not been undertaken or done by unspecified sources or persons.

(GURBANDURDY ARBADOV)

ABSTRACT

Nowadays, efficient hole cleaning has become one of the major challenges in the oil and gas industry as measured depths and horizontal displacements has been increasing drastically in the ERD (extended reach) wells. Insufficient cutting transport in inclined and horizontal wells can lead to undesirable incidents that may cost drilling operators millions of dollars. If these incidents are not handled properly, they can ultimately lead to loss of the well. An investigation by Amoco showed that 70 % of lost time, due to unscheduled events was associated with the sticking of the drilling string in the deviated wells **[1]**. A case study by Hopkins showed that one third of all stuck pipe problems are due to insufficient wellbore cleaning **[3]**. A single stuck pipe problem may cost over one billion dollars depending on the situation. Bradley et al. reported that stuck pipe costs for the oil and gas industry were in the range of 100 to 500 million US dollars per year **[3]**.

In attempt to avoid such problems, drilling operators often include such practices as washing and reaming, back reaming, wiper trip and increase in a flow rate of drilling fluid in order to increase the drag force on a cutting. All these operations require time and significantly increase the cost of drilling.

This research paper emphasizes on improving a cutting transport in inclined and horizontal wells using MR (Magneterheological) fluid. It is a completely new approach in an oil and gas industry. MR fluids commonly known as Magneto rheological fluids are suspensions of iron particles in liquid whose viscosity increases drastically when exposed to magnetic field. Depending on desired concentration, measured amount of MR fluid will be added to the drilling mud prior to be pumped into the wellbore. As turbulent regime is desired in both inclined and horizontal sections, this approach works to induce the magnetic flux into the mud when it reaches the vertical section of the well as it will increase viscosity and decrease the Reynolds number so the Laminar regime will be attained. Laminar flow is more effective in transporting the cuttings in the

vertical sections of the well. It is crucial to mention that being capable of changing the mud viscosity to a desired value inside the wellbore is a phenomenon.

ACKNOWLEDGEMENTS

Praise to Allah for His guidance and blessings He has given me throughout this Final Year Project. It's the strength from Him that is what keeps us going in everything we do in our lives. My greatest appreciation goes to my supervisors, IR Abd Aziz Omar and Dr. Reza Ettehedi Osgouel for giving me such tremendous helps, advices, opinions and courage all the way through the completion of this project. I appreciate the time they allocated for me, to sit and discuss the problems I've faced along the way. A million thanks to them for having such confidence in me.

My appreciation also goes to Final Year Project Coordinator, Dr. Norhayati Mellon for her guide to me and all my friends, and also to the efforts she put to ensure the smoothness of this course. Thank you so much.

Special thanks to my parents for the continuous support and courage they gave me, which always drives me to keep on going whenever I fall. Last but not least, I also want to thank everybody who have involved directly and indirectly in helping me along this project. Thanks again to all, your kindness and helps will always be remembered.

Table of Contents

\

List of Figures

List of Tables

Abbrevations and Nomenclatures

ECD	-	Equivalent Circulating Density
MR fluid	-	Magnetorheological fluid
YP	-	Yield point (Shear stress to initiate the flow)
PV	-	Plastic viscosity
ppg	-	Pounds per gallon (density of drilling fluid)
AV	-	Apparent viscosity

CHAPTER 1

INTRODUCTION

Challenging locations of hydrocarbon bearing reservoirs increased the need for directional and horizontal wells. Therefore, the interest in cutting transport problems has shifted from vertical to inclined and horizontal geometries in the last 20 years. With increasing measured depths and horizontal displacements in Extended reach (ERD) wells, good hole cleaning remains one of the major factors affecting cost, time and quality of directional, horizontal and extended reach (ERD) wells. Poor hole cleaning can result in expensive drilling problems such as stuck pipe, lost circulation, slow drilling, high torque and drag, lost control of density, poor cement jobs and etc. If not handled properly, these problems can lead to the loss of the well **[5].**

Traditionally, operators usually increase the mud flow rate to enhance the wellbore cleaning as it will increase the drag force on the cutting particle. Moreover, drilling operators often include such practices as "washing and reaming" wherein the drilling fluid is circulated and the drill string is rotated as the bit is introduced to the wellbore, back reaming wherein mud is circulated and the drill string rotated as the bit is withdrawn from the hole and wiper trips. **[5]** All these operations are time consuming and increase the cost of drilling of inclined and horizontal wells. Therefore, search for more effective methods to improve directional and horizontal borehole cleaning is vital in the oil and gas industry.

Cutting transport improvement using MR (Magneterheological) fluid is going to be the first project ever to be applied on shifting the flow regime of a drilling fluid in the wellbore. MR fluids commonly known as Magneto rheological fluids are suspensions of iron particles in liquid whose viscosity increases drastically when exposed to magnetic field. Depending on desired concentration, measured amount of MR fluid will be added to the drilling mud prior to be pumped into the wellbore. As turbulent regime is desired in both inclined and horizontal sections, this approach works to induce the magnetic flux into the mud when it reaches the vertical section of the well as it will increase viscosity and decrease the Reynolds number so the Laminar regime will be attained. Laminar flow is more effective in transporting the cuttings in the vertical sections of the well. This approach has the potential to make a significant improvement in cuttings transport of oil and gas wells while simultaneously lowering the overall well drilling costs.

1.1 Background of Study

Wellbore cleaning is one of the basic functions of any drilling fluid. Cuttings generated by the drilling bit plus any caving or sloughing must be carried out to the surface by the drilling fluid. Efficient cutting transport in highly deviated and horizaontal wells is very challenging. Under the influence of gravity, these cuttings tend to settle out of the drilling fluid. This is known as a slip velocity. This slip velocity depends on the density and viscosity of the drilling fluid. Hole angle, annular velocity and viscosity are essential parameters that needed to be emphasized on in efficient cutting transport. The following figure illustrates the forces acting on the drilled solid in deviated wells.

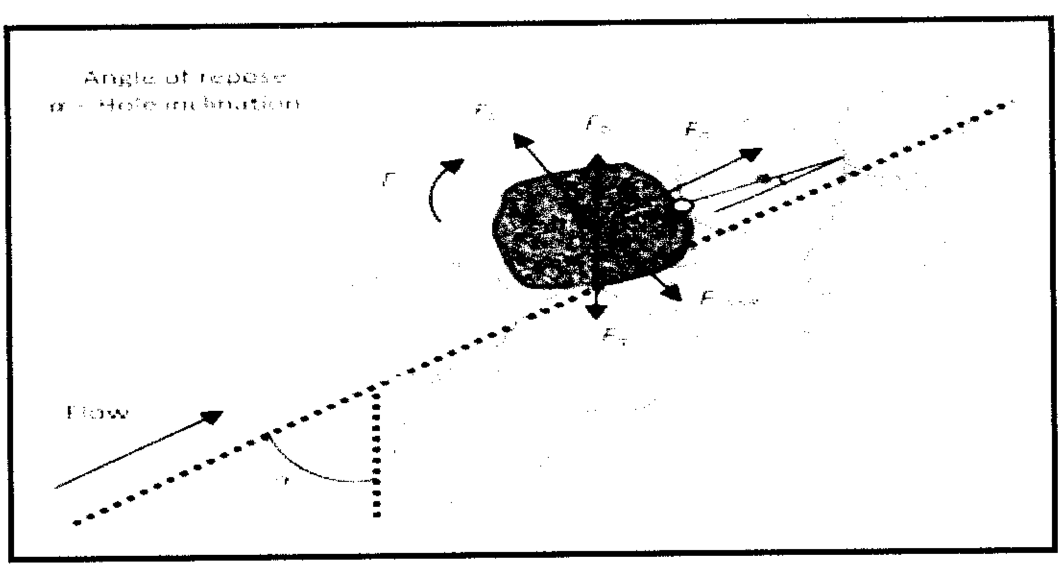


Figure 1: Forces applied to a drilled particle on a cutting bed

F_G - Downward gravitational force (associated with the slip velocity)

F_L – A lift force perpendicular to the direction of the mud flow due to the mud flowing around the cutting particle

F_b – An upward buoyant force due to the cutting being immersed in the drilling fluid

F_d – A drag force parallel to the direction of the mud flow

F_{vanR} – Wan der Waals forces among the cutting particles as particle size decreases and its surface area increases. Therefore, surface forces may show impact on the movement of the particle.

