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Thermal effects on differential pressure pipe sticking tendency

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ABSTRACT

Differential pressure pipe sticking as one of the common borehole instability mechanisms occurs when the overbalance pressure pushing drill string toward filter cake. The aim of this study is to experimentally investigate possibility of "stuck pipe" tendency taking place during the utilization of two commonly in use drilling fluids (Bentonite/Polymer, and Lignosulfonate based drilling fluids) and a new developed drilling fluid system (Sepiolite based drilling fluid) at elevated temperatures. Drilling fluid samples were thermally aged for 16 h up to 204 °C (400 °F). Rheological and filtration properties of samples were then measured for initial confirmation. After that, the samples were subjected to the differential sticking test under differential pressure of 3.447 MPa (500 psi). Sticking coefficients and corresponding sticking times were measured at various set times. Results indicated that Bentonite/Polymer and Lignosulfonate drilling fluids have lower sticking coefficients than those of sepiolite drilling fluids at temperatures below 121 °C (250 °F). However, the sepiolite drilling fluids demonstrated remarkable low sticking coefficients particularly above 149 °C (300 °F) implying low stuck pipe possibility due to the differential pressure. This study could contribute on providing database regarding the differential pressure pipe sticking tendency of various drilling fluids at elevated temperature.

1. Introduction

Borehole instability continues to be an updated difficulty for oil and gas industry despite of numerous advances in drilling techniques (Bradley, 1979; Bailey et al., 1991; Aadnoy, 2003; Bell, 2003; Wang and Dusseault, 2003; Zoback et al., 2003; Aadnoy and Belayneh, 2004; Al-Ajmi and Zimmerman, 2006; Al-Bazali et al., 2008). This problem has been a special focus point since drilling horizontal and extended reach wells have been growing up to access more resources. From economic point of view, the loss of one billion dollar per year due to the wellbore instabilities (Zeynali, 2012), on top of missing time corresponding to 40% of all drilling related non-productive time, increases the importance of wellbore stability issue for the drilling industry (Schmidt et al., 2004).

Generally the combination of different controllable and uncontrollable factors and mechanisms may lead to the wellbore instability (Bowes and Procter, 1997; Chen et al., 1998; Mohiuddin et al., 2001). Some instability mechanisms are recognized by the analysis of initial drilling fluid weight, drilling fluid density variation due to temperature and pressure, problems per well, and the hole enlargement of vertical wells. The collapse of the wellbore wall, the drilling fluid invasion, and the drill string sticking (stuck pipe) are the major reasons for the wellbore instability (Mohiuddin et al., 2006). Drill string sticking could be the consequence of both mechanical problems and differential pressure. Inadequate hole cleaning (pack off), borehole collapse, wellbore caving, and key seating are the major contributors in the mechanical pipe sticking. On the other hand, excessive overbalance in the annulus could create high differential pressure to push drill string toward the wall mud cake. When drill string contacts to the mud cake, the internal cake pressure decreases. This decrease in the internal pressure can hold the pipe against the borehole wall. This mechanism refers to differential pressure pipe sticking firstly reported by Outmans (1958). Some researchers expressed the importance of differential pipe sticking as one of the stuck pipe mechanisms that effects the drilling operation and the cost of the well (Adams, 1977; Weakley, 1990; Wisnie and Zheiwei, 1994). Several studies also emphases that the differential pipe sticking severely affects well cost and operation time as a non-productive time (Adams, 1977; Biegler and Kuhn, 1994; Wisnie and Zheiwei, 1994; Aadnoy et al., 1999). In spite of these adversities, stuck pipe incidences can be reduced by the proper management of the mud cake and drilling fluid properties (Haden and Welch, 1961; Annis and Monaghan, 1962).

The importance of pipe sticking can also be realized by considering some industrial reports and statistics. The cost of stuck pipe has exceeded $30 million per year in 1991 as reported by British Petroleum; however, the total cost of pipe sticking for industry was so crucial and reported to be more than $250 million

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annually (Bradley et al., 1991). The stuck pipe due to differential pressure sticking has been presented by BP as the major reason for 61% of total cost in the Gulf Coast region (Bradley et al., 1991). Sedco Forex has recognized the stuck pipe as a main source for 36% of all reported drilling problems over a 15-month period in the world (Jardine et al., 1992).

Although the cost of stuck pipe in deep oil and gas wells is estimated to be the quarter of total budget (William C et al., 2005), in some cases 40% of the total well cost stems from events related to differentially stuck pipe (Siruvuri et al., 2006). Furthermore, a performed analysis on the drilling data, extracted from sixty wells in a field, presented the differential pipe sticking and the hole pack off as two major factors responsible for 13% and 8% of stability problems, respectively. Although the share of these factors were lower than stability problems related to tight-holes (65%), stuck pipe was mentioned as the major reason of productivity loss for evaluated wells (Mohiuddin et al., 2006). Even though the reported statistics considerably vary, the common point in all of them indicate and emphasize the importance of the instability problems resulting from the differential pressure pipe sticking.

