Hole Cleaning in Horizontal and Highly Deviated Wellbores Drilled with Coiled Tubing: Drillpipe Rotation Drawback Is It Significant?

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Abstract – ***Coiled tubing (CT) has been recently applied for frequent drilling operation. Pushing the limits for coiled tubing drilling to include extended reach drilling is opposed by hole cleaning issues. Hole cleaning problems are claimed to be critical in coiled tubing drilling due to lack of drillpipe rotation. This paper is intended to show how significant is the effect of not rotating the inner pipe on hole cleaning during coiled tubing drilling. The drillpipe was constrained at its ends only allowing it to exhibit eccentricity at the mid-section. This allows to simulate the whirling motion of the drillpipe which is claimed to add to good hole cleaning. The effect of pipe rotation was studied and the data collected were graphically correlated in the form of weight percent of recovered particles versus hole inclination at different drillpipe rotational speeds and annular fluid velocities. Results showed that pipe rotation significantly improve hole cleaning; up to 68% improvement was recorded for intermediate velocities (1.86 ft/sec & 2.29 ft/sec). The effect of pipe rotation is less significant at lower annular velocities and lower inclinations (1.43 ft/sec and 60 degree from vertical respectively); however, it has a significant effect at intermediate annular velocities but this effect is diminished with further increase in velocity. The results emphasized that turbulent flow are critical for cuttings removal at horizontal/highly deviated wellbores.***

Key Words: *Hole cleaning, Horizontal and highly deviate wells, Extended reach wells, Coiled tubing drilling, Drillpipe rotation.*

1. INTRODUCTION

Coiled tubing (CT) has been utilized successfully for frequent applications such as solids washing, acidizing, drilling cementing, well unloading, through tubing drilling, underbalanced drilling, etc. CT rigs utilize continuous tubing to rapidly reel bits, motors, and other tools in and out of wells, which directly reduces drilling time and cost savings for the drilling operations. They significantly reduce drilling, completion and workover costs in many areas of the world and are ideal for underbalanced drilling since they can be reeled in and out of the well under pressure. CT has distinct advantage in these areas over conventional jointed pipe due to the lack of requirements for connections, use of an internal wireline and capillaries for survey and geosteering purposes, and much higher operating surface pressure limitations than conventional jointed pipe. Furthermore, a CT unit is a smaller, more portable assembly than a conventional drilling rig and typically requires only about 50% of the foot print space on site for operation in comparison to an equivalent system using jointed pipe; this lowers environmental impact on site as well as reducing site construction, use and abandonment. Generally there are several advantages and disadvantages of coiled tubing drilling compared to conventional jointed pipe drilling, outlining these comparisons is out of the scope of this paper; such comparisons may be found in the work of Bennion *et al.* [1].

Decline in oil production and the need to reduce cost and improve recovery from the existing hydrocarbon reservoirs were among the incentive factors that led to the appearance of horizontal and multi-lateral wells. The fact that many reservoirs are practically depleted, the need to make the re-entry of horizontal or multilateral wells effective, and the need to minimize formation damage and to increase the rate of penetration poses difficult challenges to oil industry. Several re-entry operations have used CT, and proved the equipment technically feasible for both window-milling and drilling the build section as a precursor to the horizontal drilling operation. The technique is also well placed for drilling highly deviated/ultra-short radius wells [2, 3, 4].

The increasing cost of environmental compliance particularly in highly sensitive areas increases the need for more benign technologies. Slim hole drilling with coiled tubing provide one solution to environmental issues by reducing the surface disturbance and waste disposal. CT further minimizes environmental impact because it lack necessity for connections and smaller foot print requirements; mud spillage accidents are reduced several folds. Furthermore, slim hole drilling reduces significantly drilling costs. Therefore, many CT applications are drilled slim hole to reduce these problems as well as problems associated with low annular fluid velocities in the horizontal section.

Horizontal and highly deviated wells are now routinely drilled all around the world after their economic benefits have been fairly established. Coiled tubing drilling technology is currently limited at 500 – 700 m (1640 – 2296 ft) of horizontal outreach and relatively small hole sizes in order to maintain sufficiently high annular velocities for adequate hole cleaning purposes. High frictional losses, associated with the necessity of injecting fluid through the entire length of the coiled tubing string at all times, are also problematic. Inability to rotate CT may further exacerbate the problem with hole cleaning [1].

