Available online at http://ijcpe.uobaghdad.edu.iq and www.iasj.net
Iraqi Journal of Chemical and Petroleum Engineering
Vol.21 No.3 (September 2020) 1 – 8
EISSN: 2618-0707, PISSN: 1997-4884

Experimental Study for Assessment of Cutting Density Effect on Hole Cleaning Efficiency in Inclined and Horizontal Wells

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Abstract

The poor hole cleaning efficiency could causes many problems such as high torque, drag, poor hydraulics and pipe stuck. These inherent problems result in an avoidable high operation cost which this study tried to address. In this study, the effect of cutting density on hole cleaning efficiency in deviated and horizontal wells was investigated. Experiments were conducted using 40 feet (12 m) long of flow loop made from iron and PVC. However, the test section was made from PVC with (5.1m) long and (4" ID) for outer pipe and (2" OD) inner pipe. The cutting transport ratio (CTR) was determined from weight measurements for each test. Cutting Transport Ratio has been investigated for effects of the following parameters; flow rate, cutting size and density, yield point of drilling mud, and inclination angle. Once the setup was positioned at the desired inclination, the cutting was transported for 3 minutes at a constant flow rate and yield point. The amount of cutting removed during each test was thereafter weighted to determine cutting transport ratio CTR.

The results obtained from this study showed that the cutting density has a slight to moderate effect on hole cleaning efficiency. Also, there was a remarkable improvement in the cutting transport ratio annular velocity and hole inclination angle was increased. However, the yield point (Yp) was negligible at maximum values of annular velocity. Therefore, at high value of yield point the cuttings with large and medium size were transported more than small size. This case is inversed at a low value of Yp. Moreover, for all sizes the heavy cutting transport less than light cutting. Finally, the critical angle was recorded between 65°-75°. Sigma plot 12.5 program has been used to graph all figures in this paper.

Keywords: Cutting transport ratio, Particle density, Hole cleaning Efficiency, Yield point

Received on 12/01/2020, Accepted on 31/05/2020, published on 30/09/2020

https://doi.org/10.31699/IJCPE.2020.3.1

1- Introduction

Directional and horizontal wells have proven to be successful field development methods in order to meet the demand for a higher rate of returns and increased recovery factor. Increase in the number of such wells being completed has led to a growth in the frequency of hole-cleaning procedures being conducted in the oilfield. Wellbore cleanout is often performed to remove solid particles such as post-fracturing residual proppant, milled plug debris or produced sand [1].

The complexity of this process is governed by independent factors (flow rate, and fluid and solid properties) as well as the interaction between each of these factors. The available research comprises of many empirical correlations and some rules-of-thumb (such as to circulate 2-3 times the annular volume) to achieve efficient cleaning [2,3,4].

Most often, these correlations are specific to certain configurations and cannot be applied universally. The effect of such factors affecting wellbore cleanout mechanism has been widely studied previously. Multi-factor interactions between these parameters further govern the efficiency of cuttings removal.

Many studies have concluded that the fluid flow rate or flow velocity has the most significant and direct impact on solids removal. Similarly, a higher density of the fluids has a positive impact on hole cleaning by reducing the effective weight of the solid particle.

Additionally, research on the influence of fluid rheology is another common theme amongst several studies. These parameters are studied widely majorly due to the reason that they are easily controllable in field cleanout operations. However, certain parameters, especially cutting density, cannot be controlled in the field and hence, it is neglected in most of the studies related to hole-cleaning.

A dense particle can settle from suspension into a stationary bed relatively easily, making it difficult to remove from the wellbore. Although the density of the solid particles to be removed from the wellbore cannot be modified, the cleanout process can be designed to account for the predicted solids density. Specifically to the drilling process, the increase in cuttings density can result in a substantial increase in Equivalent Circulating Density (ECD) of the mud system.

An unexpected and unpredicted increase in ECD can cause severe problems such as unwanted fractures in the formation and subsequent loss of mud.

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This results in severe damage to the formation and significantly reduces hydrocarbon production. Hence, it is imperative to study the magnitude and effect density of cuttings in addition to other controllable parameters to optimize cleanout efficiency [5,6,7,8].

Furthermore, for a laminar flow, the effect of particle density on the hole cleaning mechanism in vertical section can be predicted using simplified physical relationships.

