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A Comparative Study of Pressure Losses and Hole Cleaning Efficiency of Water and Polymer solutions in Horizontal Wells

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Abstract

The main objective of this study is to experimentally investigate the effect of the CMC polymeric drag reducer on the pressure drop occurred along the annulus of the wellbore in drilling operation and investigate the optimum polymer concentration that give the minimum pressure drop. A flow loop was designed for this purpose consist from 14 m long with transparent test section and differential pressure transmitter that allows to sense and measure the pressure losses along the test section. The results from the experimental work show that increasing in polymer concentration help to reduce the pressure drop in annulus and the optimum polymer concentration with the maximum drag reducing is 0.8 kg/m^3. Also increasing in flow rate and corresponding fluid velocity in the gap of the annulus helped to reduce the pressure losses due to fluid flow.

Keywords: hole cleaning, polymer, horizontal well, drag reducer

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1- Introduction

Poor hole cleaning while drilling operations especially in high deviated well is the main reason for many unwanted issues encountered while drilling. For This purpose, the numerous researchers work on cutting transportation [1][2][3]. Since force of gravity has acted against the transportation direction, it can cause the build-up of cuttings on the bottom of the wellbore. Those deposits are usually called cuttings bed.

Sufficient sweep of drilled cuttings from hole and transport it to the surface is a main challenge in oil well drilling, for vertical well operation this issue was well studied since that any parameters can reduce the slip velocity of the cuttings can efficiently influence on the hole cleaning , but for the deviated well operation hole cleaning is still a big challenge [4].So proper strategy of hole cleaning is an important to get good drilling operations because insufficient hole cleaning may lead to many problems such as [5]:

a) Low rotation per minute(RPM).
b) Increase torque and drag force.
c) Increase risk of pipe stuck.
d) Difficulty in landing the casing and hole cementing.
e) Difficulty while logging.
f) Bit wearing, etc.

The drilling fluid circulation rate is the most effective parameters on hole cleaning and that was proved by many previous studies.

The problem with flow rate value is that the increasing in rate of circulation will cause a sharp increase in bottom hole pressure and that will lead to increasing the dynamic bottom hole pressure and may cause fracture to the rock. The solution should be offered the ability to transport more cuttings to the surface while keep the bottom hole pressure without big change.

Many ideas subsist in the industry as what an optimum concentration of drilling cuttings should be to keep ECD in safe margin and they find that cuttings concentration below 1 percent of volume is very safe and above that concentration has a significant effect on ECD [6].

Al-Yaari et.al (2009) [7] in their study focus on the evaluating of the pressure reading difference and the flow pattern features for various flow regimes and also determined the effect of the polymer on pressure drop in the region of phase inversion at higher mixture speed and a high pressure drop is happen in pipe lines. The polymer molecular weight and concentrations were investigated in this study. The results from the experimental work show that the increase in polymer concentration increases the drag reduce and that because of enhancing the formation of aggregates which play a crucial role in reducing pressure drop.

Al-Wahaibi et.al (2013) [8] experimentally studied the performance of drag reducing polymers through two different pipes diameter in horizontal oil-water flows. the results of this study show that the polymer concentration of 2 ppm give a significant drag reduction and that increase as the polymer concentration increase also the drag reduction increase as superficial water velocity increase.

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2- Experimental Setup and Design

2.1. Flow Loop Design

A cuttings transportation flow loop was built to determine the effect of different parameters on hole cleaning.

The cuttings transport flow loop consists of approximately 14 m (46 ft.) long with transparent glass test section of 3m (9.84 ft.) long with 4 inch (101.6 mm) ID, the glass tubes (Duran manufacturer) are made from high quality optical glass (Borosilicate glass) with 100% transparency required for imaging and recording while test.

The glass tubes (two tubes) are connected to each other by specially designed Teflon joints that having an inner diameter equal to the pipes to ensuring a smooth path for the flow. The transparent test section changed with PVC tube for same diameter when the inclination angle less than 90°.

The inner metal drill pipe with 2 inch (50.8 mm) OD settled with eccentric position positive 0.5, it is fixed by metal structure designed to be not influenced on cuttings path.

The inner pipe in this study designed to be stationary (no RPM) during the experiments to simulate the actual slide drilling conditions (in long horizontal and extended reach wells sometimes it is not possible to rotate the drill pipe and depend on down hole motor rotation).