The formulas for the forces acting on the cutting particle are illustrated in the following table.

FORMULA FOR FORCES ACTING ON BED CUTTINGS	
FORCE	*EQUATION*
Gravity (F_G)	$F_G = \frac{1}{6} \rho_L g \pi d_p^3$
Buoyancy (F_B)	$F_B = \frac{1}{6} \rho_L g \pi d_p^3$
Lift (F_L)	$F_L = \frac{1}{8} C_L \rho_L u^2 d_p^2$
Drag (F_D)	$F_D = \frac{1}{8} C_D \rho_L u^2 d_p^2$
Van der waals (F_{van})	$F_{van} = -\frac{A_H d_p}{24 s^2}$

Table 1: Formula for the forces acting on the particle

Cutting transport in horizontal sections of the wells is more difficult than in the vertical sections. The hole cleaning process must counteract gravitational forces acting on the cuttings to minimize settling during both dynamic and static periods. In the vertical sections, the transport velocity counteracts the gravitational forces (slip velocity) acting on the cutting whereas in the deviated and horizontal sections the case is different. The cuttings settle to the low side of the hole as the slip velocity is not in direction opposite to the transport velocity. Following figure clearly indicates the gravitational force to transport velocity relationship.

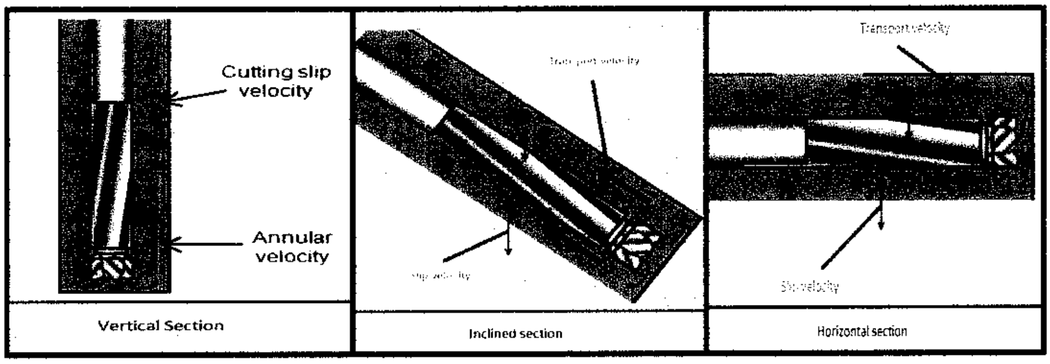


Figure 2: Gravitational force to transport velocity relationship in different hole sections

1.2 Problem statement

However, most of the previous works performed to enhance transport were to increase the mud flow rate and viscosity as it increases the drag force. These works does contribute to the cutting transport in the vertical sections but not in the horizontal and inclined sections as cuttings settle out of the drilling fluid and form a cuttings bed. Moreover large viscosity increases the pressure losses which will lead to more power consumption. Increment in flow rate may increase the drag force but if not controlled properly it may lead to incidents such as erosion of the wellbore and formation damage. These problems may increase the ECD as mud with high flow rate will be coming out from the bit nozzles and form more cuttings. This indeed may lead to formation fracture as it will increase the hydrostatic head of the mud.

Due to the gravitational force acting on the cutting particles and the mud flow direction is not counteracting the slip velocity in the inclined and horizontal sections, the flow regime of the drilling fluid in those sections is preferred to be in turbulent regime. On the other hand, laminar flow is effective in cutting transport in vertical sections as transport velocity opposes the gravity. The flow regime is controlled by Reynolds's number and Reynolds number can be manipulated by varying mud viscosity. For better cutting transport, there should be low viscous mud in the horizontal and deviated *sections for turbulent regime whereas high viscous mud is needed in the vertical sections for laminar flow. So the challenge will be, to change the viscosity of the mud inside the wellbore when it reaches the vertical section and this sounds a bit impossible.*

1.3 Objectives and Scope of Study

This study seeks to attack cutting transport problem by increasing the viscosity of the mud when it reaches the vertical section which will lead to decrement in the Reynolds number and shift the flow regime into Laminar flow as it is desired in vertical sections. The mud coming out of the bit nozzles will have viscosity in acceptable ranges in a way, low viscosity which will lead to the turbulent regime. This phenomenon will be attained by using MR (Magnetorehological) fluid.

MR fluids commonly known as Magneto rheological fluids are suspensions of iron particles in liquid whose viscosity increases drastically when exposed to magnetic field.

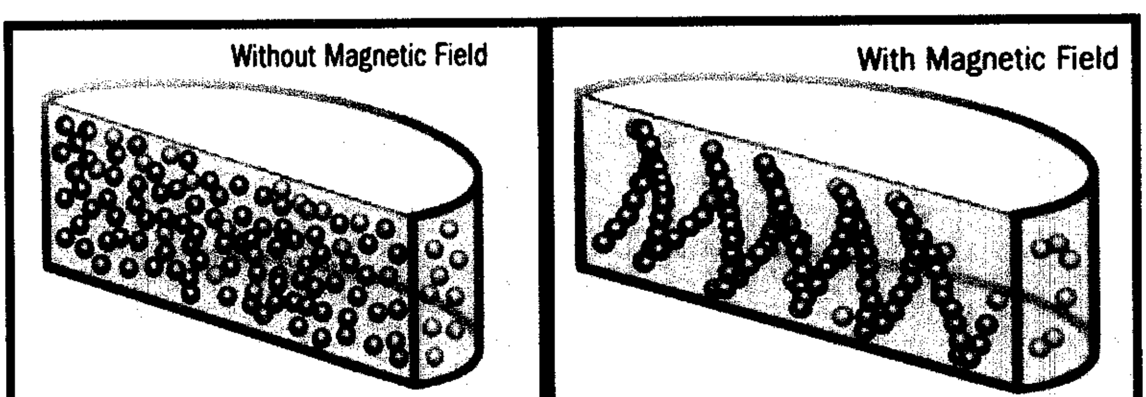


Figure 3: MR fluid under magnetic force

So, our objective is to add MR fluid into the drilling fluid and induce magnetic flux to the mud flowing in the well when it reaches the vertical section of the hole. This will increase the viscosity of the mud and shift the flow regime into Laminar as the regime in the deviated and horizontal sections are turbulent. Then the mud will attain its original position and viscosity value when it will reach the flow line and shale shakers as magnetic force will be induced only in the vertical section of the wellbore. Flow regime is manipulated using Reynolds number.

$$Re = \frac{\rho v D_H}{\mu}$$

If

Reynolds Number > 2100 (turbulent regime)

Reynolds Number < 2100 (Laminar regime)

Turbulent - Low viscosity

Laminar – high viscosity

As you can see from the formula, viscosity is indirectly proportional with the Reynolds number. Therefore, increasing viscosity will decrease the Reynolds number and the flow will shift to laminar regime. The following figure illustrates our challenges that we may face during the application of this method.