From past research, a number of experimental investigations were conducted to study the factors affecting the removal of drilled cuttings in vertical wells; cuttings density being one of them. Nguyen and Rahman borrowed this definition and conducted a study that involved summarizing the effect of cuttings density of uniform bed thickness as a part of it. Simulations conducted involved use of two cuttings type having specific gravity values of 2.62 and 1.7.

According to a mechanistic model Nguyen and Rahman, a decrease in cuttings density is expected to reduce significantly normalized bed height. Moreover, the Minimum Transport Velocity (MTV) required to initiate bed particle movement (indicated at the point where normalized bed height thickness reduces to zero) for bed with denser particles was much higher (1.07 m/s) as compared to lighter particles (0.8 m/s). This is attributed to the increased ability of any fluid to suspend lighter particles for a longer duration in the flow stream, especially in near horizontal sections, and hence, result in better transport efficiency [9].

Li and Wilde studied different particles which have a specific gravity in the range of 1.25 to 3.6. The bed erosion tests were conducted in a flow loop at different inclination angles. The results obtained agree with model predictions. More dense particles were difficult to clean from the test section. The efficiency of fluid was studied in terms of "Transport Ratio", defined as the ratio of injected to deposited solids concentration. A higher value of transport ratios indicates better solids removal capacity [10].

The result of the investigation showed that particles with low-density resulted in high transport ratios demonstrating easily removal of such particles. In addition, the solids concentration in a horizontal section was higher than that in a vertical well section for a given flow rate for same particle density. The solids concentration increases in each type of profile with an increase in particle density.

Cano et al. also recognized the importance of particle density on the transport efficiency of the cleanout fluids. High-density particles require increased hydrodynamic forces to be dislodged from the bed and carried by the cleaning fluid. The results obtained from all the studies mentioned above have a common finding that heavier particles are difficult to transport if other hydraulic parameters are kept constant. However, the challenge is to determine the magnitude of the effect of particle density and correlate its impact in predicting solids transport during the hole-cleaning. This study focuses on trying to solve this problem by utilizing data obtained in this study and published data in the literature to account for the effect of particle density on hole cleaning efficiency [11]. However, the challenge is to determine the magnitude of the effect of particle density and correlate its impact in predicting solids transport during the hole-cleaning. This study focuses on trying to solve this problem by utilizing data obtained in this study and published data in the literature to account for the effect of particle density on hole cleaning efficiency.

Mohammed Alawami et al., calculated the CCI in real-time with developed automatically system. Based on rig sensors were used to generate thousands of raw values with continuously, these raw data makes the calculations for human is more easy and possible. The model is developed to take some well details, such as hole size and casing size with conjunction the raw data and use it as an input, to generate the CCI. This system takes us one step closer toward the ultimate goal of having an integrated and fully automated hole cleaning evaluation and intervention tool that does not require any human involvement [12].

Amel H. Assi, used various drilling fluids to improve lifting capacity. Three mud types were used including oil base mud, Xanthan polymer and a mixture of CMC and bentonite. Carrying Capacity Index (CCI) has been used for assessment lifting capacity, the results show a good values were reported for Xanthan polymer rather than other drilling fluids under study [13].

Faleh and Karrar investigated and assessed the influence of various nanoparticles on the performance of drilling fluids to make the drilling operation smooth, cost effective and efficient. We exam the effect of Multi Wall Carbon Nanotube and Silicon Oxide Nanoparticles as Nanomaterial to prepare drilling fluids samples 14].

Moreover, other method was presented by Ayad A. Alhaleem to study the efficiency of drilling with casing operation in an Iraqi oil field to overcome oil well control, minimizing the total cost through enhancing drilling efficiency, drilling with casing was proposed as an enabling technology. By using DWC technique, the total drill/case phase time was reduced up to 20% comparing to conventional drilling in the same field [15].

In this study the effect of cutting density on the efficiency of hole cleaning operation and related performance parameters was succinctly investigated. This was achieved by conducting a number of experimental tests using two types of cuttings with different sizes and density, while fluids with varying rheology were incorporated as cleanout fluids at varying flow rates.

