CUTTINGS TRANSPORT IN HORIZONTAL AND HIGHLY DEVIATED WELLBORES

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ABSTRACT

Drilling horizontal and highly deviated wells is almost always accompanied by hole cleaning issues and cuttings transport problems. This study was conducted to gain more in-depth understanding of cuttings transport in this type of wells. A flow loop was designed to address the whirling and orbital motion of a self-eccentric drillpipe under various conditions of hole inclinations, fluid velocity and viscosity as well as particle size. In this study, it has been observed that the orbital motion of the drillpipe plays a crucial role in the rate of cuttings-bed erosion and transport pattern under the action of streaming fluid and hence affect hole cleaning capabilities of the drilling fluid in highly deviated and horizontal sections of the well. Pipe rotation was seen to improve hole cleaning to up to 74 %. Annular velocity and degree of turbulence is also shown to be critical for efficient hole cleaning requirements. Increasing hole inclination from 60° to 90° has a substantial effect on hole cleaning, in most situations a 28% improvement was established as the angle turns from 60° to 90°. However, the effect of increasing fluid viscosity at velocities of this study adversely affect hole cleaning. Increasing the system kinematic viscosity from 1 cSt to 10 cSt turns the system from turbulent to laminar flow and resulted in about 38 % reduction in hole cleaning. Finally cuttings size was found to have a minor effect on hole cleaning. In this study, cuttings of 1.2 and 2.4 mm were used. Higher velocities and pipe rotation as well as higher viscosities and hole inclination seemed to assist transportation of large particles than smaller ones.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Introduction

Horizontal and extended reach drilling have undergone rapid development in the past decade and expected to see more evolution in the near future. Horizontal and extended reach wells are considered a practical approach to develop offshore fields through accessing impossible targets and replace uneconomic infill conventional vertical drilling around faults and other obstructions. Utilization of this technique, however, is often associated with serious problems during drilling, which in more than one occasion minimize the advantages gained by such drilling. Excessive torque/drag, upright equivalent circulation densities, lost circulation, barite sag, inefficient hole cleaning and frequent sticking are some of the problems encountered while drilling horizontally (Cameron, 2001).

With the introduction of these applications, reduction in cuttings transport performance becomes serious and hole cleaning aggravated as hole deviation and well depths and/or out reach increase (Sifferman and Becker, 1992). The cuttings tend to accumulate and concentrate at the bottom hole. If the accumulation of cuttings continues, the cuttings aggregations tend to form beds at the low sidewall of the annulus which impede drillpipe movement into and out of the wellbore and often the drillpipe gets stuck. This increases non-drilling time and cost considerably (Sifferman and Becker, 1992). Cuttings beds greatly increase drag, hindering drillpipe sliding and limit the lateral reach of the well (Azar and Sanchez, 1997).

This severe impedance, oppose the rotation of the drillpipe and greatly reduce the amount of torque delivered at the bit.

Hole cleaning is essential for the drilling practices to succeed; good hole cleaning efficiencies are required to complete the well at lower costs. Inadequate hole cleaning can trigger other wellbore problems such as mechanical drillstring sticking, increase in torque and drag, 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.

This chapter will provide an introduction to the wellbore problems that are related to hole cleaning. Problem statement, objectives and scope of the study will be finally presented.

1.2 Drill-Cuttings Generation and Transportation

Cuttings are generated during drilling as the drill bit scrapes, gauges and/or grinds the formations that are being drilled (Aird, 2000). This action is achieved by applying weight to the bit to overcome the compressive strength and crushes the rock surface; further application of rotation produces a tearing or shearing action. As drilled cuttings are generated by the bit during drilling operation, they must be removed from the well. This task is normally achieved by circulating the so called drilling fluid down the drillstring and via bit nozzles, flushing the bit teeth, sweeps and/or entrains cuttings up the annulus to the surface. For the drilling fluid to success in its job it must be of the right velocity, density and rheology.

1.3 Hole Cleaning and Other Wellbore Problems

Aird (2000) reported a number of drilling problems that may be possible to take place when the drilling fluid has failed to efficiently transport drill-cuttings out of the wellbore. Of these problems is the formation of cuttings bed that can produce excessive drags while drilling or tripping and induce high resistance to pipe rotation (torque and drag); increase in equivalent circulation density and pump pressure that may develop to formation breakdown and lost of circulation (lost circulation); poor bit and/or bottom hole cleaning that will slow down rate of penetration (bit and bottomhole balling); excessive regrinding of cuttings that may facilitate fines invasion to reservoir rock, in case of conventional overbalanced drilling and result in permeability impairment (formation damage); hole pack-off; wellbore instability; and in severe cases pipe sticking.