Extending the reach of horizontal and highly deviated wells is currently of utmost importance to operating companies. Laterals are stretched up to more than 5 kilometre which allow to develop reserves that otherwise would have been bypassed or require more subsea developments. While drilling extended reach wells, single problem in the beginning of the well may become a limiting factor for achieving the pre-planned lateral length of the well. However, pushing the limits for coiled tubing drilling to include extended reach drilling is opposed by hole cleaning issues.

Most of hole problems encountered while drilling such wells even with conventional jointed pipe drilling are generally accredited to inadequate hole cleaning and difficulty in transporting drill-cuttings along horizontal and highly deviated sections of the well. Since these wells are characterized with a high ratio of lateral departure to vertical depth, the problem seems to aggravate many folds. In these sections, none or only a finite component of the bulk flow acts against tendency for cuttings to settle and rest on low sidewall of the annulus as what is known as cutting beds. CT has lower thrust which reduces good transfer of weight to bit; this also may be further aggravated by presence of cutting beds due to insufficient hole cleaning in highly-deviated and horizontal sections of the well. CT also has lower torque capacity because of smaller down hole motors. These factors greatly limit the CTD rate of penetration.

Effective removal of cuttings is the primary task of any drilling fluid. Efficient hole cleaning is essential for the drilling practices to succeed and are required to complete the well at lower costs. However, inadequate hole cleaning can trigger other wellbore problems such as mechanical drillstring sticking, lost of circulation, bottom hole and bit balling, formation damage, and difficulties in running casing strings and deploying logging equipment. These problems add to the well cost significantly and if corrective measures were not undertaken successfully, it may lead to side tracking and possible loss of the well.

The ability to continually or periodically rotate conventional jointed pipe is thought to result in superior hole cleaning conditions due to keeping a complete cuttings bed from forming. However, to what extent did absence of pipe rotation affect cuttings removal in wellbores drilled using CT is not emphasized by an experimental work. This paper is intended to show the effect of not rotating the inner pipe in coiled tubing drilling. The drillpipe was constrained at its ends only allowing it to exhibit eccentricity at the mid-section. The effect of pipe rotation was studied and the data collected were graphically correlated in the form of weight of recovered particles versus annular velocity either with or without drillpipe rotation.

2. EXPERIMENTAL DESIGN AND PROCEDURE

2.1 Experimental Design

A wellbore simulator has been built. The simulator is a low-pressure ambient-temperature flow loop that allows the effect of different flow rates, fluid viscosity, hole inclinations and drillpipe orbital motion to be effectively evaluated. The inner pipe in this section was supported at its ends only (no centralizer) allowing it to exhibit eccentricity at the mid-section. Rotating torque was supplied to the inner pipe through an electric induction motor completed with a frequency inverter. Rotating the eccentric pipe produces whirling like motion to the inner pipe.

The annulus flow section of this loop was designed with the aim of simulating field conditions while drilling the lateral section of highly deviated and horizontal slim hole wells as shown in Table 1. Field conditions in Table 1 are taken according to survey of SPE papers describing case studies (1992 – 2002) [4, 5]. Equivalent diameter in this Table is calculated according to Reed and Pilehvari [6].

The outer tube of the experimental wellbore is consisted of transparent acrylic tube; the total length of the column approaches 5-meter (16.4 feet). The column inside diameter was designed to be 76.2-mm (3-in) and the transparency of the tube is required to allow a smooth observation of cuttings transport mechanism and thus enable identifying type of transport mechanism under different operational conditions. An Aluminium hollow pipe with an outside diameter of 50.8-mm (2-in) was selected to simulate the drillpipe. The pipe was supported at its ends only with two rigid polymer flanges that are attached to both ends of the transport column. The flanges allow rotation of the inner pipe and maintain the required seal of the annulus at the same time.

Cuttings were injected manually a head of the circulating fluid using a set of well-arranged ball valves. Valves were arranged to ensure smooth introduction and placement of cuttings in front of the flow stream. Valve arrangement permits isolation and connection of cuttings trap from the circulation system and diverts part of the flow stream behind the injected cuttings.