2- Description of Parameters for CTR Estimation

The cuttings used in this study were limited to limestone and anhydrite of different densities. The cuttings transport tests were conducted in a closed loop test section. Two types of cuttings are used in the scope of this study light (low-density) limestone which having a specific gravity of 2.71 g/cc and heavy (high-density) anhydrite having a specific gravity of 2.97 g/cc.

A calculated initial weight was fed into the test section for each type of cuttings to maintain similar initial conditions of cuttings transport. Preliminary cuttings transport tests indicated that 240 g of limestone was calculated based on assuming ROP=2.31 ft/hr and porosity and density of this cutting equal 12% and 2.71 g/cc respectively. Also, the weight measurement for anhydrite was depended on same value of ROP in limestone calculations but, porosity and density of this cutting equal 0% and 2.97 g/cc respectively. Cutting transport tests at a different flow rate were run for 3 minutes and a collected weight was recorded for each run 3 min. Table **1** summarizes the test matrix for this investigation.

Table 1. Range of data for cutting transport ratio estimation

Parameters	Range
Inclination Angle θ (degree)	55°-90°
Mud Weight (ppg)	8.75, 8.8, 9
Pv (cp)	7.6, 13.5, 13.7
Yp (lb/100ft^2)	11.3, 19.7, 30.2
Flow rate (gpm)	48.43, 70.44, 92.46
Cutting size (mm)	1.7, 2.36, 4
Cutting density (ppg)	22.57, 24.47

3- Experimental Work

3.1. Configuration of the Flow Loop

Fig. 1 illustrated the cutting transport loop with the capacity to run all set experiments in a normal pressure and normal temperature system as seen in. The rig was simulated for field condition by assuming the drilling bit to be 8.5 inch (215.9 mm) and the drill pipe 5 inch (127 mm). The rig was designed to be 12.19 m (40 ft) long from iron, except the test section was made from PVC with long of 5.1 m (16.73 ft) consists of two pipes outer pipe: the inner and outer diameter for outer pipe was 4½" in (110 mm) and inner diameter 4" in (101.6 mm) respectively. The inner pipe with outer diameter equal 2" (50 mm). The inner pipe designed to be centralized with outer pipe.

Fig. 1. Cuttings transport loo

Furthermore, the solid-liquid mixture was provided from a 0.55 m^3 (550 liters) container (mud tank) where the liquid pumped and combined with the drilling cuttings as illustrated in Fig. **2**. Mud was agitating with a mixture instilled at bottom of mud tank.

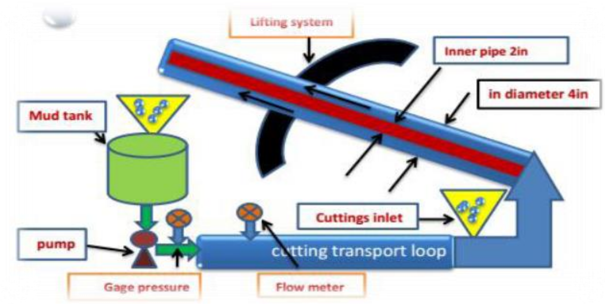

Fig. 2. Schematic of cuttings transport loop

The actual drilling cuttings were used in this study with three diameters 1.7 mm (0.0669 in), 2.36 mm (0.0929in) and 4 mm (0.155 in) and of density of 2.71 and 2.97 gm/cm^3. Coarse sands taken from Bai Hassan oil field for well 192 from depth 1270 m to 1370 m were selected as solid particles. After cuttings were sift, washed and separated for three size 1.7, 2.36 mm and 4 mm then weight of 240 g (0.592 lb) and 300 g (0.661 lb) as test sample. The total amount of sift cuttings which were ready prior to each run approximated 10 kg (22 lb). All cutting sizes and types show in Fig. **3**

