Experimental investigation into shielding effect of magnetic powders in drilling fluids

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Introduction

The drilling fluid is one of the factors that may contribute significantly to errors in directional surveying of wellbores, because the magnetic properties of the fluid shields the Earth's magnetic field measured by the magnetic sensors used in measurement while drilling (MWD) directional tools (Wilson and Brooks, 2001; Amundsen et al. 2006). The magnetic properties of a drilling fluid is known to vary significantly, depending on factors, such as mechanical wear of down-hole and surface equipment, the mineralogical composition and the bulk material transferring procedures of the drilling fluid additives, and the circulation properties of the drilling fluid (Torkildsen et al., 2004; Amundsen et al. 2008). In this contribution we shall show that it can also depend significantly on operational aspects of the drilling and data logging processes.

To understand this shielding effect and its dynamics we have performed laboratory measurements where powders of known magnetic of properties have been added to a well defined non-magnetic model drilling fluid. The time dependent shielding of the Earth's magnetic field was then monitored using a fluxgate magnetometer immersed into the fluid.

Here we present results for shielding caused by the addition of magnetite and soft iron powders. These materials were chosen because they are certain (iron) or likely (magnetite) to be present in a real drilling fluid, and have quite different magnetic properties: Iron is a soft ferromagnetic; magnetite is strongly paramagnetic. As a base fluid which will keep the powders in suspension we have chosen a common xanthan gum solution, widely used as a base fluid for water-based drilling fluids in the petroleum industry, and which is very weakly diamagnetic.

Experimental set up.

To create a situation mimicking the condition of the fluid as in drilling field, an experimental set-up as sketched in Figure 1 was built. The drilling fluid was contained in a parallelepipedal tank, made of transparent Plexiglas plate of a thickness of 12 mm, with internal size of 1200mm x 750mm x 200mm. The magnetic field was measured with a ***Mag*-01**(H) fluxgate magnetometer and probe **Mag B** (see Figure 2), connected to a PX1-1042 data acquisition unit and analysed using a NI-Labview platform. In the present paper we only report results with the probe placed vertically at the geometric centre of the fluid volume. We have used the vertical component of the Earth's field as the external magnetic field.

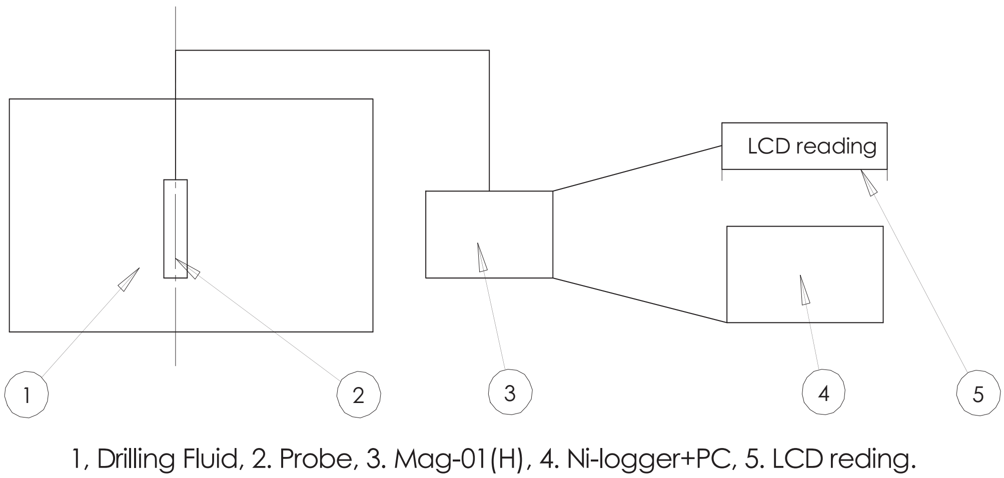

Figure 1 Schematic of measuring system

The drilling fluid was first prepared as solution of water with 0.3% (by weight) xanthan gum powder, whereafter magnetite or iron powders was added. The mixture was thoroughly stirred. For further details on the experimental set-up and preparation of the fluid, see Amundsen et al. (2008).

Figure 2 Fluxgate magnetometer Mag-01 (H) and the single-axis probe

For comparison purposes we also recorded measurements of the shielding effect of dry powders by just burying the magnetometer probe in the powders and recording the vertical components of the Earth's magnetic field. The results are given in Table 1, along with the Earth's magnetic strength as measured without shielding.