Table -1: Comparison of field and experimental conditions

Parameter	Real conditions	Experimental conditions
Hole inside diameter (cm)	7.0 – 9.5 – 12.1	7.62 (3 in.)
Inner pipe outside diameter (cm)	5.08 – 6.03 – 7.3	5.08 (2 in.)
Ratio of Inner hole diameter to outer pipe diameter	0.73 – 0.64 – 0.6	0.67
Ratio of hydraulic diameter to outer pipe diameter	0.27 – 0.37 – 0.4	0.33
Equivalent diameter of annulus (cm)	1.28 – 2.3 – 3.2	1.7
Annular Velocity (cm/sec)	30 – 150	43 – 83
Fluid density (g/cm3)	1.02 – 1.14	1 – 1.06
Particle density (g/cm3)	2.50	2.72
Particle diameter (mm)	2 – 7	2.4
Rate of penetration (m/hr)	2.7 – 15	1.4
Dynamic viscosity @ 25° C (cP)	1 – 2	0.9 – 1.81
Reynolds number	3000 – 20000	4340 - 15661

Drill cuttings are represented by igneous rock fragments with a specific gravity of 2.72. Rock cuttings are collected, washed and dried. The cuttings are then sieved; the solid particles generally irregular with average size of 2.4-mm. The particles are then weighed and divided into separate units according to the addressed rate of penetration. Cuttings rate of injection was selected as low as possible in order to consume a reasonable amount of cuttings per test and to organize the introduction of cuttings units per each minute of the test. The cuttings injection rate was kept constant at a value of 162 g/min (0.357 lb/min) which simulate approximately slow hard rock drilling at a rate of 1.4 m/hr (4.5 ft/hr).

Experiments were conducted with tap water, a slightly viscous system composed of 20% glycerine/water and a viscous system composed of 60% glycerine/water; the corresponding kinematic viscosities of the fluids were 0.9, 1.71 and 10.5 cSt, respectively (0.9 cP, 1.81 cP and 12 cP, respectively). Flow rates of the circulating fluid were set between 66 and 126 L/min (23 and 33 gpm). The corresponding fluid velocities in the annular space were ranged between 43.59– 82.9 cm/sec (1.43 – 2.72 ft/sec). Finally the experiments were run for four hole angles namely 60º, 70º, 80º and 90º from vertical.

2.2 Experimental Procedure

(1) The device was arranged for each of the four positions of hole inclination and the effects of viscosity, pipe rotation at different annular velocities were investigated.
(2) In each test the flow was adjusted first either with or without pipe rotation for at least five minutes, running the test for extra 10 minutes.
(3) Cuttings injection started by isolating the cuttings injection system from main flow, opening the inlet valve of the injecting system, placing the cuttings (162 g) inside the cuttings injector trap, closing the inlet valve, looking at the system wall clock, adjusting the stop watch, and opening the valves to place cuttings inside the system and at the same time divert part of the flow to force injected cuttings forward.
(4) Before the end of each minute of injection, the injection system valves were closed to isolate the system, the next patch of cuttings were placed through the inlet valve, and at the beginning of the next minute cuttings were injected to the main flow.
(5) Step 3 and 4 were repeated throughout the test period (10 minute).
(6) After each test cuttings transported during the test period and accumulated at the separating system are collected carefully, placed in a suitable marked container, dried, and finally weighed.
(6) The percent of recovered weight of cuttings at the end of each test was plotted against annular velocity at different hole inclinations, fluid viscosity with and without pipe rotation.

3. RESULT AND DISCUSSION

3.1 Water System

The effect of pipe rotation was significant for water. Figures 1 – 4 clearly show the significant improvement in hole cleaning gained by rotating the inner pipe at a constant rotary speed of 10 rpm. In Figure 1, pipe rotation add slightly to cuttings transport at 60 and 70 degree hole inclinations since the water annular velocity of 43.59

cm/sec (1.43 ft/sec) seriously failed to clean these systems. Significant improvement in cuttings removal by addition of pipe rotation was clear in the 80 and 90 degrees hole inclinations; the percent of recovered particles (%WRP) was at 55% and 81% of TIW (Total Injected Weight of Cuttings) compared to only 4% and 6%, respectively when pipe rotation is not used (an improvement of 51% and 75% respectively).