The fluid feed line made from PVC with 4 inch ID as long of 8 m and the main function is to transport the drilling fluid to test section and in position while it near the inlet of the test section the cuttings are injected to flow to pass as two phases(cuttings-drilling fluid) during the test section.

The test section was attached with the feed line through movable joint in order to change the degree of test section inclination.

All experiments were conducted under ambient temperature and atmospheric pressure conditions; a schematic diagram of the flow loop was shown in Fig. **1**.

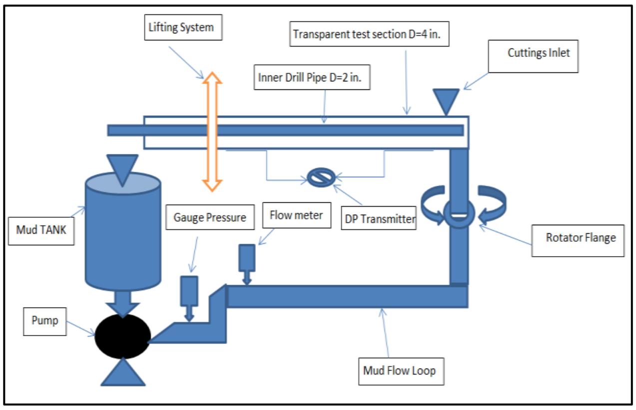

Fig. 1. Cuttings transport flow loop (schematic diagram)

The drilling fluid is mixed in a mixing tank of 1 m^3 (1000 liters) where the liquid is supplied to feed line (in case of water-polymer drilling fluid there are two separate tanks, where the polymer is dissolved in water in first tank and then allowed to rest for 15 hour in 0.725 m^3 (725 liters) tank and then transported and diluted to desired concentration into suction tank). The agitator kept working for two hours before drilling mud have been pumped to feed line to prevent the separation and settling of the mud material.

The test fluid is pumped and circulated through the system by a 3 H.P. centrifugal pump which provides a maximum capacity of 220 GPM (50 m^3/hr.). The pump has been selected to be suitable in case of coarse solid particle dissolution pass through it.

The pump outlet is connected to two lines, one is a bypass line and the other one is going to the flow meter,the bypass line is used to regulate the flow rate of the mud pump and also as a jetting tool when polymer has been mixed in mixing tank.

The flow rate is measured by means of a volumetric flow meter of 21 m^3/hr. maximum flow rate measuring range. The flow meter is already calibrated and has accuracy equal to 0.1%.

During the experiment, the frictional pressure drop between two points in test section was measured. The first point is located 1 m (3.28 ft.) away from the annulus inlet and the second point is located 2.5 m (8.2 ft.) from the annulus outlet.

The two points is selected in the middle of test section away from the annulus inlet/outlet to avoid the end effect and also to obtain data from the fully developed flow section.

These two vents are connected to a differential pressure transmitter (Schoppe and Faeser GMBH Inc.) by a brass lines filled with water, the connected lines are bled before each test to eliminate the contamination problem of the pressure vent, the device reading range is 0 – 25 millibar.A high speed digital camera is also used in this experiment to record the different phenomena that occur inside test section and the cuttings-fluid flow patterns.

The drilling fluid (drag reducing fluid) was prepared by using Carboxymethyl Cellulose (CMC for short) as a commercially available polymer, and actual cuttings from field was used in this experiment.

2.2. Experimental Procedure

All experiments were done under atmospheric pressure and ambient temperature with no rotating drill pipe eccentric at positive 0.5.

Before the start of each run the drilling mud was mixed and prepared and also the PH raised to 10 by adding specific amount of caustic soda (in case of water-polymer drilling mud the mixed procedure presents by Wyatt et. al. was implemented).

Before run, the drilling fluid was agitated for 15+ minute and sample is taken to measure the fluid properties.

A brief description of the experimental work steps followed during the execution of the experiments is presented as follow:

1. Prepare the drilling fluid (Water or polymer) in the mud tank.
2. Check the differential pressure transmitter lines for being full with water.
3. Adjusted all other factors involves in this experiments:
   - Cuttings types Limestone and limestone-dolomite.
   - Cuttings size two ranges (1.7 and 3.36 mm).
   - Annular velocity two ranges (2.0558and 2.8781 m/sec.), these two ranges are selected as the minimum value is the lowest velocity that cleaning cuttings and permit the visually recognize to the flow pattern, and the maximum value have been choose as the maximum reading of flow meter available.
   - Drilling fluid type (water , 0.8 kg/m^3 polymer and 1.8 kg/m^3 polymer)
4. Start the pump and adjusted the liquid flow rate (66 and 92.5 GPM).
5. Wait for flow pattern stabilization by checked in both visual observation and examining the differential pressure reading.
6. Start recording data (flow rate and pressure drop reading).
7. Inject the cuttings that simulated the desired ROP.
8. Start Camera to record the cuttings transport mechanisms.
9. Start record data (flow rate and pressure drop reading).
10. Collect the outlet cutting from sieve screen, to calculate the cuttings recovered.
11. Stop Camera.
12. Circulate with High flow rate to clean the annulus from remain cuttings after test.
13. Repeat steps 3 to 13 with new cuttings density.
14. Stop pump.
15. Repeat steps 3 to 14 for new mud type.

3- Effects of Polymer concentration on Drag Reducer Drilling Fluids

Drag reduction additives first utilized during the hydraulic fracturing operations to pump sand with lower horsepower [9].The drag reducer has a benefit in hole cleaning as it work to reduce the pressure loss during the circulation. The drag reducing percent for different polymer fluid compared with water can be calculated from the following equation Eq.1 [10]:

$$DR\% = 100\left(\frac{\Delta P without\ DRP - \Delta P\ with\ DRP}{\Delta P\ without\ DRP}\right) \quad (1)$$

Where:
DR= Drag reducing
ΔP without DRP=Pressure drop due to flow of water, millibar
ΔP with DRP=pressure drop due to flow of polymer, millibar.

Table **1** shows the results of the drag reducing and pressure drop for different polymer concentration against water. As Shown from the Fig. **2** the polymer concentration that gives the minimum frictional pressure drop remains the same for different flow rates, also the drag reduction percent increase as the flow rate increase for the same polymer concentration. In this study only two values of flow rates were involved and that show an increase in drag reduction (DR) with the increment of flow rate value but in previous study discover that the DR reaches its maximum value for a certain flow rate and after that any increase in flow rate will cause reduction in DR due to shear degradation of the polymer molecules and that makse the effectiveness of the drag reducing polymer reduces after that value of flow rate “Several studies have suggested a direct relationship between changes in molecular weight distribution and drag reducing effectiveness for a variety of polymers. An alternative explanation for the polymer degradation is that some or all of the degradation is associated with a decrease in the amount of polymer aggregation or entanglements. A decrease in aggregation would be caused bymechanical stresses breaking up existing aggregates and preventingfurther aggregate formation in a shear flow” [11,12].

Table 1. Drag reduction percent for 90° hole inclination

Flow Rate m^3/hr.	Fluid Type	Pressure Losses m bar	Drag Reduction %
15	Water	12.5	-
15	0.8 kg/m^3 polymer	9.5	24
15	1.8 kg/m^3 polymer	10	20
21	Water	20	-
21	0.8 kg/m^3 polymer	13	35
21	1.8 kg/m^3 polymer	14.5	27.5

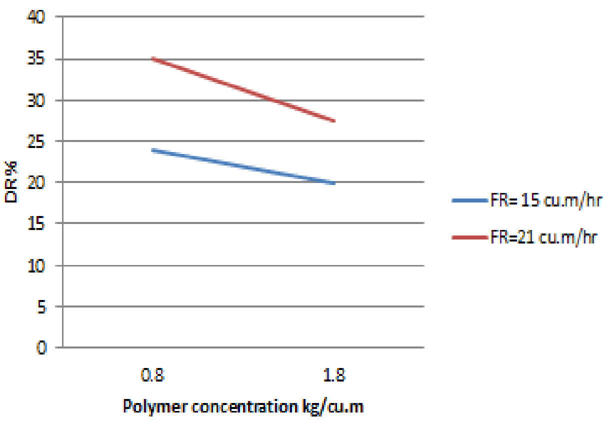

Fig. 2. Polymer concentration versus drag reduction for different flow rates

4- Polymer Concentration Effect on Delivered Cuttings Concentration

As shown from the Fig. **3** that the polymer concentration have a significant effect on the amount of cuttings transported, the increase in polymer concentration will increase the DR value until it reaches to maximum value of DR (at polymer concentration equal to 0.8 kg/m^3 were the drag reduction values are 24% and 35 % for flow rate 15 and 21 m^3/hr, respectively as shown in Fig. **2**) and after that any increasing in polymer concentration have a contrary effect on DR, any increase in DR will cause most efficient cuttings transported.

