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The effect of imposed electrical current on torque release at the metal-mudcake interface

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Differential sticking arises in drilling operations when the drillstring embeds into a layer of mud on the borehole wall. The present work is aimed at proving the concept of an unconventional method of releasing the drill string, namely, the application of an electrical current. An instrument has been designed and constructed to measure the slippage torque at the interface between a steel disc and a filtercake prepared from a model aqueous drilling mud. Experiments have demonstrated that a cathodic current of 1 mA cm^{-2} reduced the slippage torque by about 50% with both mild and stainless steel. The same effect was obtained galvanically, using a magnesium sacrificial anode connected to the steel, thus dispensing with the need for an external power source. It is hoped that this effect could be used to inhibit differential sticking in aqueous drilling muds, as well as offering a fast method of stuck pipe release.

1. Introduction

Differential sticking, otherwise known as 'stuck pipe', arises in drilling operations when the drillstring becomes embedded into a mud cake, formed on the borehole wall by a process akin to pressure filtration [1]. This situation is shown schematically in Fig. 1. Such incidents can significantly increase drilling costs and, in the worst cases, result in the abandonment of partially drilled wells.

Differential sticking is most likely to occur when rotation of the drillstring is stopped, and is more severe with aqueous than with oil-based drilling muds. Aqueous muds, however, are preferable for many applications, because they are safer and easier to dispose of after the drilling is complete. There is, therefore, commercial interest in enhancing their resistance to differential sticking.

Various countermeasures are employed to inhibit differential sticking or to free the stuck pipe, for example adding a lubricant to the drilling mud [2–4], or pumping a 'pill' of mud dispersant chemical to the stuck zone [5]. Alternatively, the application of an electrical current was shown to be effective in a drilling simulation rig [6]. The present authors recently reported that the coefficient of friction between metal and porous sandstone immersed in aqueous drilling muds was significantly reduced on imposition of a cathodic potential [7]. The present work was aimed at extending these studies by measuring the slippage torque at the steel/mudcake interface under conditions of applied current.

2. Experimental details

A benchtop instrument, shown in Fig. 2, was designed to measure the friction at the interface between a filtercake of aqueous drilling mud and a rotating steel spindle. It was based on a modified Gel Strength Tester manufactured by Sheen Instruments Ltd, Teddington, England. The spindle was ground to a spherical radius of 10 cm, to ensure good conformation with the mudcake, and rotated at 2 rpm against a filtercake prepared from an aqueous drilling mud. The motor shaft was fitted with a calibrated spring balance, allowing a vertical load of up to 54 N to be applied. The filtercake and counter electrode (partially masked to spread out the current) were held in a polypropylene container on a torque measuring table. The cell was connected to a d.c. current source (Hewlett Packard, model 6186C) via a sliding contact at the working electrode and a flexible lead at the counter electrode. Unless otherwise stated, working electrodes were of mild steel (type EN3AWP); counter electrodes were of stainless steel (type AISI 316).

The aqueous mud contained 10.5 ppb (pounds per barrel) sodium chloride (1 ppb = 8.75 g dm^{-3}) 1.75 ppb xanthan gum, 4 ppb carboxy methyl cellulose and 150 ppb barite. Filtercakes were prepared by vacuum filtration of 50–60 ml of mud for 16–20 h, and then loaded into the cell without delay. Measurements were first made at open circuit, then progressively from cathodic currents to anodic currents. After each experiment, the indentation in the filtercake was used to estimate the area of mud/metal contact; this was typically 4 cm^2.

3. Results and discussion

Figure 3 shows the effect of applied current on

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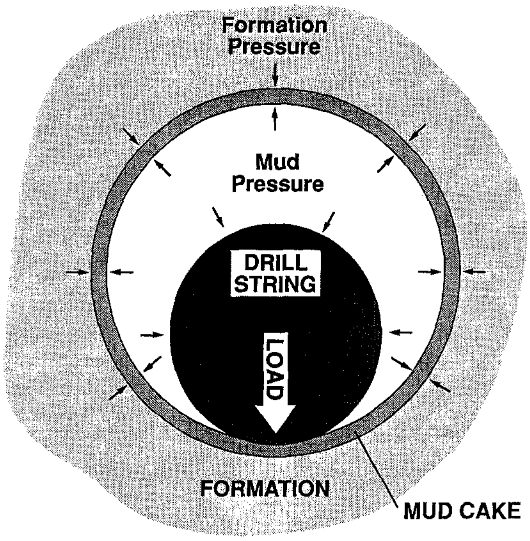

Fig. 1. Schematic representation of differential sticking.

slippage torque for mild steel in contact with a filtercake at an applied load of 40 N. Application of a cathodic current gave a sharp decrease in torque, whereas a small anodic current gave an increase. The torque decreased by 70% from the zero current value when cathodic current densities greater than $-1.5\,\mathrm{mA\,cm^{-2}}$ were applied to the spindle.