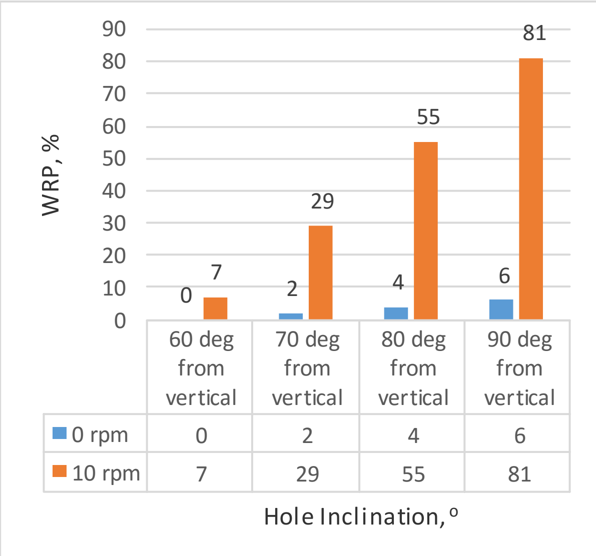

Fig-1: % of Recovered particles in water flowing at 1.43 ft/sec

However, in Figure 2, pipe rotation was found to greatly improve cuttings transport at 56.69 cm/sec (1.86 ft/sec), at all hole inclinations. The recovered weight of particles (WRP) at 60, 70, 80 and 90 degree were at 59%, 77%, 90% and 98% of TIW compared to only 4%, 14%, 23% and 30% respectively, when pipe rotation is not used. This means that pipe rotation was responsible for transporting a 55%, 63%, 67% and 68% of TIW in addition to the 4%, 14%, 23% and 30% originally transported by 56.69 cm/sec (1.86 ft/sec) velocity alone. This particular gain in cuttings transport due to pipe rotation is generally greater than the improvement caused even by increasing velocity from 1.43 ft/sec to 2.29 ft/sec at the same angles.

When pipe rotation was added to the previous system while it was flowing at 69.80 cm/sec (2.29 ft/sec), cuttings transport was found to enhance further. The amount of recovered particle at 60 degrees hole inclination was increased from 24% to 90 % of TIW (Figure 3). This means that pipe rotation was responsible for adding 66% of TIW in addition to 24% originally transported by 2.29 ft/sec (69.80 cm/sec) velocity. This improvement is slightly better than with the 1.43 ft/sec and 1.86 ft/sec velocities. This scenario is repeated for the 70 degree hole inclination but with a slightly lower degree (62% of TIW in addition to 36% originally transported by 2.29 ft/sec).