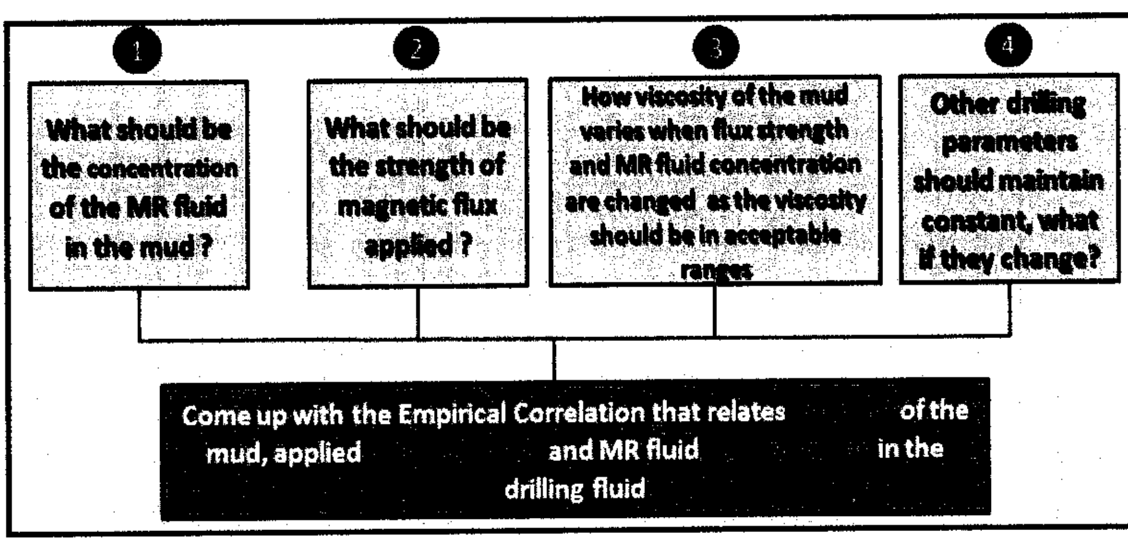


Figure 4: Our challenges and objective

Completing this individual project according to our goals and intentions will give us an opportunity to manipulate the viscosity of the drilling fluid while it is being circulated inside the wellbore. This is a big phenomenon.

CHAPTER 2

LITERATURE REVIEW

2.1 Conventional ways of enhancing cutting transport

Traditionally, drilling operators increase the flowrate and viscosity of the mud to combat the poor hole cleaning. These actions are performed in order to increase the drag force on the cuttings. High viscosity mud can lead to higher pressure losses thus increases the overall power consumption and decrease the drilling rate. Increasing flow rate may increase the drag force on the cutting but if not controlled properly, it can drastically increase the ECD as high flow rated mud will be ocming out of the bit nozzles and produce more cuttings. If ECD is not controlled properly, it can lead to formation fracture as the hydrostatic head of mud may exceed the formation fracture pressure. Moreover, drilling operators often include such practices as "washing and reaming" wherein the drilling fluid is circulated and the drill string is rotated as the bit is introduced to the wellbore, back reaming wherein mud is circulated and the drill string rotated as the bit is withdrawn from the hole and wiper trips. [5] All these operations are time consuming and increase the cost of drilling of inclined and horizontal wells.

2.2 Improve cutting transport by attaching gas bubbles to drilled cutting particles with chemical surfactants.

Title: **A new Approach to improve cutting transport in Horizontal and Inclined Wells.**
Authors: Mengjiao Yu, Daniel Melcher, Nicholas Takach, Stefan Z. Miska, Ramadan Ahmed, The university of Tulsa
Date: **26-29 September 2004**
Type and purpose of paper: **Conference paper prepared for presentation at the SPE Annual Technical Conference and Exhibition held in Houston, Texas**

This proposed study works to counteract gravitational force while simultaneously increasing drag force on the cutting particles by attaching gas bubbles to the drilled cutting particles with chemnical surfactants. Th egas bubbles will pull the cuttings upward because of their buoyancy in the drilling mud thereby counteracting the gravitational force. Counteracting the gravitational force is very important in the deviated and horizontal wells as the cutting tend to settle out of the mud and form a cuttings bed on the low side. When it comes to enhancing the drag force, increment in the surface area of the drilled solids increases the drag force. Gas bubble/ cutting aggregation will have larger surface area than the cutting alone, resulting in a greater drag froce. The folowing figure clearly illustrates the gas bubble and cutting aggregation.

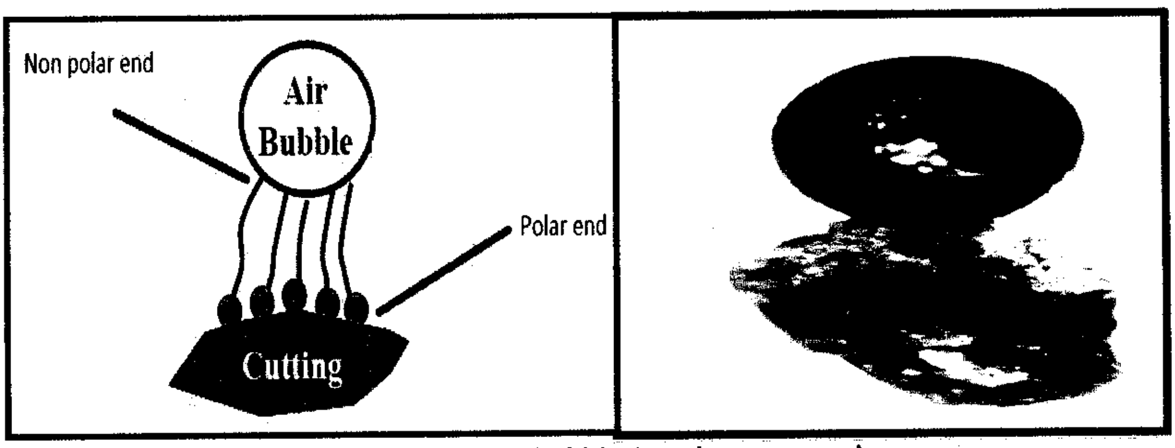


Figure 5 : Gas bubble / cutting aggregation

In addition to the theory behind this technology there were labaratory experiments conducted. Experiments conducted to see the effect of chemical surfactant, pH and particle size in the gas bubble / cutting aggregation. Two types of surfactants were used, one to attach the air bubble to the cutting and the other is to strengthen the air bubble itself. Thecorresponding chemical solution with pH value from 9 to 11 resulted in the optimum bubble/ cutting aggregation to cuttings up to 1.4 mm in diameter that can be floated to the top of the fluid. No attachment was observed without chemical surfactant. "Collector" is a chemical surfactant used to attach the bubble to the cutting and it has polar (to the cutting) and nonpolar (to the bubble) end whereas "frothers" is the surfactant used to enhance the bubble strength.

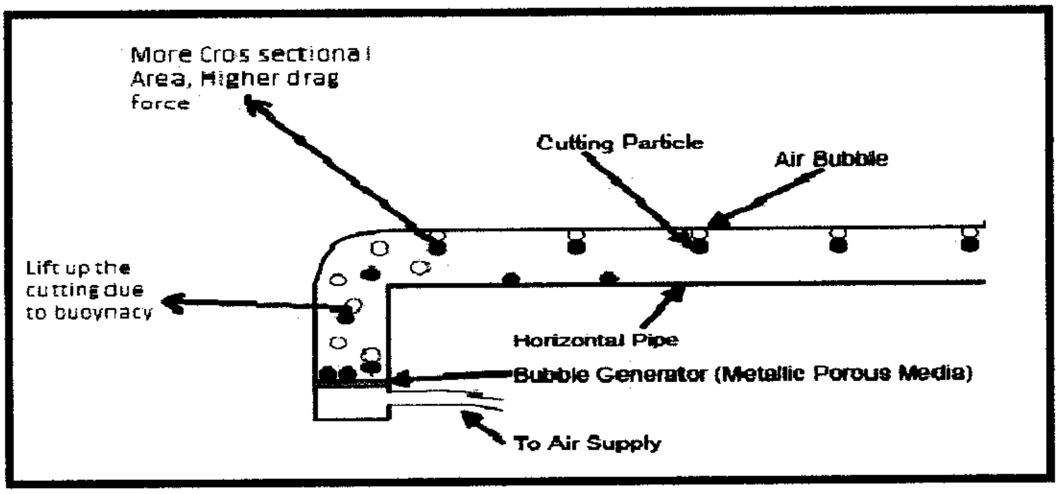


Figure 6 : Experimental set up

The surfactants used were:

- Xanthates
- Potassium octyl hydroxamte
- Amine hydrochlorides
- Amines

2.3 Drilling practiceas and sweep selection for efficient hole cleaning in deviated wells (drill pipe eccentric and sweep)

Succesfull drilling of wells requires sufficient hole cleaning. When drilling deviated wells, some of the primary factors contributing to the challenges in hole cleaning is the drill pipe eccentric in the hole, the need for slide drilling (to build angle and maintain direction) and the resultant skewed flow distribution in the annulus.

When drilling deviated or horizontal wells, the drill string usually located on the low side of the well. Forcing majority of fluid to flow above the string. The shear thinning and yiled stress characteristics of the fluid do not favor flow on the restriction below the drill string in the deviated and horizontal wells. But rheology modification cannot overcome this problem.