1.3.1 Drillstring Sticking

It is a condition when part of the drillstring get stuck in the hole which in one way or another inhibit pipe movement and in turn, further drilling progress (Rabia, 1985). Many reasons have been reported for pipe sticking since 1937 (Darley and Gray, 1988). Pipe sticking may be due to key seating or due to an accumulation of cuttings around the pipe or balling up of the bit (mechanical sticking) or a result of differential pressure.

In differential sticking, differential pressure (difference between hydrostatic pressure of mud and formation pore pressure) is imposed by the magnitude of the hydrostatic pressure because formation pressures are at fixed levels. Differential force, however, is sensitive to changes in mud density, contact area and friction forces (Rabia, 1985). Inefficient hole cleaning will indeed result in an increase in mud density and in turn, an increase in differential force that promote pipe sticking. During such sticking the drillstring can not be moved up or down but free circulation is easy to establish.

Hole cavings and cuttings that accumulate in bottomhole due to insufficient hole cleaning offer potential hazards for pipe to become stuck as shown in Figure 1.1. When pipe is stuck in this manner, free fluid circulation is generally shut off or the pressure required for circulation increased substantially. This may violate the optimized ECD and give rise to formation fracturing and lost of circulation problems.

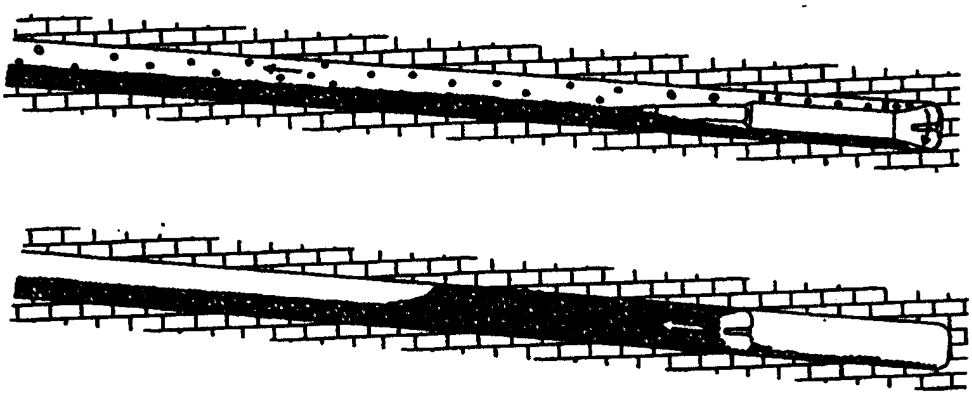

Figure 1.1: Mechanical drillstring sticking while tripping out of the well (Rasi, 1994)

1.3.2 Torque and Drag

Torque is the force required to rotate the drillstring, it is the difference between the torque applied at the rig floor and the torque available at the bit. While drag is the incremental force above the string weight required to move the pipe vertically, in other words it is the difference between the static and tripping weight of the drillstring. Excess torque can cause drillstring twist off while high drag forces can cause pipe sticking and pipe parting. Torque and drag are accounted for in planning and drilling extended-reach and horizontal wells to ensure the rig rotary and hoisting equipment are adequately sized and the drillstring is properly designed.

Torque and drag problems are associated each other and may be profound in extended-reach and horizontal wells. A variety of sources for excess torque/drag may exist: drillstring sticking, improper hole cleaning and the general friction interaction associated with side forces along the drillstring (Sheppard *et al.*, 1987; Aarrestad and Blikra, 1994).

Total surface torque is comprised of frictional string torque, dynamic torque, drill-bit torque and mechanical torque. Frictional torque is generated by contact loads between the string and casing or open hole and depend largely on the magnitude of contact loads, which in turn determined by drillstring tension and/or compression, dogleg severities, drillpipe/hole size, drillstring weight, well profile, inclination and tortuousity. Whereas drill bit torque depend on type of drill bit and formation to be drilled. However, mechanical torque is a result of cuttings beds been accumulated at bottom hole and/or borehole ledges (Payne and Abbassian, 1997).