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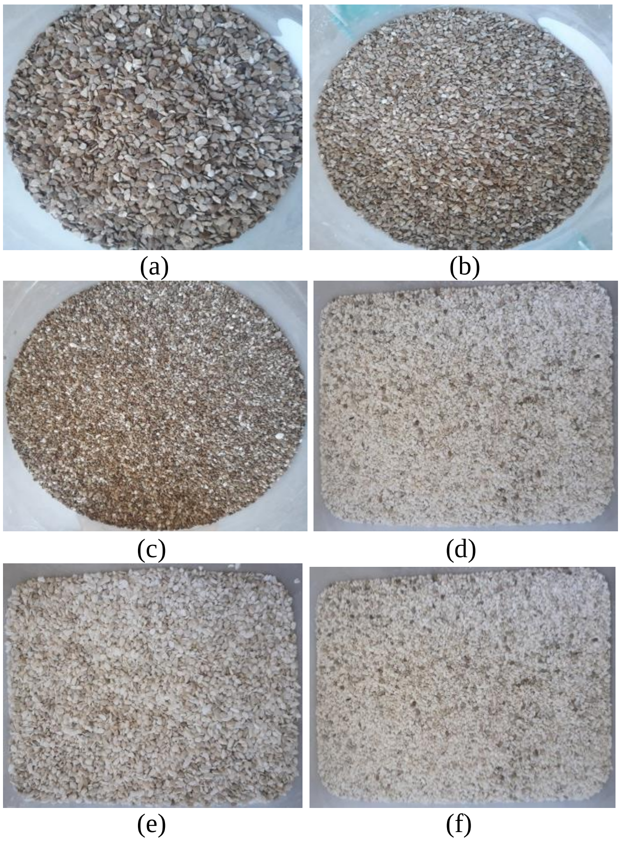


Fig. 3. a. Limestone 4 mm, b. Limestone 2.36 mm, c. Limestone 1.7 mm, d. Anhydrite 4 mm, e. Anhydrite 2.36 mm, f. Anhydrite 1.7 mm

3.2. Description of Mud System

The drilling mud used in this experimental work has been prepared from water, caustic soda (Sodium hydroxide) and bentonite, adding caustic soda and bentonite to water, mixing these components for six hours at a high and then medium speed.

3.3. Experimental procedure

In the beginning washing, drying and sieving the cutting drill then weight 240 g and 300 g as injection cutting for limestone and anhydrite respectively. 12 experiments for each run 6 experiments for limestone and other 6 for anhydrite was set up for inclination angle from (55^o-90^o). Three flow rates (48.43, 70.44, and 92.46 gpm) used in all of these experiments. Repeat this procedure with new size and type of cuttings. After completed all experiments for the first run, increase yield point of mud (higher yield point) with added more bentonite and caustic soda then start second run with the same parameter in first run.

Calculate cutting transport ratio using equation below:

$$\text{CTR (\%)} = \frac{\text{dry weight of cutting collected}}{\text{Initial weight of cutting injected}} \times 100 \tag{1}$$

Summarized procedure can be seen in Fig. **4**:

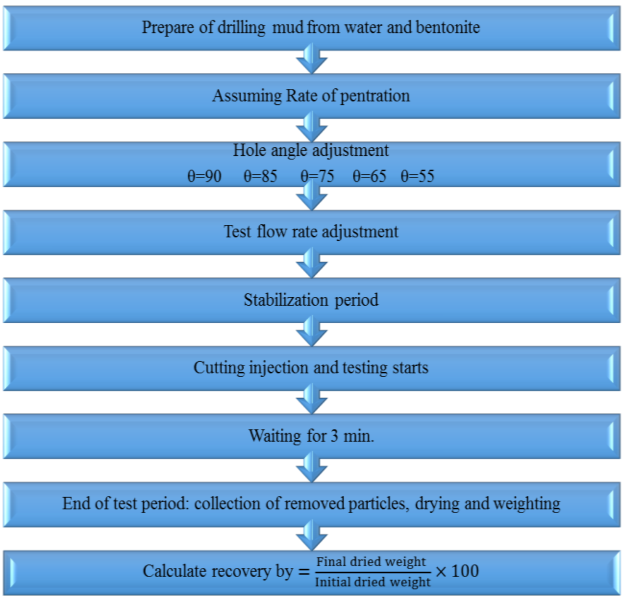


Fig. 4. Experimental procedure diagram

4- Results and Discussion

4.1. Description of Mud System

The three water-based mud systems were used for the investigation. All samples were prepared from bentonite and fresh water.

A rotational viscometer (Model 900) was used to measure the rheological properties of drilling fluids before and after each experiment. It was found that rheology of these fluids can be best described using a Bingham plastic model as shown in Fig. **5** and in Table **2**.