Due to the gravitational force, the cuttings tend to fall to the slow side of the deviated or horizontal wells. Regardless the fluid rheology, the efficient hole cleaning in these kind of situations is nearly impossible without drill pipe rotation. The rotation will agitate the settled cuttings into the flow stream.

There are several sweep formulations available for various well angles. It is preferred to use weigthed sweeps for deviated and horizontal wells as weighted sweeps add buoyancy effect to the system. This reduces settling velocity of drilled solids and allows weighted fluid to penetrate to the region below the drill pipe which is usually eccentric in deviated and horizontal wells. Unfortunately, weighted sweeps increase ECD. Therefore, it should be controlled.

High viscosity are also preferred in deviated wells when the drill string rotation is eccentric. As a fluid has a yield stress and it requires a stress to be applied that exceeds the yield stress of the fluid for the fluid to flow. When the pipe is eccentric, in the narrow gap region of the annulus, the yield stresss is low. For the flow to occur in that low side of the well, the prevailing stress conditions should exceed the fluid yield stress. If not , no flow will occur at the low side and minimum solids transport will occur. Therefore, high viscosity sweeps with low yield stress should be good for efficinet hole cleaning in condition of eccentric pipe.

CHAPTER 3

METHODOLOGY

3.1 Fann Viscometer overview

The experimental was started by obtaining information on the Viscometer or rheometer to be used. Throughout this research, our main target will observe the increment in Apparent viscosity of a drilling fluid after applying a magnetic flux. Therefore, the key parameter to measure will be the apparent viscosity of a mud which is the viscosity of the drilling fluid measured at a given shear rate and it is measured using viscometer. Apparent viscosity (AV) is one-half of the dial reading at 600 rpm (1022 sec-1 shear rate) of the viscometer. The FANN VISCOMETER used in the individual project is illustrated in the following figure:

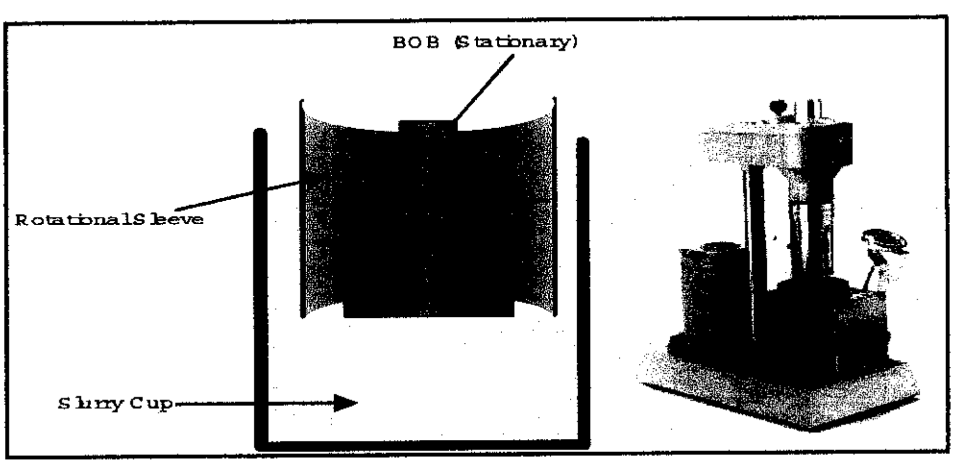


Figure 7: Viscometer

A sample of mud is placed in a slurry cup and rotation of a sleeve in the mud gives readings which can be mathematically converted into apparent viscosity (AV) and yield point (YP). Viscosity measurements are made when the outer cylinder, rotating at a known velocity, causes a viscous drag to be exerted by the fluid whereas the BOB stays stationary.

3.2 Prepare the most convenient type of drilling fluid which is miscible with MR fluid

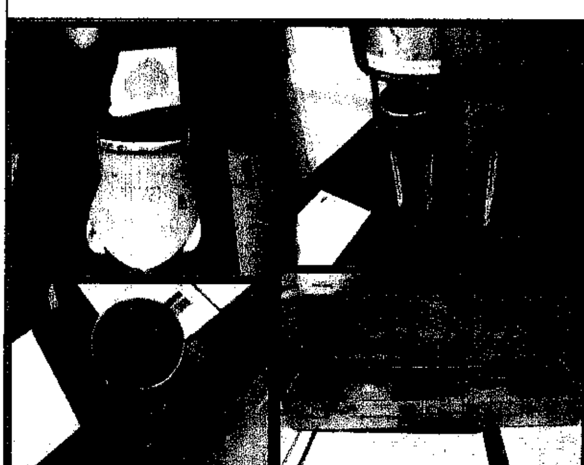
Nowadays, there are two types of drilling fluids which are mainly used by drilling operators. They are water based and oil based drilling fluids. Water based mud is simple and easy to prepare and used in the shallow sections of the wellbore whereas oil based mud is used in the deeper sections of the wellbore.

3.2.1 Prepared water Based mud

The composition of the water based mud was as follows:

- 350 ml of distilled water
- 22.5 g of Bentonite (Viscosifying agent)
- 174 g Hematite (Weighting agent)

The preparation process is illustrated below:

350 ml Distilled water , 22.5 g Bentonite	Result
	Mud weight = 9.1 ppg It was desired to increase the MW to 12 ppg using Hematite. The formula is : Hematite $_{mass}$= 1680 ($W_2 - W_1$)/ 40 – W_2 = 1680 (12-9.1) / 40 – 12 = 174 g (Hematite) After adding the calculated amount, the density of mud was 11.9 ppg.

Fann viscometer was used to measure the Yield point and Apparent viscosity of the mud.

AV (cP) = RPM_{600} / 2= 53/2= 26.5 cP

$YP = RPM_{300} - PV = 41 - 12 = 29\ lb/100\ ft^2$

Small amount of MR fluid was added to the prepared mud and was checked for the miscibility. The MR was not miscible in Water based mud due to the following composition of the MR fluid:

- Magnetizable content: 24 vol.% Carbonyl Iron Powder
- Base Fluid: Poly-α-olefin
- Density: 2.47 g/cm3 (25°C)

The base fluid of the Carbonyl Iron powder (magnetic particles) was a Poly-α-olefin which was not miscible with water as oil is not miscible with water. Special oil – water emulsifier (Confi-MUL P primary emulsifier) was used to tackle this miscibility problem. Confi-MUL P primary is a emulsifier which widely used in the drilling industry for the oil – water miscibility in oil based muds.

Despite the addition of emulsifier, the MR fluid was not miscible with water. The next step was to prepare oil based mud as Poly-α-olefin could be dissolved in oil.

3.2.2 Prepared oil based mud

The composition of the prepared oil based mud is illustrated in the following table:

Table 2: Oil based mud composition

Component	Amount
Diesel	300 ml
PolyPac UL (Fluid Loss reducer)	3 g
Confi-MUL P primary emulsifier	2 g
Bentonite (Clay)	25 g
Barite weighting agent	220 g
Lime alkalinity agent	4 g

Confi gel (Gel strength)	10 g
LP MUL S (Particle suspension)	12 g

The prepared oil based mud yielded a viscosity of 11.6 ppg. Small amount of MR fluid was added and stirred in a special lab scaled mud mixer. MR fluid was miscible perfectly in the prepared oil based mud.

3.2.3 Test pure MR with Magnetic field applied

Prior to start the experiment, it was intended to test the pure MR fluid by applying magnetic flux to see if it freezes or not. The following figure illustrates the procedures clearly:

Figure 8: Pure MR test

As it is illustrated above, small amoutn of pure MR fluid was puored in and current was supplied from power supply. At maximum current supply (30 v), the density of flux generated was flactuating between 4 and 7 millitesla and this was enough to line up and freeze the MR fluid. The intensity of magnetic field was measured using Gauss meter.

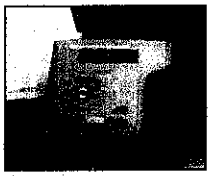


Figure 9: Gauss meter

As the current supply is removed , the MR fluid regains it is original position in few milliseconds.

3.2.4 Generating MAGNETIC force on the viscometer

Magnetic flux can be generated in many ways. The basic theory behind the phenomenon is summarized and illustrated in the picture below.