One can see from Table 1 that the magnetic fields were reduced about to one third of the Earth's field in the media of either powder. The shielding was measured not to vary with time, indicating that the magnetic properties of the powders were stable, as expected.

Table 1 Shielding effects of magnetic powders

	Magnetic field (μT)		
Powders used	No powder	Iron	Magnetite
Measurement 1	46.63	15.65	22.18
Measurement 2	45.76	14.26	18.79

Measurement results

Once the powders were mixed into the xanthan gum fluid, the probe was immediately immersed into the drilling fluid and positioning at the geometric centre of the fluid volume. The vertical component of the Earth's field in the magnetite drilling fluids was measured. There was no significant difference in the measured vertical magnetic field strengths between the empty (air-filled) tank and one filled with the pure xanthan gum solution, 45.3μT.

The measured magnetic field did hardly change when adding iron powder to the fluid. A typical result is shown in Figure 3 for a concentration of iron powder in the fluid of 2.67%. It is seen that the field strength remains at the same value as for an empty tank. This absence of shielding is quite unexpected, considering the strong shielding caused by the dry powder (see table 1), although the total mass of iron surrounding the probe is of course much higher in the latter case.

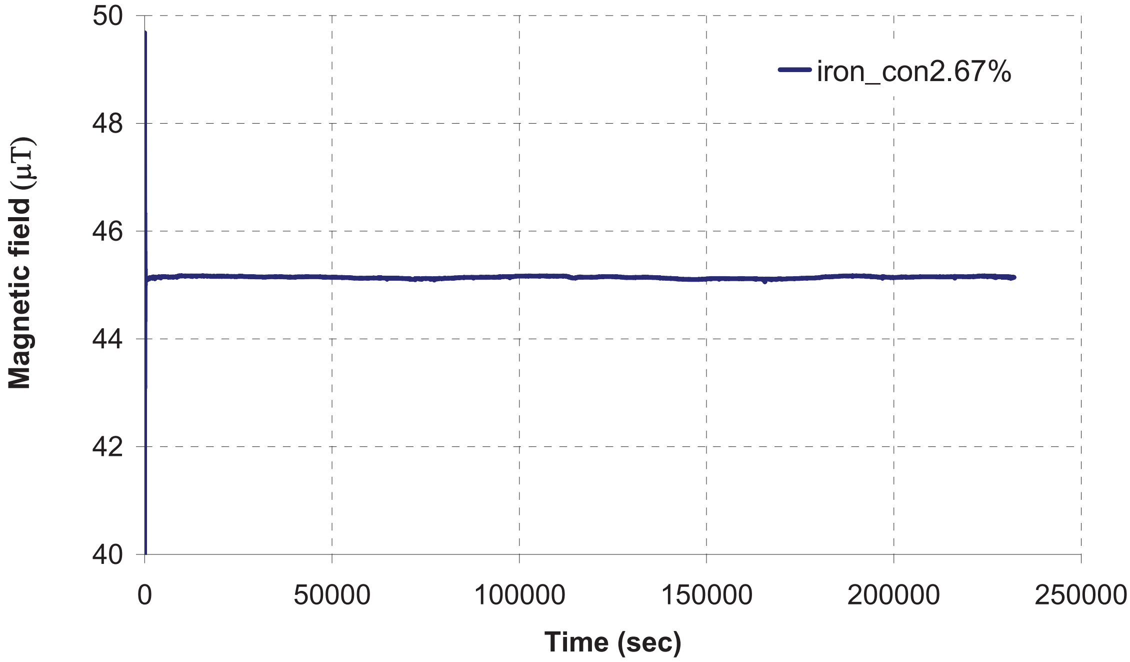

Figure 3 Magnetic field as a function of time in the fluid mixed with iron powders

In contrast to the case of iron powder, for the fluid mixed with the magnetite powder we observed a strong, and strongly time dependent, shielding effect. In Figure 4 is shown the evolution of the measured magnetic field within the fluid as a function of time over a 3 day period for different concentrations of magnetite powders, which were set to be 0.67% 1.33 % 2.67% 5.33% in different rounds of measurements.