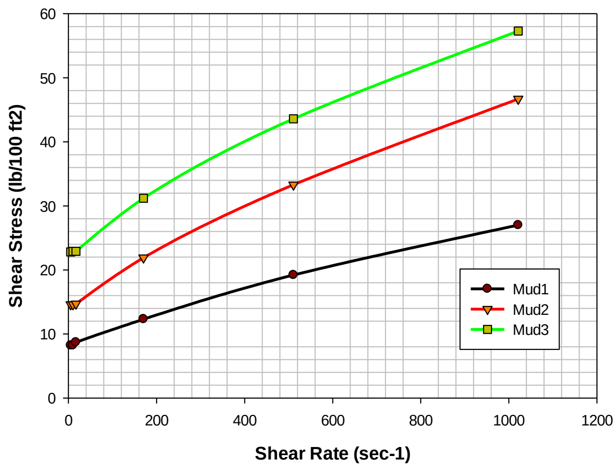


Fig. 5. Shear stress vs. shear rate for different mud type

Table 2. Rheology results for different mud type.

Mud type	θ_{600}	θ_{300}	θ_{100}	θ_{10}	θ_6	θ_3	Gel (10s)	Gel (10min)	Pv	Yp	ρ_m	Marsh funnel
Mud1	27	19.2	12.3	8.7	8.2	8.2	10.9	15.4	7.6	11.3	8.75	36
Mud2	46.7	33.3	21.9	14.7	14.6	14.6	18.2	20.3	19.6	13.5	8.83	46
Mud3	57.3	43.6	31.2	22.9	22.9	22.8	26.6	40.1	30.2	13.7	9	56

4.2. Effect of cutting Density on Cleanout Behavior

The cutting density is one important factor that effect on cutting transport ratio in all type of wells.

The main goal in this experimental work to study the different of cutting density on hole cleaning in three mud system.

The density difference between fluid and cutting governs the required hydrodynamic force to lift or roll particle from the stationary bed into the flow stream.

As expected, a heavier particle is more difficult to transport.

In this study, two different cuttings rock densities with three sizes (1.7, 2.36 and 4mm) were used in flow loop experiments. The specific gravities of the limestone and anhydrite were 2.71 and 2.97. Fig. **6** were showed the cutting transport ratio for limestone and anhydrite with different sizes and for all fluids varying inclination (55°,65°,75° 85°, and 90°).

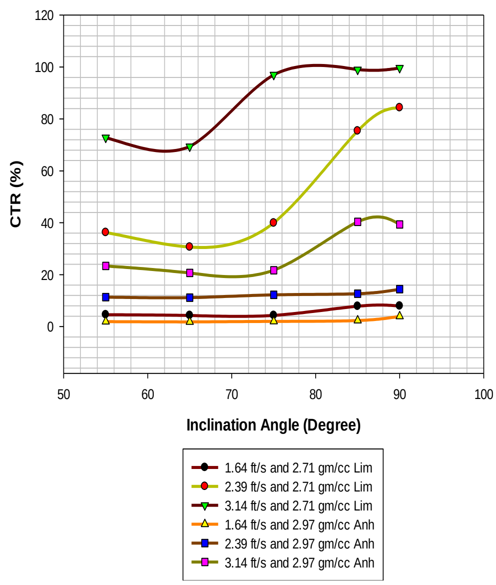
The results obtained show that, relatively, for all angle and all sizes we observed the cutting with light density transported more than heavy density.

The graphs suggest that increase in cutting density at constant flow rate results in a reduction in cuttings transport performance.

Also, increasing in yield point and annular velocity leading to increases in hole cleaning efficiency for all sizes and for two types of cuttings.

However, the effect of yield point is become small at high values of annular velocity. Cutting transport efficiency is increasing with increase in inclination angle from 75°-90° and decrease at 65° after that shows increase between 65°-55° for two types of cutting.

The critical angle for cutting transport is improved at 65 degree. Lastly, the heavy and large size of cutting is more difficult with transport.