In other words, the increase in polymer concentration will increase the hole cleaning efficiency till it reaches the point of maximum DR and then any more polymer concentration added will affect negatively on the cuttings transport, which was also observed in previous study [13].

The improvement recorded by the drilling mud with CMC low viscosity polymer has been influenced by two main factors that influences on cuttings slipping velocity. In general, these two factors are the ability of the polymer to reduce the slipping velocity of the drilling cuttings due to its buoyancy in the drilling fluids and the effect on the Reynolds number of the cuttings were it reduced and that will increase the drag coefficient of the particles, as a results of these two factors the hole cleaning will improved, and that also observed by other studies [14,15].

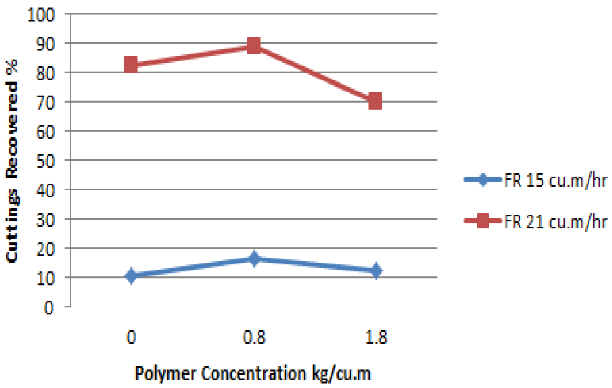

Fig. 3. Polymer concentration Vs. CR% for 90° inclination

5- Cuttings Density and Size Effect on Delivered Cuttings Concentration

Cuttings density has a direct influence on the cuttings slip velocity and that influence dominated clearly in near vertical well angles but for the horizontal and near horizontal well the influence of the cuttings density has a direct influence on the gravity force and by means on the lifting/sliding force of the cuttings bed, and that clearly observed in Fig. **4** and Fig. **5.**

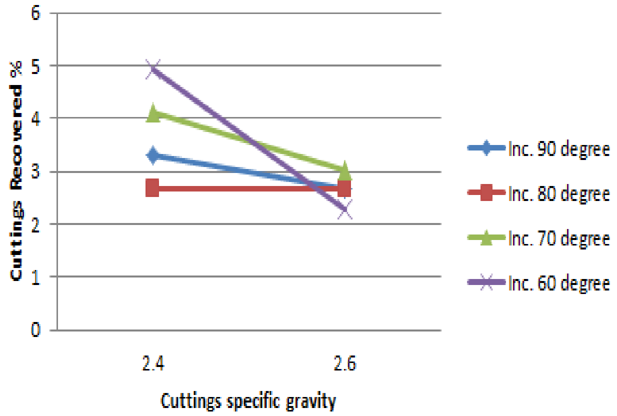

Fig. 4. Cuttings S.G. vs. CR% for 3.35 mm size with water and FR=15 m^3/hr

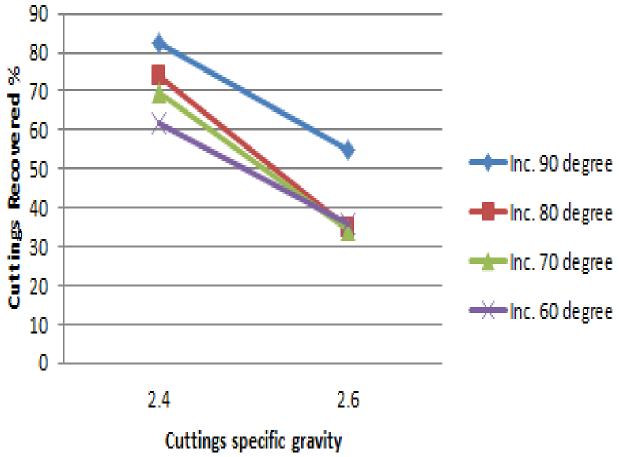

Fig. 5. Cuttings S.G. vs. CR% for 3.35 mm size with water and FR=21m^3/hr

The size of the drilled cuttings also has a big influence on the bed height and cuttings recovered percent since that large cuttings size have a tendency to form bed and roll along the low side of the well bore.

The cuttings with large size at high angles (65° and more) tend to form stationary bed at the low side of the well, in that case and with absence of the pipe rotation only the high flow rate can disturbed the bed and achieve a homogeneous suspension, as shown in **Figure.6 and Figure.7**, also from these figures it can observed that the influence of the cuttings size is more simple compared with the density of the cuttings and that can be seen in **Figure.7** when the density of the cuttings increased the effect of the size being less.