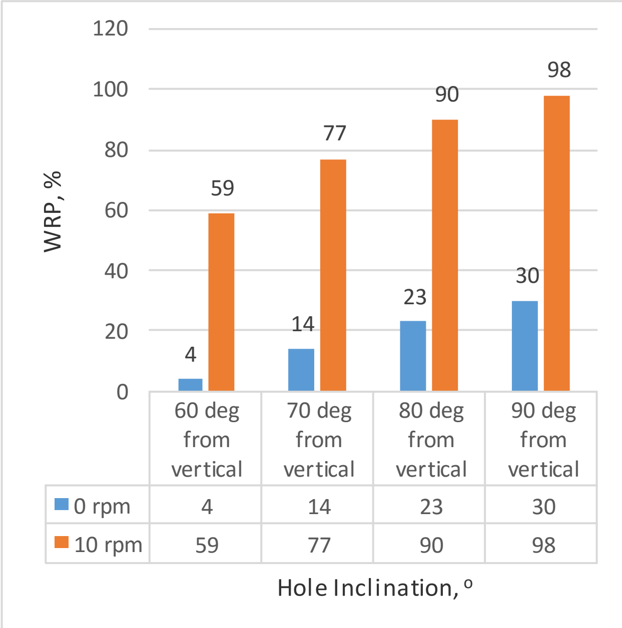

Fig-2: % of Recovered particles in water flowing at 1.86 ft/sec

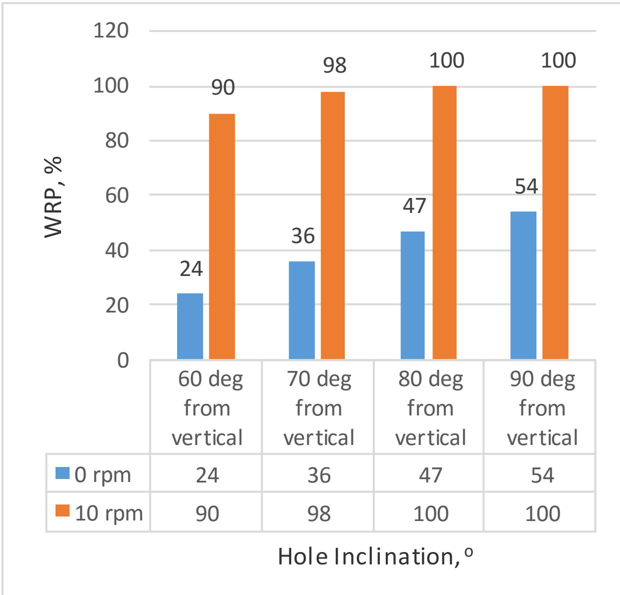

Fig-3: % of Recovered particles in water flowing 2.29 ft/sec

The case of 80 and 90 degree inclination is slightly less at 69.80 cm/sec (2.29 ft/sec) compared to the previous velocities. Improvements in cuttings removal revolved around 50% for both 80 and 90 degrees hole inclination compared to 67% and 68% of TIW, respectively at 56.69 cm/sec.

Likewise, pipe rotation at 82.91 cm/sec (2.72 ft/sec) adds to cuttings transport at 60 degree hole inclination by increasing the amount of recovered particles from 62% to

100% of TIW (Figure 4). Again the pipe rotation was responsible for transporting 38% of TIW in addition to 62% originally transported by 82.91 cm/sec (2.72 ft/sec) velocity. This improvement is obviously less than with 69.80 and 56.69 cm/sec (2.29 and 1.86 ft/sec) velocities. The case of 70 degree inclinations pretty some follows the case of 60 degree inclinations.

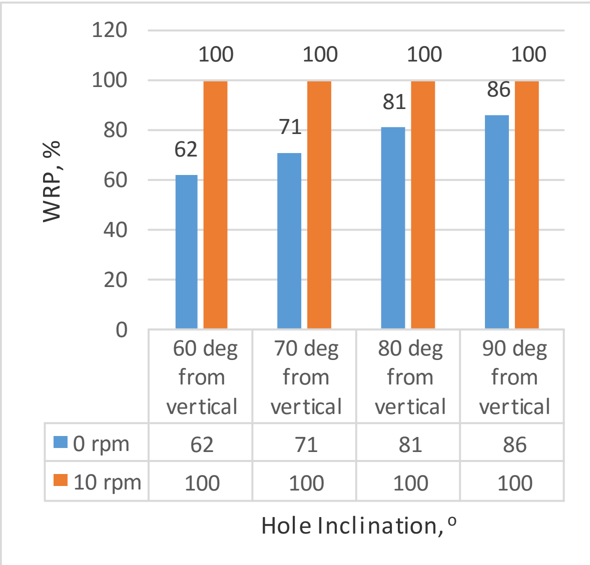

Fig-4: % of Recovered Particles in water flowing at 2.72 ft/sec.

3.2 Slightly Viscous System

The slightly viscous system was composed of 20% glycerine/water with a dynamic viscosity of 1.81 cp approximately double that of tap water. The results of this system were parley different from those of tap water previously shown (Figures 1-4). At all velocities and hole inclinations and for the cases with or without pipe rotation, cuttings removal was only slightly less for the case of slightly viscous system compared to those of tap water. Differences in the range of 1% - 6% in cuttings removal with the slightly viscous system always exhibiting lower efficiencies. Accordingly, the results and trends previously shown for tap water are considered valid for this system (Figures 1-4).

3.2 Viscous System

As previously mentioned, the viscous system was composed of 60% glycerine/water with a dynamic viscosity of 12.3 cp approximately 13 times that for the tap water used. Though the viscosity of this system is not applicable at field (Table 1), we are keen through this system to investigate and illustrate the effect of higher viscosities on cuttings removal with and without pipe rotation. The results shows that the viscous system was unable to transport the cuttings out of the test section during the period of the test at the lower velocity used in this study (1.43 ft/sec) with or without pipe rotation. When the velocity was increased to 56.69 cm/sec (1.86 ft/sec) the situation not much changed for the case without pipe rotation.