Figure 4 shows the effect of a current of $-2.5\,\mathrm{mA\,cm^{-2}}$ on the same system, for a range of loads. Measurements were made by going from low to high loads. At each load the torque was measured before, during and after application of the current; the mean of the two $i = 0$ measurements was plotted. For both $i = 0$ and $i = -2.5\,\mathrm{mA\,cm^{-2}}$, slippage torque showed a linear variation with load. The two lines intersected the ordinate at the same load, but the slopes indicated that the reduction in torque produced by the application of current increased with

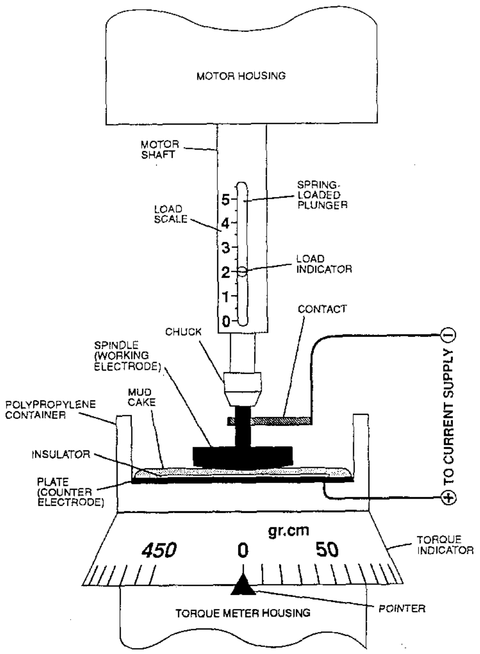

Fig. 2. Instrument for measuring the slippage torque at the metal–mudcake interface.

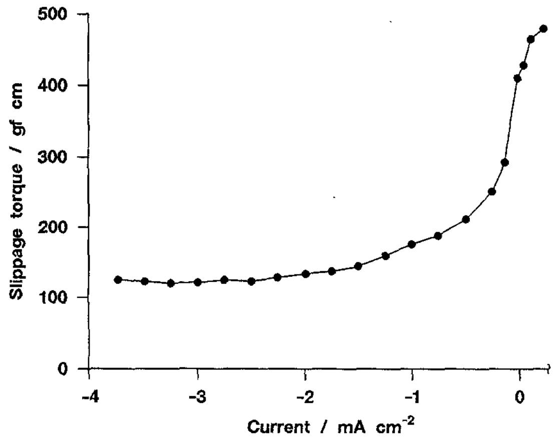

Fig. 3. Effect of applied current on slippage torque for mild steel in contact with a mud filtercake at a load of 40 N.

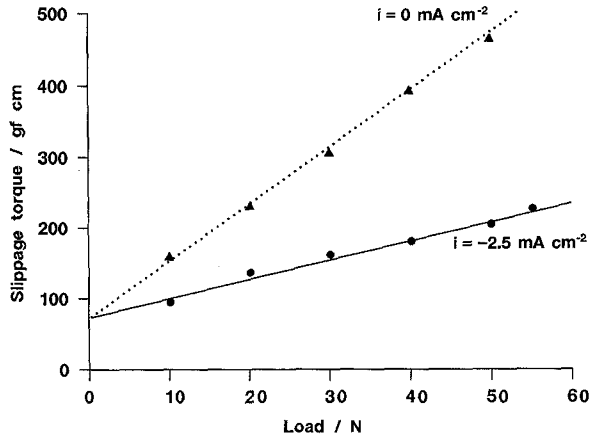

Fig. 4. Effect of load on slippage torque for mild steel in contact with a mud filtercake at current densities of 0 and $-2.5\,\mathrm{mA\,cm^{-2}}$.

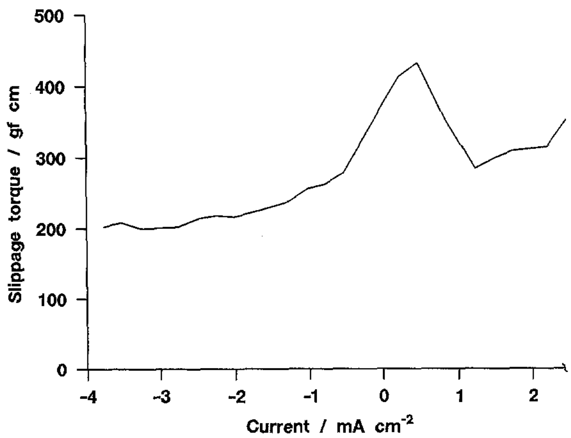

Fig. 5. Effect of applied current on slippage torque for mild steel in contact with a filtercake of sulfate-based mud at a load of 50 N.

load. This is encouraging since the contact stress in a typical drilling operation (5–10 MPa) is higher than that applied here (~ 0.1 MPa).