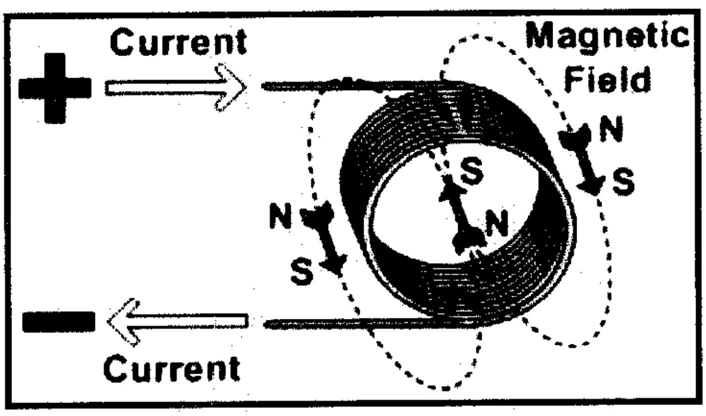


Figure 10 : Magnetic coil

By using the basic principle illustarted in the *figure 10*, it was have planned to generate Magnetic flux in three ways and see which one is more effective and meets the minimum requriement strength of magnetic force for MR particles in the drilling fluid to be dsisturbed.

Attempt 1 : Coil up the circulating cup

The first attempt in generating the Magnetic flux was to coil up the circulating cup of Fann viscometer manually and apply current from one end. Coiling up manually requires crucial attention as there should be no gaps between the turns and it must be coiled up smoothly and precisely. The following figures clearly illustrate the whole work.

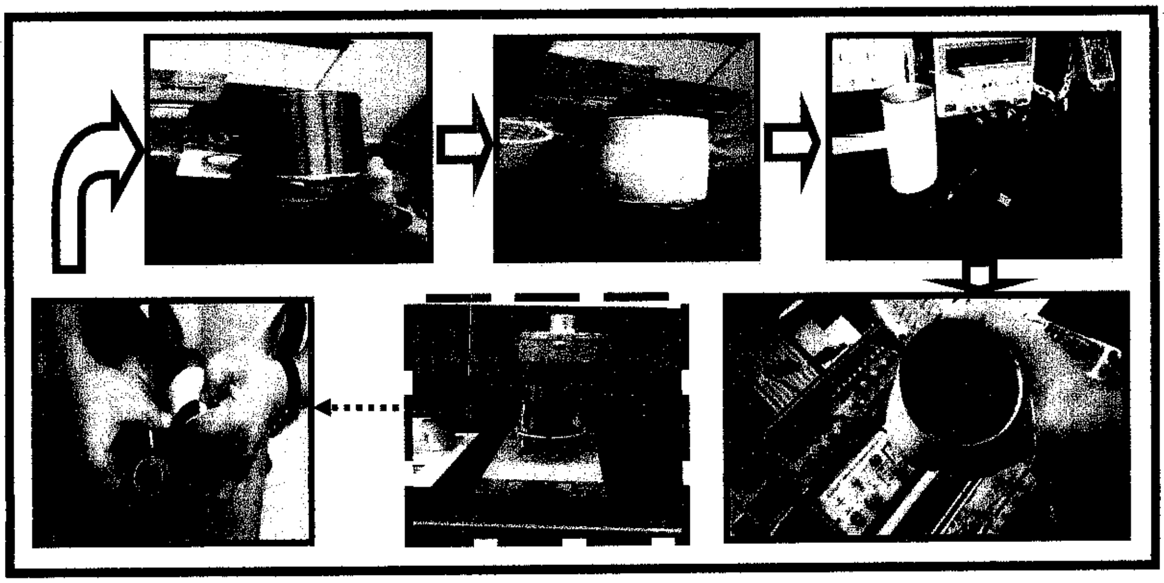


Figure 11: Magnetic field generation, Attempt 1

In Attempt 1, as illustrated in *Figure 11*, circulating cup was coiled up and connected to current supply. Magnetic flux density inside the cup was tested using Gaussmeter. Gaussmeter is the device used to measure the Magnetic flux density. The flux density was flactuating between 1 and 2 millitesla(20 gauss). Small amount of MR fluid was poured into the circulating cup and Magnetic flux was applied. It was anticipated that the MR particles would line up and fluid would freeze. MR particles were not affected with that strength of Magnetic field applied. This insufficient flux density was due to less number of layers of coils around the cup as there is only a single layer of wire around the cup. Moreover single layer of wire has less resistance which can result in short circuit if no external resistor is supplied. Therefore, a power resistor with 2.2 ohm resistance and has a ceramic coating which increases theoverheating of resistor. It was attached to the positive side of the wire. This resistor has less resistance which indeed give us an opportunity to increasecurrent supply. Increasing the layers of coils should be done linearly on top of each other. Doing it manually was nearly impossible. Therefore, another attempt was made to come up with an idea to generate denser Magnetic flux.

Attempt 2 : Use Transformer type winded coil (Machine winding)

Transformer type coil with few layers of wire was available in the university lab. The set up is illustrated on the following figure :

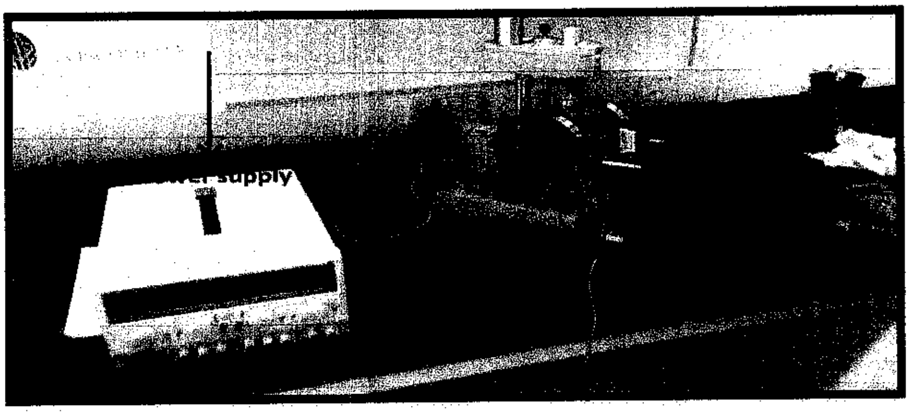


Figure 12 : Magnetic field generation, Attempt 2

This set did not work as well, due to distance between the coils and circulating cup, the field strength was not enough to line up the MR particles inside the mud.

Attempt 3

The most effective way of inducing magnetic flux was successfully found out in the third attempt. It is illustrated below.

Figure 12 : Magnetic field generation, Attempt 3

Due to the above illustrated set up, the circulating cup of the viscometer was changed to a smaller diameter cup. This may have led to minor human errors and fluctuations in the results.

3.2.5 Conduct the experiment and observe the effect of both MR concentration and Magnetic field on the viscosity of mud

The third way was used to supply the magnetic field around the viscometer cup while it is on. The whole experimental set up is illustrated below:

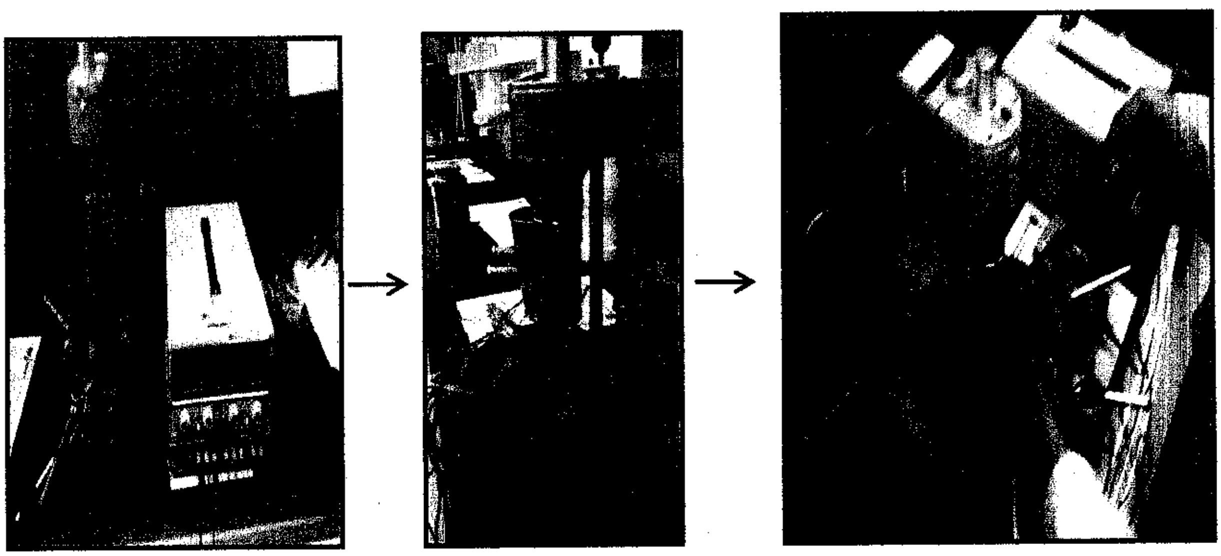


Figure 13 : The experimental set up

CHAPTER 4

RESULT AND DISCUSSION

The composition of the prepared oil based mud is illustrated in the previous chapter. Viscometer results with respective MR concentrations are illustrated below in the following tables. Two parameters of our interest, the AV (Apparent viscosity) and YP (Yield point) of the drilling fluid were analyzed by changing the MR concentration in the mud and Magnetic flux. The expectation was to see the increment in both AV and YP values by increasing the MR concentration and Magnetic field strength. Adding 10 ml of MR fluid did not affect the apparent viscosity of the mud. Observations were obtained after adding 20 ml of MR fluid.

4.1 Addition of 20 ml MR

Volume ratio was used to calculate the concentration.

Volume ratio (MR ml / ml solution) = $\frac{(20\,ml\,MR)}{(20+300)ml} x\,100 = 6.25\,\%$

Current	RPM				AV (cP)	YP (lbf/100 ft^2)
	100	200	300	600		
1	16	27	37	65	32,5	9
1,2	16	27	38	68	34	8
1,4	16	29	39	69	34,5	9
1,6	16	29	39	69	34,5	9
1,8	17	30	40	70	35	10
2	17	30	40	70	35	10
2,2	18	31	41	72	36	10
2,4	18	31	41	73	36,5	9
2,6	19	31	42	74	37	10
2,8	19	32	42	74	37	10
3	19	32	42	75	37,5	9

Table 3: 6.25 v/v % MR

The values for YP and AV were calculated using the following formulas:

AV (cP) = $RPM_{600} / 2$

YP (lb/100 ft^2) = RPM_{300} – PV where PV = RPM_{600} - RPM_{300}

4.2 Addition of 30 ml MR

Volume ratio (MR ml / ml solution) = $\frac{(30\ ml\ MR)}{(30+300)ml} x\ 100 = 9.10\ \%$

Current	RPM				AV (cP)	YP (lbf/100 ft^2)
	100	200	300	600		
1	16	27	37	65	32,5	9
1,2	16	27	37	67	33,5	7
1,4	16	27	37	68	34	6
1,6	17	28	38	70	35	6
1,8	18	29	39	70	35	8
2	18	29	40	72	36	8
2,2	18	30	40	73	36,5	7
2,4	18	30	40,5	74	37	7
2,6	18	30	41	75	37,5	7
2,8	18	31	41,5	75,5	37,75	7,5
3	18	31	42	76	38	8

Table 4: 9.10 v/v % MR

4.3 Addition of 40 ml MR

Volume ratio (MR ml / ml solution) = $\frac{(40\ ml\ MR)}{(40+300)ml} x\ 100 = 11.76\ \%$

Current	RPM				AV (cP)	YP (lbf/100 ft^2)
	100	200	300	600		
1	16	27	37	65	32,5	9
1,2	16	27	37	65	32,5	9
1,4	17	28	39	67	33,5	11
1,6	17	29	39	67	33,5	11
1,8	17	29	41	69,5	34,75	12,5
2	17	29	41	71	35,5	11
2,2	17	30	42	73	36,5	11
2,4	18	30	43	73,5	36,75	12,5

2,6	18	30,5	43	74,5	37,25	11,5
2,8	18,5	31,5	43,5	75	37,5	12
3	18,5	31,5	44,5	76,5	38,25	12,5

Table 5: 11.76 v/v % MR

4.4 Addition of 50 ml MR

Volume ratio (MR ml / ml solution)= $\frac{(50\,ml\,MR)}{(50+300)ml}\ x\ 100 = 14.25\ \%$

Current	RPM				AV (cP)	YP (lbf/100 ft^2)
	100	200	300	600		
1	16	27	37	65	32,5	9
1,2	17	28	39	67	33,5	11
1,4	18	29	39,5	67,5	33,75	11,5
1,6	18	29	39,5	68,5	34,25	10,5
1,8	18,5	30	40,5	70,5	35,25	10,5
2	19	30,5	42	71,5	35,75	12,5
2,2	19	31	42,5	72	36	13
2,4	19	31,5	43	73,5	36,75	12,5
2,6	19	31,5	43,5	74,5	37,25	12,5
2,8	19	31,5	43,5	75	37,5	12
3	19	32	44,5	75,5	37,75	13,5

Table 6: 13.25 v/v % MR

4.5 Addition of 60 ml MR

Volume ratio (MR ml / ml solution)= $\frac{(60\,ml\,MR)}{(60+300)ml}\ x\ 100 = 16.67\ \%$

Current	RPM				AV (cP)	YP (lbf/100 ft^2)
	100	200	300	600		
1	16	29	38	66,5	33,25	9,5
1,4	18,5	30,5	39	69	34,5	9
1,8	19	32	42	72	36	12
2,2	20	33	43,5	74	37	13
2,6	20,5	34	45	77	38,5	13
3	21	35	46,5	80	40	13

Table 7: 16.67 v/v % MR

4.6 Addition of 70 ml MR

Volume ratio (MR ml / ml solution) = $\frac{(70\,ml\,MR)}{(70+300)ml} x\ 100\ = 18.92\ \%$

Current	RPM				AV (cP)	YP (lbf/100 ft^2)
	100	200	300	600		
1	18	30	39,5	69	34,5	10
1,4	18,5	31	41	71	35,5	11
1,8	20,5	33	44,5	76	38	13
2,2	21	34,5	45,5	77,5	38,75	13,5
2,6	22	36	48	81,5	40,75	14,5
3	23,5	38	49	83	41,5	15

Table 8: 18.92 v/v % MR

After getting all the results, several graphs were sketched in order to see the effect of MR fluid concentration and Magnetic flux on the AV and YP.

4.7 The effect of Magnetic on AV field at constant concentration

In order to observe the effect of Magnetic field on our mixture, 9.10 v/v % MR mixture was chosen randomly. The concentration was kept constant by altering the amount of current where the current is directly proportional to Magnetic flux density.

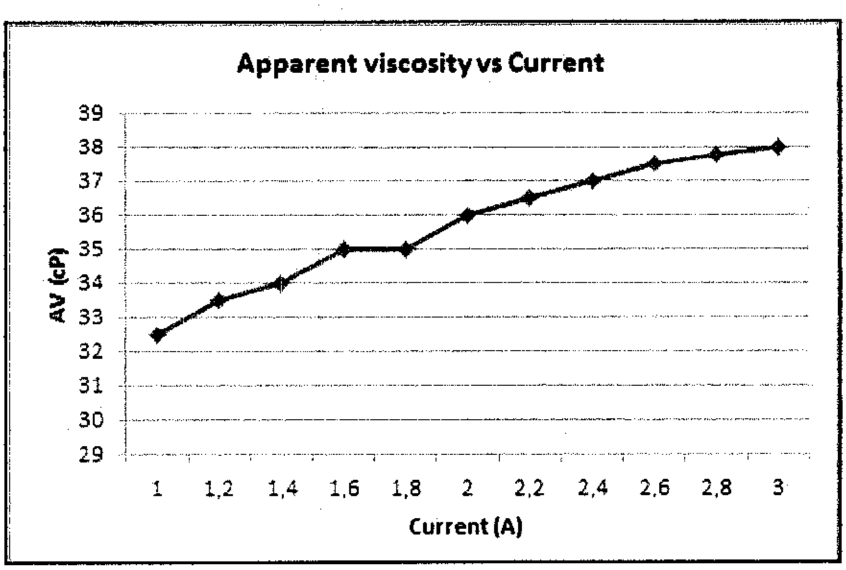


Figure 14: AV vs Current , 30 ml MR

It was observed that the Apparent viscosity of the drilling fluid mixture increases with increasing the flux. The concentration was kept constant, 9.10 v/v % MR fluid.