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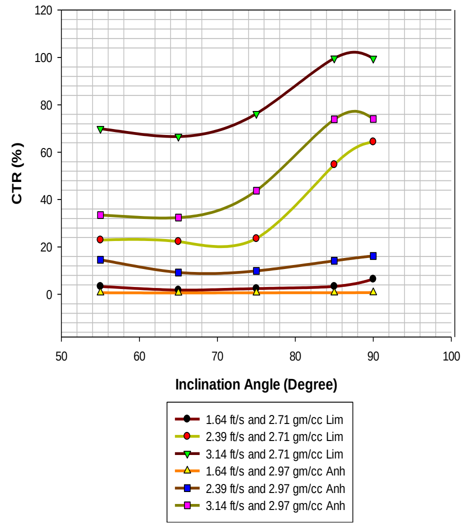

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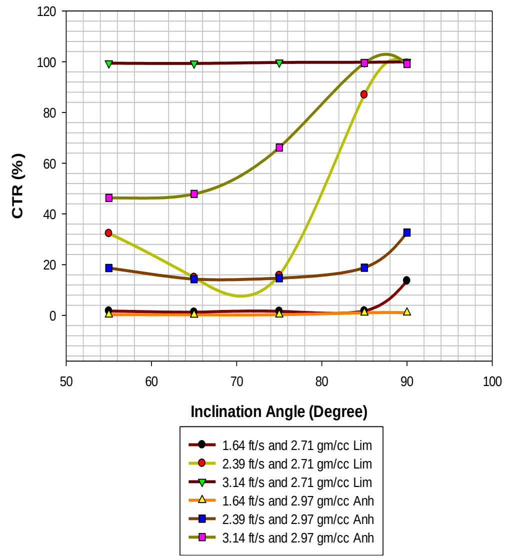

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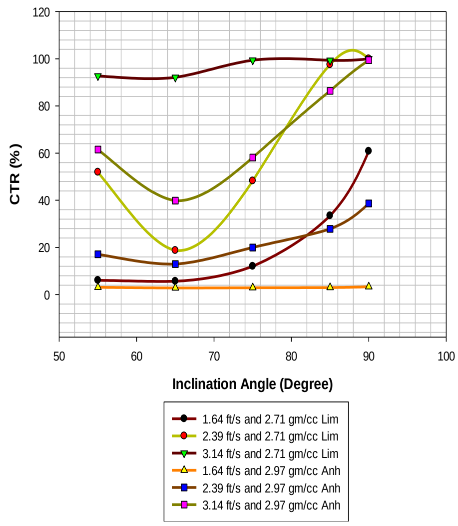

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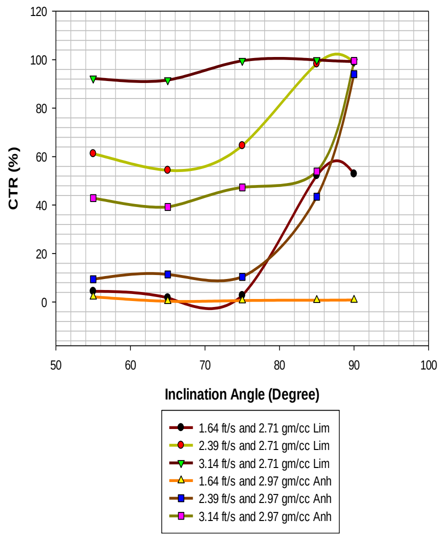

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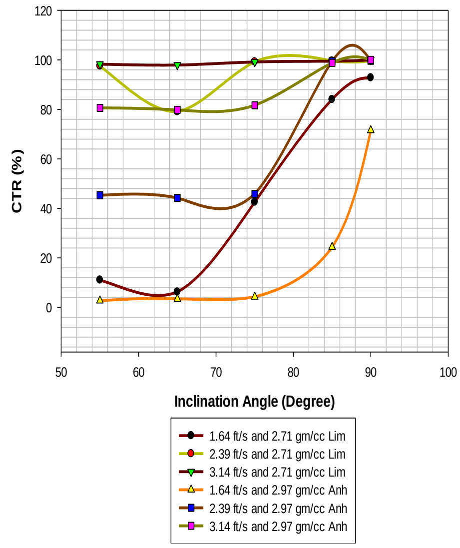