To explore the effect of anodic current would have been difficult with the chloride based drilling mud due to corrosion of the spindle. To overcome this problem, experiments were conducted using a stainless steel spindle and a filtercake in which the chloride was replaced by an equivalent quantity of sulfate. Figure 5 gives the current torque curve which shows

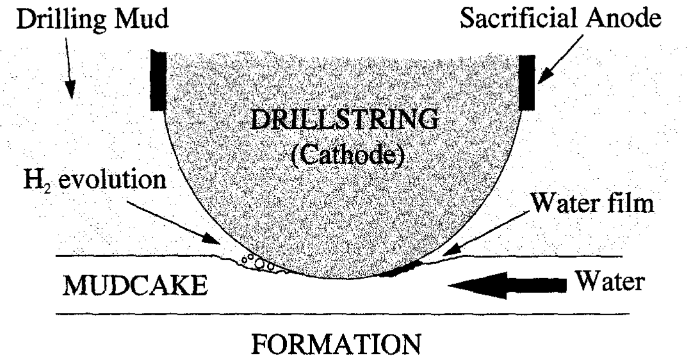

Fig. 6. Schematic illustration of the potential mechanisms through which the imposed current enhances stuck pipe release.

a peak in the slippage torque around $0.25\,mA\,cm^{-2}$. At cathodic currents the torque gave a response similar to that seen with the chloride mud, namely a decrease with current. At anodic currents however, the initial decrease in torque was followed by an increase at currents above $1\,mA\,cm^{-2}$, possibly reflecting changes in the surface composition of the stainless steel [8, 9].

Khasayev *et al.*[6] have reported that the electro-osmotic transport of water to the cathode, with the consequent buildup of water at the electrode/mudcake interface, is responsible for the reduction in slippage torque with imposed current. This conclusion has been supported by Chilingarian and others [12–15]. For example, Chilingarian *et al.* [15] reported a thirty two fold increase in the water flow rate through clay bearing sand cores on application of an electric current. The authors suggested that this was due to the movement of the positively charged double layer towards the negatively charged cathode, with the associated movement of free water. Additionally, the role of current in inducing a collapse of the clay structure [13, 14] cannot be ignored.

A further contribution to the reduction in slippage torque could be the disruptive effect of gas evolution at the metal surface, since the measured cell voltage was around 2 V, consistent with that expected for water electrolysis. Evidence in favour of this contribution is provided by Fig. 5, which shows that the slippage torque was reduced by both small anodic and cathodic currents, corresponding to the evolution of hydrogen or oxygen at the interface.

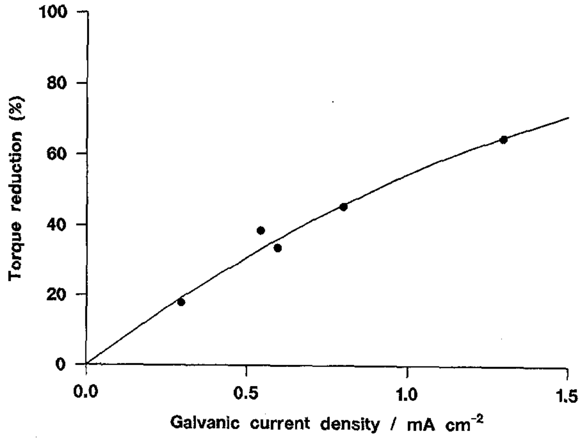

Fig. 7. Effect of galvanic current density on slippage torque for mild steel in contact with a mud filtercake at a load of 40 N.

Figure 6 provides a schematic illustration of the possible mechanisms through which the imposed current enhances stuck pipe release. For a field application of electrochemical stuck pipe release, the most important consideration is the method of applying the electrical current. Possible methods include:

(i) Direct application of a current via a wireline.
(ii) Fitting sacrificial anodes such as zinc, aluminium or magnesium and alloys thereof, to the drillstring.
(iii) Addition of the above metals in the form of powder. These could be pumped to the stuck zone where they would come into contact with the drillstring, giving a cathodic potential.

To test the efficacy of sacrificial anodes as a means of differential sticking release, further experiments were performed, using a magnesium plate in place of the stainless steel counter electrode. Currents in the region of -0.25 to $-1.25\,mA\,cm^{-2}$ were measured when the spindle and magnesium were electrically shorted. These gave substantial reductions in slippage torque compared to the open circuit values, as shown in Fig. 7.

The results presented here demonstrate the influence of electrochemical currents on friction at the metal–mudcake interface. Further work to test these concepts at higher temperatures and loads is reported elsewhere [11].

4. Conclusion

The effect of imposed electrical current on the release torque at the interface between mild steel and an aqueous drilling mud filtercake has been studied using a benchtop instrument. A reduction of almost 50% in the slippage torque was produced at cathodic currents around $1\,mA\,cm^{-2}$ at a range of loads. Currents of this magnitude can be generated via galvanic couples. The effect could be developed to minimize differential sticking in aqueous drilling muds or to help free stuck pipe once it has occurred.

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