1.3.3 Lost Circulation

Lost circulation is defined as the partial or complete loss of drilling fluid. Lost circulation occurs when the mud hydrostatic pressure exceeds the breaking strength of the formation, which creates cracks along which the fluid will flow (Rabia, 1985).

Lost circulation is perhaps the most costly drilling problem encountered in oil and gas exploration, with exception of blowouts. The cost factors include lost rig time, expensive remedial techniques, loss of drilling mud and costly constituents, plugging potentially productive zones, blowouts resulting from decreased hydrostatic pressure subjected to formations other than the thief zone and in severe cases potential loss of the hole.

Lost of circulation may be a slow seepage into formation while in some other cases, a major seepage may result and in most severe conditions, a complete loss of drilling fluid may take place. Lost circulation occurs as a result of a sudden increase in hydrostatic pressure of drilling fluid which can arise from a sudden increase in mud density or surge pressures.

Improper hole cleaning will result in an increasing number of cuttings resting at bottomhole. As result of bit action and drillstring smashing these cuttings are subjected to severe regrinding and pulverized into small fines. Fines that are not removed by solid control equipment are suspended, build up and permanently entrained in drilling fluid. Mud density increases substantially which give rise to lost circulation. This also increases pump pressures and increases mud equivalent circulation density. Flow past restrictions such as cuttings beds contribute also to the possible increase in ECD particularly in horizontal and extended-reach wells. Formation breakdown occurs if the mud ECD exceeds formation fracture pressure. Mud pressure may then induce a fracture or open a natural fracture leading to losses and/or differential sticking if drilled with too high an overbalance.

1.3.4 Bottomhole and Bit Balling

Bit balling may be described as the accumulation and possible adherence of drill-cuttings on or about the bit face and/or bottom hole assembly. Cuttings pad could also accumulate in front of the bit face that would impede the overall performance of the bit without actually sticking to the bit itself.

If drilled cuttings are not removed from beneath the bit as fast as they are generated, they would be reground and a layer of broken rock will build up between the bit and true bottomhole (bottomhole balling) as well as between the bit teeth (bit balling). These phenomena greatly reduce penetration rate and preventing further drilling progress. Bit balling worsens if the drilled formation is soft shale or swelling shale that absorbs water from water-based drilling fluid (Darley and Gray, 1988).

1.3.5 Formation Damage

Physically, formation damage is generally caused by invasion of foreign fluids and/or solids into reservoir rock. Invading solids can block the pore channel and impede production. However, possible effects of foreign fluids are emulsification with formation fluids, resulting in capillary blocking of pore throats (Gatlin, 1960).

Chemically, the formation can be damaged by chemical reaction between the filtrate and pore contents and/or matrix materials. Main factors are swelling or dispersion of clays and precipitation by chemical reaction between mud filtrate and the pore contents as well as the solution of salts and minerals from the matrix. The sensitivity of pay zone to damage by fluids filtrate is largely depending on its clay content because these interstitial clays hydrate or swell when in contact with the invaded filtrate resulting in a substantial reduction in void space and permeability.

Cuttings fines may invade and precipitate in pore space and hence, plug the internal pores and result in a serious blocking to oil flow. For fines to migrate deep inside the formation, they must be smaller than pore openings (< 1/3 pore size). An extreme case of whole mud invasion is loss of circulation into reservoir rock.

Horizontal and highly deviated wells are more susceptible to formation damage than vertical and near vertical ones. That is because horizontal drilling takes a longer time, resulting in a conical shape damage zone; this damage can significantly reduce the productivity of a horizontal well. In horizontal and highly deviated well, cuttings beds are more likely to settle at the low sidewall of the annulus; the drillstring is always resting on the same side due to gravity. This fact facilitates cutting-fines production and thus formation damage occurrence. Furthermore, ECD is expected to increase dramatically because of inefficient hole cleaning and cuttings beds formation. With increase in ECD the overbalance pressure on formation pore pressure increase. Hence, more force acts on the mud solid particles and drill-cuttings fines to enter into formation pores.

1.3.6 Shale Stability

Efficient hole cleaning is very important to avoid sticking problems after shale failure has occurred. However, inefficient transport of cuttings will indeed lead to annulus overload and thus, effectively raise mud pressure and in general ECD. Mud pressure exerted on shale formations will increase, which in turn causes an increase in pore penetration and destabilization of the shale formations.