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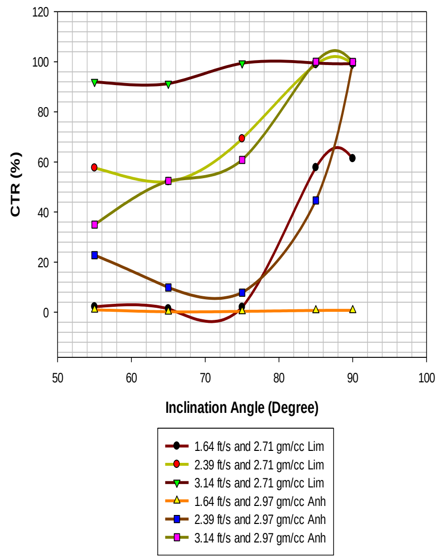

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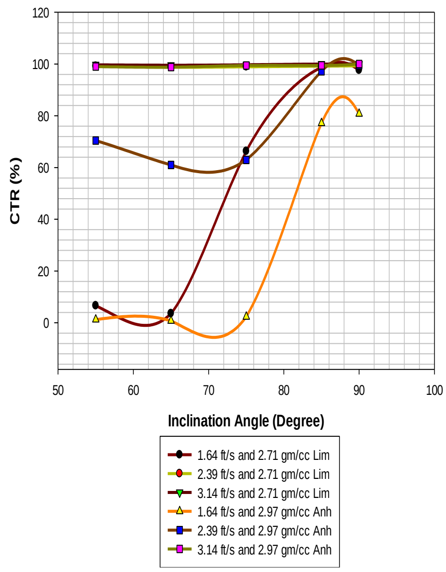
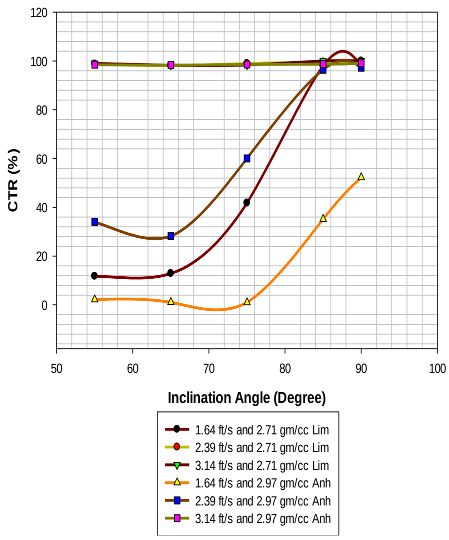


(i)



(g)

Fig. 6. a. Effect of cutting density on CTR for size 1.7 mm and Yp=11.3, b. Effect of cutting density on CTR for size 2.36 mm and Yp=11.3 lb/100ft^2, c. Effect of cutting density on CTR for size 4 mm and Yp=11.3 lb/100ft^2, d. Effect of cutting density on CTR for size 1.7 mm and Yp=19.7 lb/100ft^2, e. Effect of Cutting Density on CTR for size 2.36 mm and Yp=19.7 lb/100ft^2, f. Effect of Cutting Density on CTR for size 4 mm and Yp=19.7 lb/100ft^2, g. Effect of cutting density on CTR for size 2.36 mm and Yp=30.2 lb/100ft^2, h. Effect of cutting density on CTR for size 1.7 mm and Yp=30.2 lb/100ft^2, i. Effect of cutting density on CTR for size 4 mm and Yp=30.2 lb/100ft^2

5- Conclusions

Based on this this study we show the cutting transport ratio and cleanout efficiency increase with increase flow rate for all yield point value of mud and inclination angle considered. Increase in flow rate improves annular velocity acting on the cutting recovery.

Higher flow rate indicates higher annular velocity of mud acting to transport of the cutting, leading to improved cutting transport. The maximum cutting recovery has been observed at the maximum annular velocity (third velocity 3.14 ft/s) for all size and inclination angle. The effect of annular mud is become more in high inclination angle and high yield value of Yp than other cases.

The amount of cutting that can be transported much with increase in yield point of fluid. This case was showed for the same flow rate and inclination angle and for all cutting size. The effect of yield point will be low at the higher value of annular velocity.

The direct relationship exists between cutting transport and inclination angle. The critical inclination angle exists between 65° and 75°. In this angle exists at which all fluids have similar performance, especially at low Yp and minimum value of annular velocity and for all cutting size.