However, when pipe rotation was functioned on, cuttings removal was increased as seen in Figure 5. The improvements ranged from 25% at 60 degree hole inclination to 52% at 90 degree hole inclination. These are lower than improvements gained with water system flowing at the same velocity (55% and 68% at respective inclinations). However, the result of the viscous system at 56.69 cm/sec resembles that of water system at 43.59 cm/sec were the improvements at higher inclinations surpasses those at lower inclination.

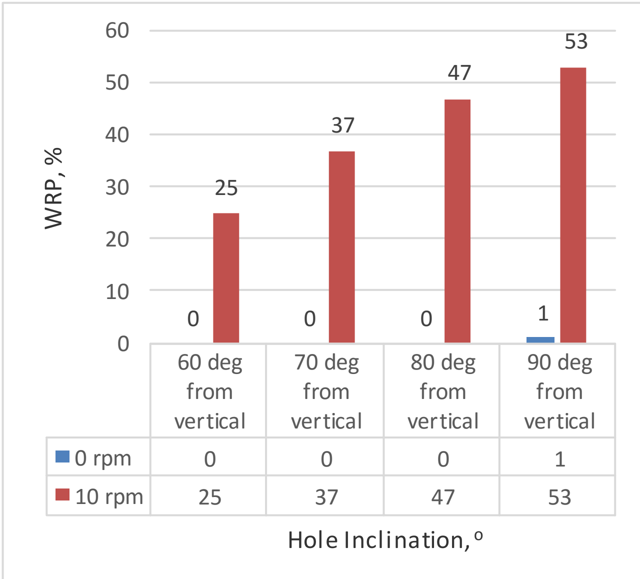

Fig-5: % of Recovered particles in viscous systems flowing at 1.86 ft/sec

With further increase in velocity, the viscous system was not able to provide good cuttings removal when flowing at 69.80 cm/sec (2.29 ft/sec) without the aid of pipe rotation. As it is depicted in Figure 6, the best cuttings removal was merely 20% of TIW at 90 degree hole inclination. This is significantly less than that obtained with water at the same velocity and inclination (54%). With introduction of pipe rotation the improvements in cuttings removal were ranged between 56% and 64% for all hole inclinations. The result is equivalent to the result with water at 56.69 cm/sec. Finally, the velocity was increased to 82.91 cm/sec (ft/sec) as shown in Figure 7. Cuttings removal improvements with pipe rotation ranged between 30% and 36% over those gained by annular velocity alone.

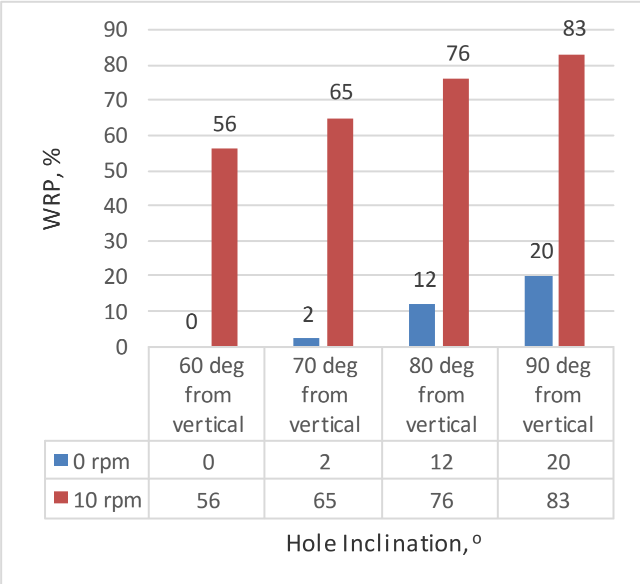

Fig-6: % of Recovered particles in viscous systems flowing 2.29 ft/sec.