1.4 Problem Statement

Cuttings removal and hole cleaning is a function of many factors. The most important factors are hole inclination, hole geometry (annulus dimensions and eccentricity), drilling fluid properties (rheology, density and type), annular velocity of the drilling fluid, characteristics of drill-cuttings (cuttings size, shape and density), drillstring rotation and rate of penetration (Azar and Sanchez 1997). However, the empirical cuttings transport literature contains confusing observations and recommendations. Conflicting observations were made in particular regarding the effect of drillpipe rotation, hole inclination, cuttings size and fluid rheological properties.

Furthermore, vast majority of previous studies except Sanchez *et al.* (1999) have considered the effect of pipe rotation to be either of minor or of intermediate significance. However, the previous studies unless that of Sanchez *et al.* (1999), force the inner pipe to rotate on its axis prohibiting whirling and orbital motion. Since the whirling or whipping motion of the drillstring at near horizontal to horizontal sections is well documented it becomes necessary to confirm its effect on hole cleaning.

Hole cleaning worsened as hole inclination increases with the mid angles are the most difficult to clean; however, there was either disagreement to define the critical angles or doubt in their presence. Since horizontal and extended reach wells involve long lateral sections, i.e. these wells are characterized by a high ratio of horizontal departure to total vertical depth; therefore it is of importance to monitor hole cleaning mechanism at these sections.

Cuttings size and shape are generally of little importance in hole cleaning especially at highly deviated and horizontal parts of the well. Since the shape of drill cuttings will definitely be irregular and the effect of cuttings size is more dominant than particle shape therefore cuttings size is more important than particle shape. However, as there was a considerable bias on whether large cuttings or smaller ones are better to transport, it seems that this point warrant more attention.

This study was conducted to gain more in-depth understanding of cuttings transport patterns in horizontal and highly inclined wells. Experiments were conducted to investigate the transport mechanism of drill cuttings while transported in highly deviated and horizontal wells using transparent fluids. A flow loop was designed to address the effect of whirling and orbital motion of a self-eccentric drillpipe on hole cleaning and cuttings transport under various conditions of hole inclinations, fluid velocity and viscosity as well as particle size. The model also allows cuttings patterns to be monitored and identified.

1.5 Objective of the Study

The objective of this study is to examine the effects of drillpipe whirling motion on cuttings transport and hole cleaning in horizontal and highly deviated wells. The effect of hole inclination (60° to 90°), cuttings size, fluid viscosity and fluid velocity on cuttings transport will also be addressed.

1.6 Scopes of the Study

(i) Fabrication of a laboratory-scale transport model and allow simulation of cuttings transport process in annular space of oil wells.

(ii) Studying the effect of inner pipe whirling motion on hole cleaning and cuttings transport, the effect of fluid velocity and viscosity, the effect of hole inclination and the effect of particle size.

(iii) Identify cuttings transport patterns at different set up parameters.

(iv) Continuous injection of cuttings to simulate rate of penetration and drill a head steady state conditions.

Four annular fluid velocities were investigated: 43.59, 56.69, 69.80 and 82.91 cm/sec (1.43, 1.86, 2.29 and 2.72 ft/sec). These velocities allow turbulent flow to exist for low viscous systems and laminar flow for high viscous systems. Generally the Reynolds number ranged between 15661 and 705.

Four fluid viscosities were also investigated. Three systems were formulated by adding glycerine in water to form aqueous solutions. Glycerine was added in quantities of 20, 40 and 60 % by volume of the total solution volume. The corresponding kinematic viscosities were: 1.71, 3.37 and 10.51 cSt @ 25° C respectively. The fourth system was local tap water whose kinematic viscosity was found to be 0.90 cSt @ 25° C.

Four hole inclinations that simulates angles of highly deviated and horizontal sections of oil wells were studied. These angles were 60°, 70°, 80° and 90° measured from vertical position.

Coarse sands of irregular shape and average specific gravity of 2.6566 have been prepared into two groups of different cuttings size. Small cuttings group has an average cuttings size of 1.2 mm (0.0472 in) and the large cuttings group has an average cuttings size of 2.4 mm (0.0945 in).

Two inner pipe rotational-speeds were used (0 RPM and 10 RPM); meanwhile the simulated rate of penetration was kept constant during the study. Cuttings were injected at a rate of 162 g/min (0.357 lb/min) which simulates approximately a lower rate of penetration at 1.4 m/hr (4.5 ft/hr).

The annular section and the conveying medium used were transparent to allow monitoring in order to identify the mode of cuttings transport under different operating conditions.

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