Nomenclatures and Abbreviations

No.	Parameter	Meaning	Unit
1	CTR	Cuttings transport ratio	%
2	CCI	Carrying Capacity Index	%
3	MTV	Minimum Transport Velocity	ft/sec
4	ECD	Equivalent Circulating Density	ppg
5	Q	Flow rate	gpm
6	RPM	Pipe rotation per minute	RPM
7	Yp	Yield point	$lb/100ft^2$
8	θ	Inclination angle	Degree
9	Pv	Plastic viscosity	cp
10	ρ_m	Mud density	ppg
11	ρ_p	Cutting density	ppg
12	dp	Cutting size	mm

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دراسة مختبرية لتقييم تأثير كثافة القطع الصخرية على كفاءة تنظيف جوف البئر في الأبار المائلة والأفقية

سهمي عدوان محمد و فالح المهداوي

جامعة بغداد/قسم هندسة النفط

الخلاصة

إن كفاءة التنظيف الرديئة لجوف البئر ينتج عنها العديد من المشاكل مثل زيادة عزمي الدوران والسحب, إنخفاض الطاقة الهيدروليكية, وكذلك مشكلة إستعصاء الأنابيب. هذه المشاكل تؤدي الى زياة الكلف التشغيلية الممكن تجنبها والتي حاولت هذه الدراسة معالجتها.خلال هذه العمل تم دراسة تأثير كثافة القطع الصخرية بشكل كامل على كفاءة تنظيف جوف البئر في الأبار المائلة والأفقية.أجريت التجارب باستخدام منظومة مختبرية تم إعدادها لهذا الغرض وبطول 40 قدم (12 م) كمنظومة تدفق و المصنعة من الحديد والبلاستيك. مقطع الأختبار تم إستخدامه من مادة البلاستك وبطول 5.1 م وبقطرداخلي للأنبوب الخارجي 4 إنج, وقطر خارجي للإنبوب الداخلي 2 إنج. إن نسبة نقل القطع الصخرية يتم حسابها عن طريق الوزن أي توزين الكمية الخارجة بعد تجفيفها على الكمية المحقونة أي الكمية الأولية حيث يتم هذه العملية في كل فحص. تم إختبار نسبة نقل القطع الصخرية لتأثير عوامل عدة منها: معدل الجريان,حجم وكثافة القطع الصخرية, نقطة المطاوعة لطين الحفر, وزاوية ميل البئر. طريقة الفحص تتم بتثبيت زاوية الميل ومن ثم معدل الجريان عم طريق الفلوميتر الخاص بقياس معدل التدفق, بعد ذلك يتم حقن الحجم المطلوب من القطع الصخرية داخل مقطع الأختبار بعدها يتم تشغيل المنظومة لمدة 3 دقائق حيث يتم جمع القطع الصخرية الخارجة خلال ثلاث دقائق وغسلها وتجفيها وتوزينها على الكمية الأصلية لحساب نسبة النقل, وتكون هذه الأختبارات بتثبيت قيمة نقطة المطاوعة للطين.

تشير النتائج التي تم الحصول عليها من هذه الدراسة إلى أن كثافة القطع لها تأثير بسيط إلى متوسط على كفاءة تنظيف جوف البئر. أيضا ، لوحظ تحسن في نسبة نقل القطع الصخرية كلما زادت سرعة الفراغ الحلقي وزادت زاوية الميل. كذلك, بينت النتائج أن القطع الصخر ية ذات الحجوم المتوسطة والكبيرة تنقل بنسبة أكبر من القطع ذات الحجوم الصغيرة عند القيم العالية لنقطة المطاوعة لطين الحفر وتصبح هذه الحالة عكسية عند القيم القليلة لنقطة المطاوعة.بالإضافة الى ذلك,أوضحت النتائج بأن القطع الصخرية ذات الكثافة الكبيرة تنقل بنسية أقل مقارنة بالقطع الصضرية ذات الكثافة القليلة وهذا التأثير لجميع الأحجام المستخدمة. وأخيراً ، لوحظ بأن الزاوية الحرجة واقعة بين 65–75 درجة. تم أستخدمبرنامج Sigma plot 12.5 لرسم جميع الأشكال في هذه الورقة البحثية.

الكلمات الدالة: نسبة نقل القطع, كثافة القطع الصلبة, كفاءة تنظيف البئر, نقطة المطاوعة.