Drilling fluid properties and its behavior under different drilling conditions directly influence the possibility of pipe sticking. Proper drilling fluid weight and quality of mud cake deposited at the wellbore wall are the essential factors playing undeniable role on stuck pipe events. It is obvious that the temperature has the detrimental effect on the rheological and filtration properties of drilling fluids. High temperature causes clay particles to be flocculated resulting in unacceptable high viscosities and water losses with excessive thick mud cake. Stickiness of mud cake and drilling fluid lubricity must be evaluated to help engineers to select an effective drilling fluid. In the absence of an efficient mud cake, sourcing from the detrimental effect of temperature on drilling fluid properties, a rise in a bottom hole pressure may lead to differential pipe sticking stability problems. A quick glance to literature is enough to understand the importance of differential pipe sticking. Several researchers tried to deal with this subject in order to help industry to avoid stuck piping. The effects of adding lubricants in the water base drilling fluid were investigated in some of recent studies. Mahto (2013) concluded that sticking tendency of the drilling fluid is reduced significantly by using vegetable oil and it may be quite suitable for the prevention of differential pipe sticking problems. However, interestingly there is not published data regarding the stuck pipe caused by differential pressure considering the effect of high temperature on drilling fluids properties.

1.1. Sepiolite based drilling fluid

Sepiolite, a magnesium silicate clay mineral with fibrous texture, is proposed to be used in both high temperature and high saline environments known as hostile drilling conditions. Several investigators have reported that the sepiolite is a temperature resistant clay up to 260 °C (Carney and Meyer, 1976; Carney and Güven, 1980; Güven et al., 1988; Serpen et al., 1992; Serpen, 1999). Although the sepiolite drilling fluid yields appropriate rheological properties in extreme drilling conditions, the unacceptable high filtration loss is the major disadvantage of this drilling fluid, (Carney and Meyer, 1976; Serpen et al., 1992; Altun and Serpen, 2005). On the other hand, recent studies indicated that the filtration properties of a new developed sepiolite drilling fluid could economically be controlled using commercial additives (Altun et al., 2010, 2014; Osgouei, 2010). Moreover, the properties of active-clay contaminated sepiolite base drilling fluid were also investigated and remediated through comprehensive experimental study (Altun and Osgouei, 2014).

1.2. Purpose of the study

The investigation of differential pipe sticking as one of the borehole instability mechanisms is the main objective of this study. A brief literature review indicated that despite the significant attempts by the industry on developing stuck pipe prevention measures, the stuck pipe incidences around the world have not been avoided. In addition, the effect of high temperature on drilling fluid properties can trigger the stuck pipe incident. This experimental study evaluates the differential pipe sticking tendency of two frequently in use drilling fluids and the recently introduced drilling fluid at elevated temperatures. The results included the effect of temperature, contact time, drilling fluid type and its rheological and filtration properties on sticking pipe possibility by determining sticking time and sticking coefficient.

2. Methods and materials

Bentonite/polymer and lignosulfonate drilling fluids were selected as the two prevalent drilling fluids. Sepiolite based drilling fluid was formulated in the concept of recent study and its differential sticking tendency was evaluated and compared with others when the temperature was the main parameter (Altun and Osgouei, 2014). First part of this study consisted of the measurement of rheological and filtration properties of all fluid samples after aging at elevated temperatures to define the efficient and proper functioning area of selected drilling fluid systems. In the second part, differential sticking experiments were conducted on the fluid samples using differential sticking apparatus to measure comparative parameters such as sticking coefficient and sticking time for different set times (contact times) at various aging temperatures. The utilized Sepiolite clay in this study commercially is named as Turk Taciri Bej (TTB) and was supplied from near Sivrihisar–Eskisehir district of Turkey. Performed XRF and XRD analysis indicates that selected clay sample was dominantly sepiolite with approximately 10% dolomite (Altun et al., 2014). Raw sepiolite clay sample was not purified by any physical or chemical methods before and after grinding. After grinding, the sepiolite was sieved to <74 μm (<200 mesh). Commercial bentonite clay provided by Karakaya Company was used as a major additive for bentonite/polymer and lignosulfonate drilling fluids. The other additives, all in technical grades, used in formulation of drilling fluids were (i) Sodium carbonate (soda ash, Na_2CO_3, product of Karakaya) and Sodium hydroxide (caustic, NaOH, product of Karakaya) to remove water hardness and PH control, (ii) A commercial deflocculant (polymer-1, anionic acrylic copolymer used as thinner, product of Halliburton) for controlling rheological properties in water-based systems for up to 232 °C and providing high temperature stability, (iii) Filtration control agent (polymer-2, vinyl amide/vinyl sulfonate copolymer, product of Halliburton), (iv) Chrome free lignosulfonate (CFL) as deflocculants, temperature stabilizer, filtration control additive and gel strength reducer, (v) Xanthum Gum (XCD), a biopolymer, used as a viscosifier to enhance drilling fluid rheology, ensuring efficient hole cleaning, (vi) Carboxymethyl cellulose (CMC) acts as a viscosity modifier and water retention agent, (vii) Polyanionic cellulose (PAC-LV) acts as a filtration control chemicals with negligible effect on viscosity, (viii) Weighting agent (API Barite). The API RP-13B Standard procedure was employed throughout the experiments. All drilling fluid samples were based on the formulation of 350 ml of water phase (distilled water) containing sepiolite, bentonite, and different amount of commercially available additives (polymers) in both unweighted and barite-weighted mud systems. Rheological properties such as the apparent viscosity (AV), the plastic viscosity (PV), the yield point (YP), and the gel strength (GS) were measured using