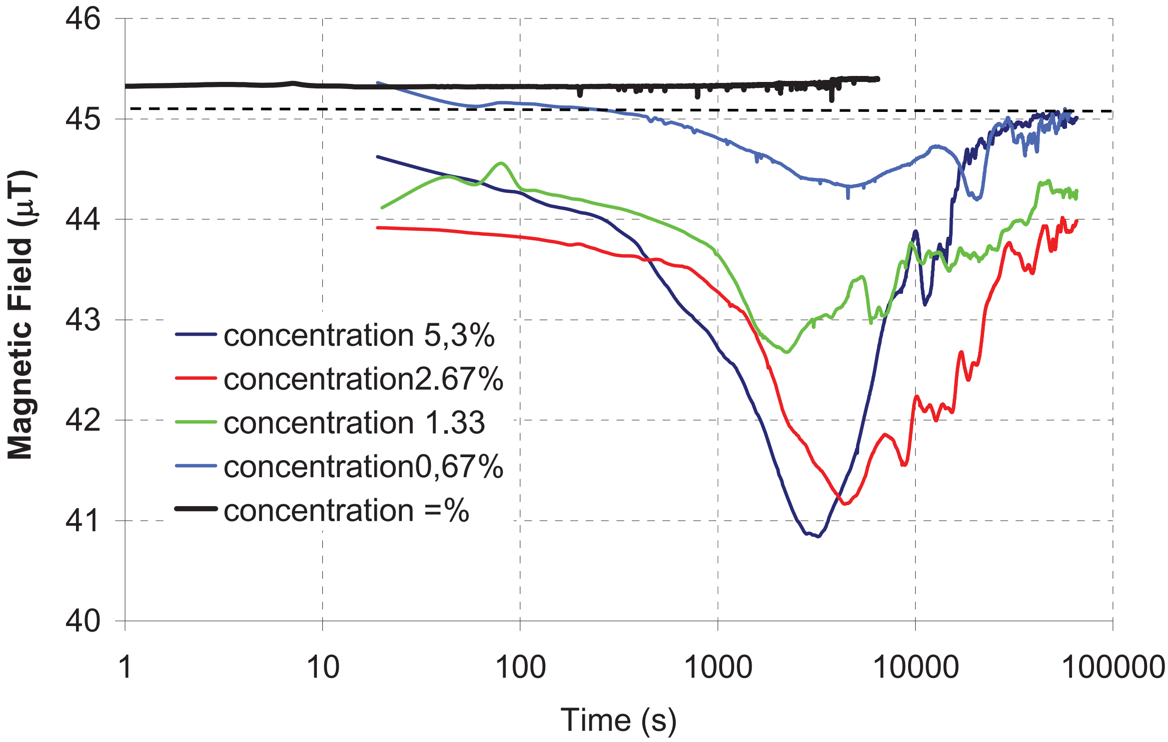

Figure 4. Magnetic field as a function of time for different concentrations of magnetite

The main feature of the results for magnetite is a rich and unexpected dynamical structure of the magnetic shielding as shown in Figure 4. There is an initial strong and rapid decay of the field for an hour, or so, until it reaches a minimum. This maximal shielding is significantly larger than expected based on the magnetic susceptibility of the dry powder. Thereafter the measured field gradually recovers, but with large superimposed slow variations. After some 3 days the field recovered to about the original level as its origin.

For the same fluid composition, the strength of the magnetic field up to the time of the minimum was quite similar from run to run; also the value of the minimum of the field strength was reproducible within 10 %, although the time for reaching it can differ by, say about 1000 s.

It might be expected that there should be an instantaneous initial shielding of the external field when the magnetite was added, but this was not seen, just as there was no shielding at all in the case of iron powder. The variations of the initial values seen in Figure 4 may well be attributable to the operation of the measurements: the probe might not have been positioned at the exact same orientation from one measurement to another.

In Figure 5 we show the maximum shielding effect, which is the relative decrease of the magnetic field strength from its initial value to the minimum value. It is seen that it depends strongly, and nearly linearly on the magnetite concentration.