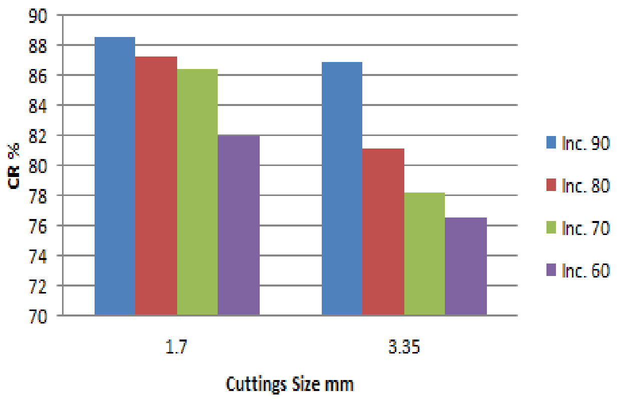

Fig. 6. CR% vs. cuttings size mm for limestone with 0.8 kg/m^3 polymer and FR=21 m^3/hr

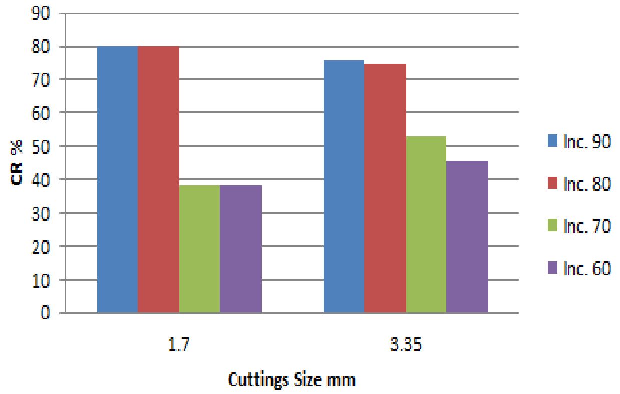

Fig. 7. CR% vs. cuttings size mm for limestone-dolomite with 0.8 kg/m^3 polymer and FR=21 m^3/hr

6- Conclusions

The results from the experimental work showed that:

1- Different CMC polymer concentration varied from 0.8 kg/m3 to 1.8 kg/m3 were used in these experiments. With polymer concentration of 0.8 kg/m3, it was obtained a minimum pressure drop and maximum drag reductions.

2- The results showed that the optimum CMC polymer concentrations which gave maximum drag reductions and cuttings removal was 0.8 kg/m3and any further added of polymer will cause reduction in DR and that mean reduction in hole cleaning efficiency.

The addition of the drag reductions agent to the drilling fluids will reduce the frictional pressure drop in the annulus and that effect will increase as the flow rate increase from 15 to 21 m^3/hr.

Nomenclatures

RPM= Rotation per minute.
ID, OD= Inner and outer diameter, mm.
H.P.= Horse power.
CMC= Carboxymethyl Cellulose.
DR= Drag reducing.
ΔP without DRP=Pressure drop due to flow of water, millibar.
ΔP with DRP=pressure drop due to flow of polymer, millibar.
FR= Flow rate, m^3/hr.

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دراسة مقارنة لبيان كفاءة تنظيف البئر باستخدام الماء و البوليمر في الابار الافقية

كرار احمد و اياد عبدالحليم

جامعة بغداد-كلية الهندسة

الخلاصة

الهدف الرئيسي من هذه الدراسة هو التطبيق العملي لمعرفة تأثير البوليمر من نوع (CMC) كمقلل احتكاك على فرق الضغط الحاصل في الفراغ الحلقي خلال عمليات الحفر. منظومة جريان صممت لهذا لغرض تتألف من 14 متر طول مع مقطع تجريبي شفاف و جهاز لقياس فرق الضغط يسمح بتحسس و قياس الضغط المفقود خلال المقطع التجريبي. النتائج المستحصلة من التجربة العملية بينت بأن الزيادة في تركيز البوليمر تساعد على تخفيض فقدان الضغط الحاصل في الفراغ الحلقي و افضل تركيز للبوليمر مع افضل تقليل للاحتكاك هو 0.8 كغم\متر مكعب, وكذلك زيادة دفق سائل الحفر و سرعة الجريان المصاحبة له في الفراغ الحلقي يساعد على تقليل فقدان الضغط الحاصل نتيجة جريان سائل الحفر.

الكلمات الدالة: بوليمر , البئر الافقي