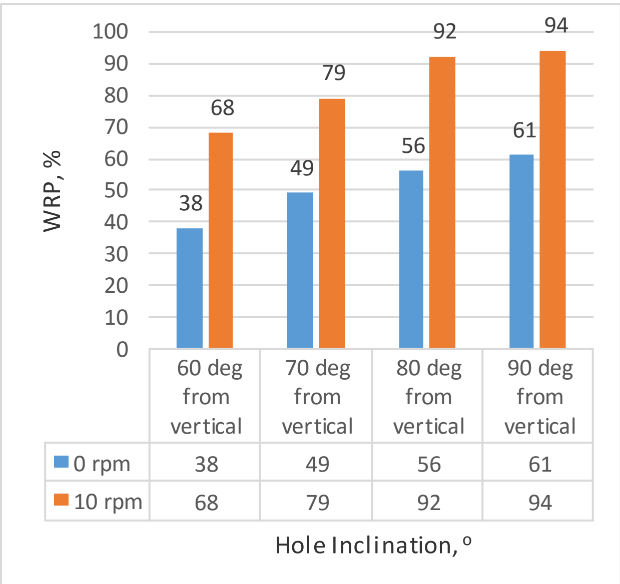

Fig-7: % of Recovered Particles in viscous systems flowing at 2.72 ft/sec

Increase in viscosity reduces cuttings removal, particularly because it results in lower Reynolds numbers below 2000. Calculated Reynolds numbers for 43.59 cm/sec, 56.69 cm/sec, 69.80 cm/sec and 82.91 cm/sec were 705, 917, 1129 and 1341. Hence the flow is laminar while circulating the viscous system. This may be the reason for this system to perform less than tap water in transporting cuttings out of the hole at all studied velocity and hole inclinations.

It is apparent that the effect of pipe rotation is small at lower velocities for the 60 and 70 hole inclination angles; however, it has a significant effect at higher inclination angles. At intermediate velocities pipe rotation equally enhance cuttings removal for all hole inclination angles. The effect of pipe rotation is diminished with further increase in velocity. It seems that there is a critical velocity at each hole angle above which the effect of pipe rotation increase with increase in velocity while beyond this critical value the effect of pipe rotation diminishes with further increase in velocity. Furthermore, the effect of pipe rotation increase with increase in hole inclination below this critical velocity meanwhile it decrease with increase in hole inclination above this critical velocity.

The diminishing efficacy of pipe rotation at higher flow rates might be due to insignificant of tangential component of liquid velocity (induced by the drillpipe rotation) at higher velocities and/or the fact that at lower flow rates, there are more cuttings for this effect to work on while at higher velocities, the turbulence induced by these velocities is high and the transport is very good. Hence, the effect of pipe rotation adds less to the turbulence of the system and enhances the transport by a lesser degree [7, 8].

Pipe rotation helps the transport of cuttings also by mechanical dragging and subsequent flying of cuttings to the upper main flow stream. This effect is evident with low and viscous fluids. However, this is restricted only to an eccentric annulus. The property of pipe rotation to fly cuttings from one side of the annulus to the other side has been observed clearly in this work in particular at the mid-point of the annulus which exhibits the highest degree of eccentricity.

It is customary to assign a zero velocity to boundaries of the annulus if pipe is not rotated. When the pipe is rotated, the velocity at the boundary of the fluid particles adjacent to drillpipe is set equal to the rotational speed of the pipe with a directional perpendicular to the hole axis. It seems that the velocity or momentum of the adjacent fluid to pipe walls is slowly diffusing to the inner fluid.

In inclined wells, the lift force tends to lift the drilled cuttings from the low sidewall of the annulus and works against the component of net gravity force on the particle that force the cutting to the low sidewall of the annulus. Whenever the lift force is greater than the effective gravitational force, cuttings will exhibit some sort of lift and will be released from the bed accumulation and join the main flow. Recognizing that the component of gravitational force on the particle increased with increasing hole inclination, the force required to initiate lift on cuttings located at the low sidewall of the annulus will be greater at higher inclinations (90°). At higher velocities, the pipe add to system turbulence; turbulence is one of the sources of lift forces imposed on particle [9], then the effect of pipe rotation decrease with further increase in hole inclination.

4. CONCLUSIONS

Based on the result obtained in this study, the following conclusion can be reached at:

(1) Pipe rotation contributed significantly to hole cleaning at intermediate velocities and at least 60% improvement in hole cleaning was reported in this study; this gain was not produced even when velocity has been increased from 56.69 to 69.80 cm/sec (1.86 to 2.29 ft/sec).
(2) The effect of pipe rotation is not significant at lower velocities and lower inclinations; however, it has a significant effect at intermediate velocities but this effect is diminished with further increase in velocity.
(3) Pipe rotation does add to cuttings removal with viscous system in the same manner as it does with water. However, the effect requires a greater velocity with viscous system than with water.
(4) Turbulent flow are better in cuttings removal than laminar flow either with or without pipe rotation.

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BIOGRAPHIES

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