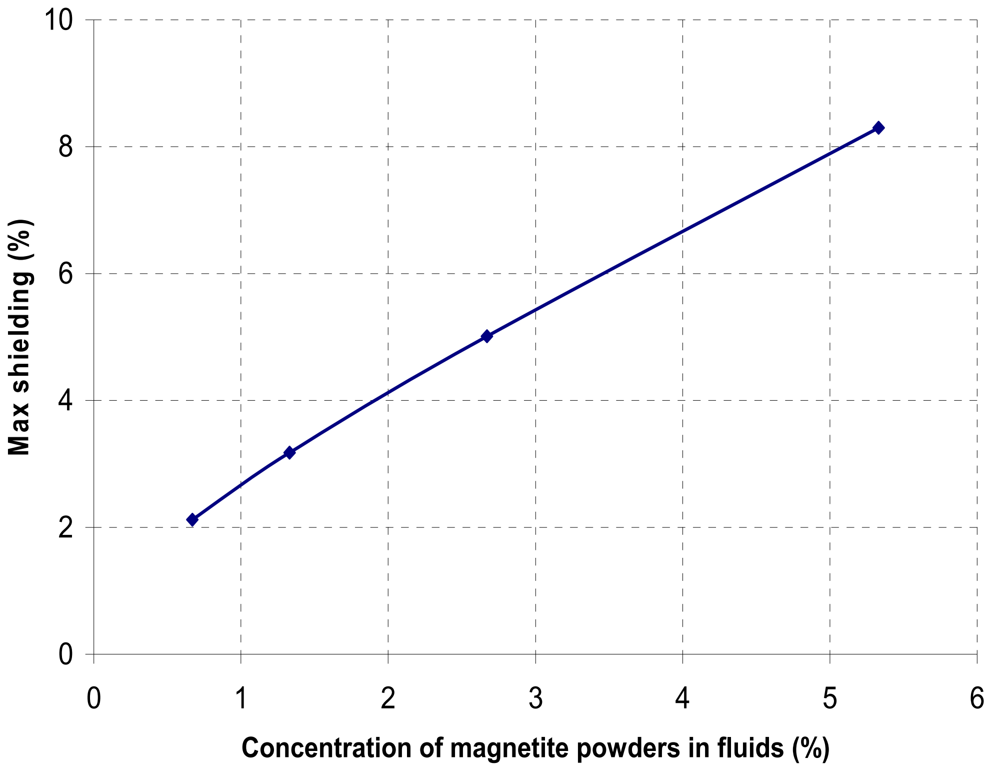

Figure 5 The maximum shielding effects

Discussion

Amundsen et al. (2008) explained the observed behaviour of the shielding effect for magnetite by invoking the fact that the magnetic polarity of individual grain will tend to orient itself to a state in the opposite direction of the external field, and hence cancelling its strength. This reorientation of the individual grain will be hampered by the viscous forces in the fluid. Since magnetic forces in the system are generally weak, the reorientation requires time. Obviously, this process of reorientation depends on the balance between magnetic moments and the hampering viscous forces exerted on the individual grain, which will be determined by the grain's magnet property, size, shape, density, the viscosity of the drilling fluid and the strength of the external magnet field.

The subsequent rise of the measured field can be explained by the fact that the magnetite dispersion is not completely stable with respect to sedimentation. Indeed, it was observed that a substantial fraction of the magnetite powders had settled out onto the bottom of the tank after 3 days, no longer contributed to the shielding of magnetometer probe.

The very different behaviour of iron and magnetite is not readily explained by the above considerations, and the very different screening effect of dry iron powder versus iron powder in solution is indeed remarkable. One major difference between the two powders is that the iron powder is ferromagnetic, so that the induced magnetic moments are much larger than for magnetite, which is paramagnetic. This means that the relaxation times for the dipoles to respond to the external field is much shorter for iron, which explains that we do not see time dependent effects on the time scale of our measurements. It does not explain that we do not see any shielding effects for iron powder in solution at all, however.

Conclusion

Experiment has been carried out with a fluxgate magnetometer to measure magnet shielding effect of the magnetite or iron powders. It was confirmed that both have a very strong shielding effect when the probe was submerged in dry powders. However, the iron powders showed no significant shielding effect when suspended in a drilling fluid, whereas magnetite powder shows a considerable shielding effect with a complex dynamical behaviour.

These results are of importance to understand the shielding caused by magnetic contaminations in drilling fluids used in petroleum drilling, as this can cause errors when performing magnetic surveying of wellbores. The strong time dependence of the shielding effects explains problems encountered in making repeatable measurements of the magnetic susceptibility of drilling fluids using simple laboratory instruments. Even slight variations in the drilling fluid properties and measurement procedures can cause significantly different magnetic responses.

References

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