4.8 The effect of MR fluid concentration

In order to observe the effect of the MR fluid concentration on apparent viscosity, the results for respective concentration were plotted on a same graph. It is illustrated below:

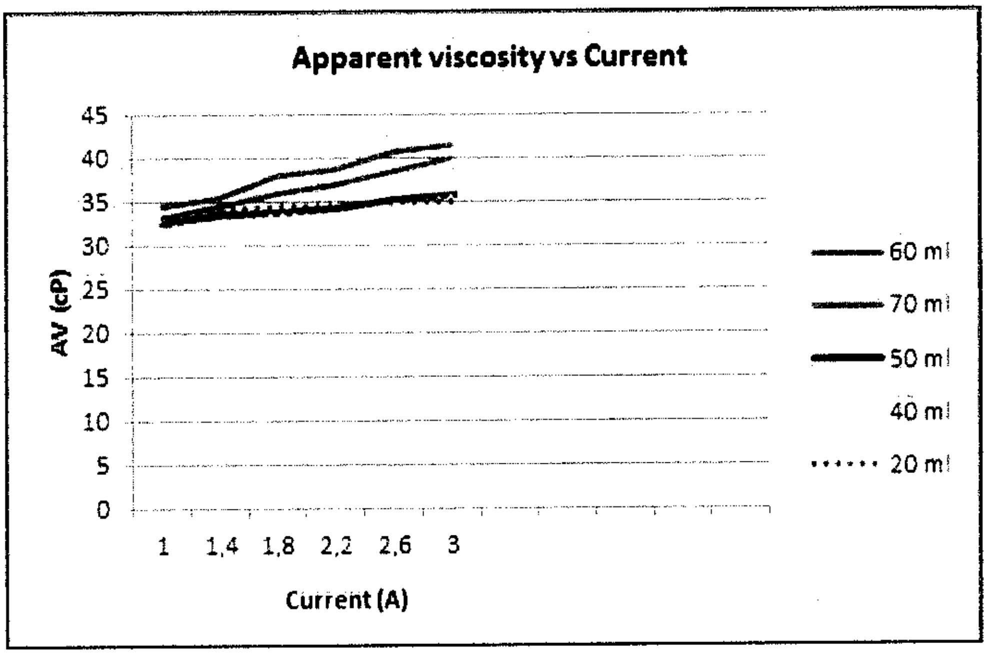


Figure 15: The Effect of concentration on AV

As it can be clearly observed, the increasing trend for the concentrations of 20, 40, 50 ml of MR fluid are similar whereas above 50 ml, there is a boost in AV at 60 ml. Moreover, above 50 ml the increment in concentration has an effect on AV. This trend was observed above 50 ml at 16.67 v/v % MR concentration. Therefore, adding MR fluid at concentrations 6.25 v/v %, 9.10 v/v %, 11.76 v/v % and 13.25 v/v % has similar effect on the AV. At concentrations 16.67 v/v % and 18.92 v/v %, the MR increment in MR fluid concentration and AV are directly proportional. This trend can be observed from the following graph as well.

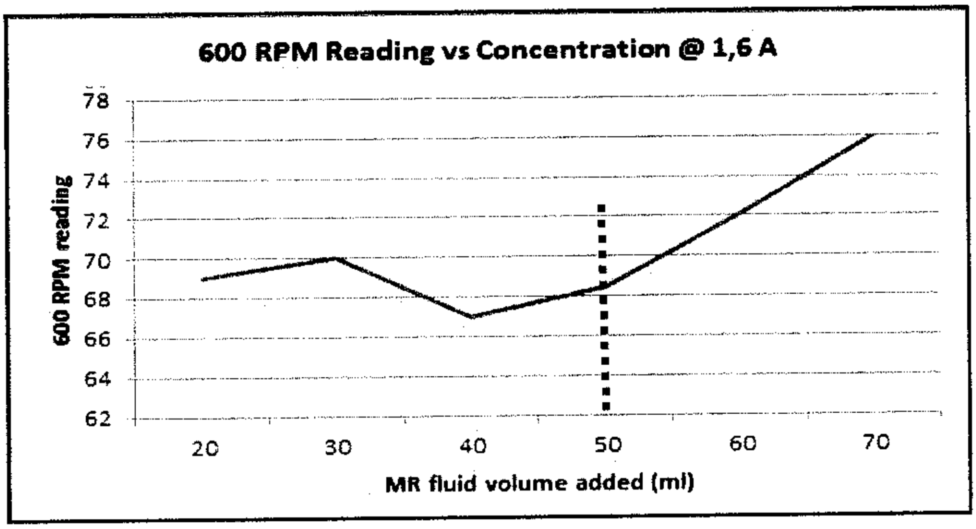


Figure 16: 600 RPM readings vs Concentration at constant 1,6 A

The current was kept constant while MR fluid concentration, it can be clearly observed that the increment in MR fluid concentration and AV are directly proportional.

4.9 AV at lower RPM readings

Both MR fluid concentration and Magnetic flux has less effect on low rpm readings below 50 ml MR fluid concentration. Significant effects on lower rpm readings were observed at concentrations above 50 ml which are at 60 and 70 ml MR fluid concentrations.

4.10 Effect of MR fluid on the Yield point

Yield point is a point at which a material starts deforming plastically. In drilling operations, it is a pump pressure required to initiate the mud flow. Yield point arises from the concentration of solids and their electrical charge in the drilling fluid. As electrical charges attract each other, there will be an initial resistance of drilling fluid before it starts flowing. If yield point is uncontrolled, it can lead to excessive pump pressures. Moreover, yield point is the ability of drilling fluid to lift up the drilled cuttings out of the wellbore. A non-zero YP causes a sudden pressure change when the fluid starts to move or when it's about to stop moving. Additionally, it causes a sudden change of the surge or swab pressures when the drill string starts to move up/down during drilling or tripping, no matter how slow the pipe moves. The disturbances provide difficulties for operators to keep the wellbore pressure constant. Therefore, keeping YP in acceptable ranges is very vital.

As magnetic particles in the mud will attract each other after applying enough amount of magnetic field, it was expected to observe an increment in YP values of the mud. The following graph clearly indicates the effect of MR fluid on the YP of drilling mud.

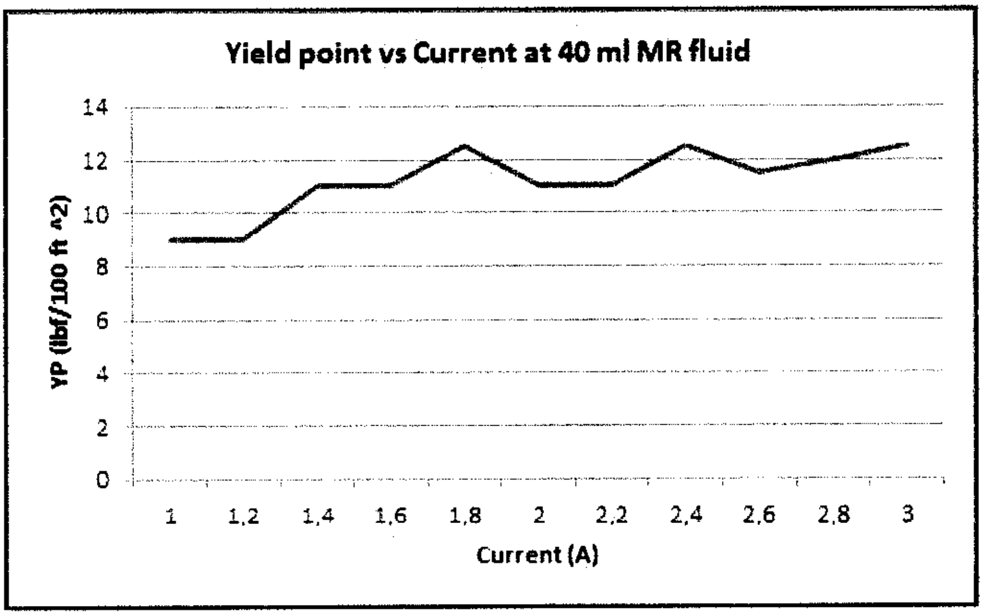


Figure 17: YP vs Current at 40 ml MR fluid

As it was with apparent viscosity, YP values boost up at concentrations more than 50 ml MR fluid. The following graph illustrates it clearly.

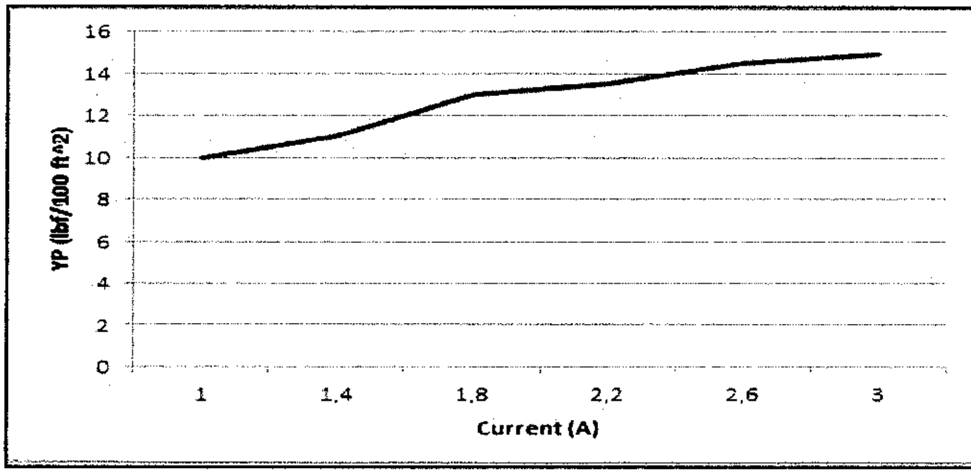


Figure 18: YP vs Current at 70 ml MR fluid

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Sufficient cutting transport plays an important role in the drilling industry. Failing to clean the wellbore effectively may lead to undesirable drilling problems. Controlling the flow regime of the drilling fluid in different sections of the well may aid operators in cleaning the wellbore effectively. Flow regime of the mud is highly dependent on the viscosity.

The study on the effect of MR fluid on the viscosity of the mud showed that the MR fluid is miscible with drilling mud and viscosity can be manipulated by applying magnetic field at the desired well sections. Moreover, there were other drilling parameters that were affected as well. Yield point, by being one of the most vital rheological properties, increases with adding the MR fluid and applying magnetic field. Other parameters are not highly affected by the addition of MR fluid.

5.2 Recommendation

The type of the viscometer used for this study was a manual viscometer. Due to this it may lead to several human errors which can result in undesirable results. Automatic type of viscometer is highly recommended for this study as it automatically indicates the readings accurately.

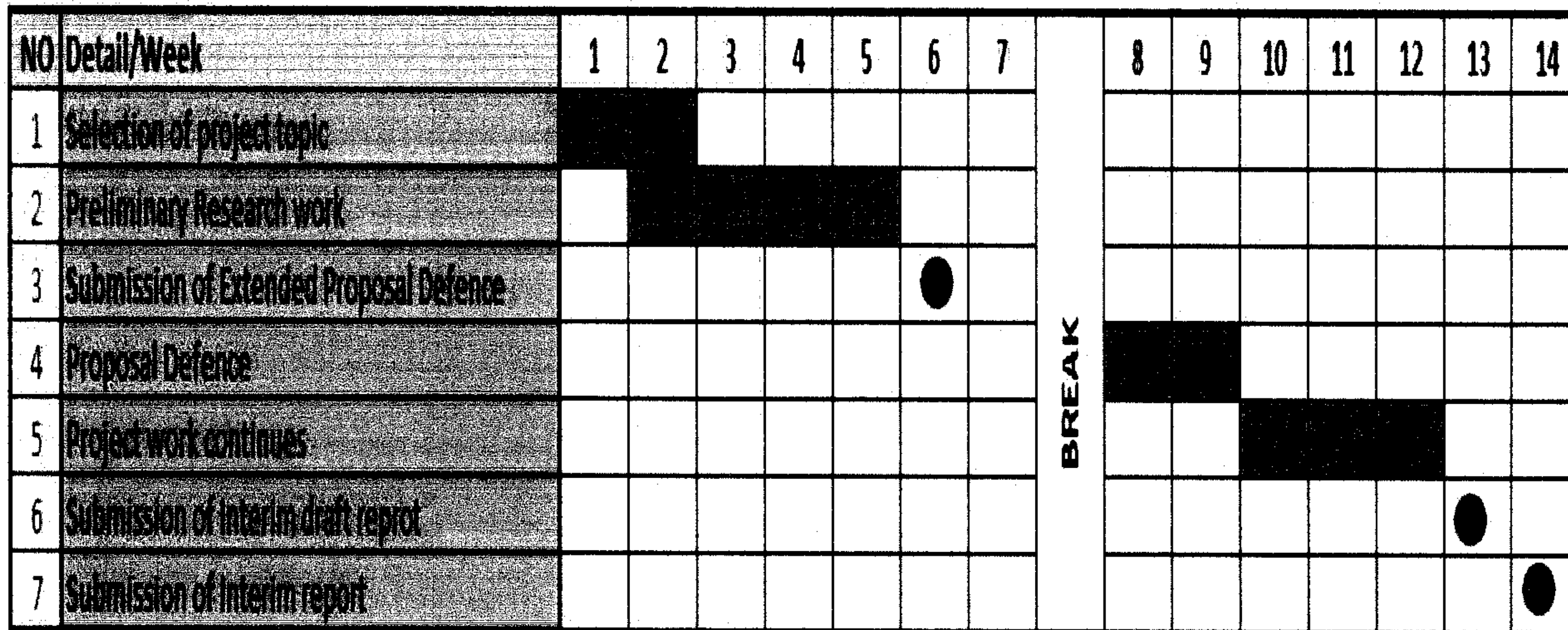
The MR fluid should be tested for high pressure and high Temperature wells as well. The manual viscometer does not simulate these HPHT conditions.

Due to the size and shape of the viscometer, there were some difficulties in applying a magnetic flux on the viscometer cup. Therefore, there were some modifications made on the apparatus. The viscometer cup was changed to a smaller diameter cup which may have led to some errors. For further studies, the original cup should be used and new methods for effective magnetic flux inducement should be found.

As water based muds mostly used in the shallower sections of the well, specific emulsifier should be found so MR fluid would be miscible in water based mud as well.

An Empirical correlation should found that relates the MR fluid concentration, apparent viscosity and magnetic strength applied so that a known amount of each parameter can be added to get the desired value.

6.1 GANTT CHART AND KEY MILESTONES



References

1. Development of the three segment hydraulic model for cuttings transport in horizontal and deviated wells, Hyun Cho, Norman Oklahoma, 2001

2. Drilling Practices and Sweep Selection for Efficient Hole Cleaning in Deviated WelIboresD. J. Power, SPE and C. Hight, Baroid, a Halliburton Company, D. Weisinger, SPE, and C. Rimer, SPE, Vastar Resources Inc. 11-13 september 2000

3. Mengjiao Yu, Daniel Melcher, Nicholas Takach, Stefan Z. Miska, Ramadan: ''A new Approach to improve cutting transport in Horizontal and Inclined Wells'' The university of Tulsa, Conference paper prepared for presentation at the SPE Annual Technical, 26-29 September 2004.

4. Mechanistic model for cuttings removal from solid bed in inclined channels, A. Ramadan a,), P. Skalle a, S.T. Johansen b, J. Svein c, A. Saasen

5 www.maths-in-industry.org/miis/135/1/cuttings.pdf

6. http://www.osti.gov/bridge/purl.cover.jsp?purl=/822109-rCPNSj/native/822109.pdf

7. http://www.slidefinder.net/7/7_drilledcuttingtransport/32626344