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Use of Mixed Metal Oxide Fluid to Combat Losses in Porous and Fractured Formations: Two Case Histories

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Abstract

Time and money expended on addressing whole fluid losses during the drilling process are coming under increasing scrutiny as the economics of the oil business become more demanding. In addition to traditional remedies (including application of cement and gunk squeezes and use of a variety of lost-circulation materials), new types of plugs have been developed and applied with considerable success. The foregoing approaches all require that drilling be suspended while the remedy is applied and there are inevitable economic consequences. Ideally losses would be controlled or eliminated without interruption to the drilling process. A new fluid, based on mixed metal oxide chemistry, has shown significant utility in arresting whole fluid losses to porous and fractured media, while allowing for continuation of the drilling process. Two case histories, one from Southern Latin America and the other from North America are presented to illustrate the value of the technology.

Introduction

According to a recent in-house estimate, whole fluid losses during drilling costs the industry around $800 million per year. Regardless of whether the real number is half or twice the estimate, the cost is clearly unacceptably high and warrants the intense focus the industry has recently brought to bear on the issue. The majority of the effort has gone into improving the efficiency (in terms of material cost, minimization of down time and success ratio) of a variety of approaches to plug placement and setting.[1,2,3] While significant progress has been made in this direction, the approach, even when applied successfully, still falls short of the best that can be conceived of, simply because it necessarily requires that drilling be stopped, thus raising the economic consequences of non-productive (non-drilling) time. Provided that the overall economics prove to be favorable, a more efficient route would be to address the issue during drilling. An ideal fluid for such an application would:

- provide drilling performance which at least matches that of conventional fluids traditionally used on the section involved
- eliminate losses or at least control them to the extent that drilling can continue uninterrupted
- have a barrel cost close to that of the fluids traditionally used

Such a fluid has been identified and successfully applied to the problem as described hereafter in two case histories.

Mixed Metal Compound-Based Fluids

In the 1980's, John L. Burba and co-workers developed a fluid based on bentonite and what they described at the time as "mixed metal layer hydroxide compounds (MMLHCs)".[4] The name "MMH" was soon applied to fluids of this general type and a number of offset products were developed over the ensuing decade. The chemistry and performance of these products showed some variation, but a recently developed mixed metal oxide (MMO) compound, which is the subject of this paper, delivers characteristics and performance similar in principle to those of the original product described by Burba, *et al*.

Burba's description of the MMH compound he used showed it to comprise flat, highly cationic crystals with face dimensions an order of magnitude smaller than the typical bentonite platelet and with an extremely high aspect ratio. When complexed with hydrated bentonite platelets, the crystals were shown to attach to the sites of negative charges on the clay's basal plane. What is significant for the current discussion is the rheological behavior of the resulting slurry.

The rheological behavior was found to be dependant on the total displacement or strain applied, rather than the rate of displacement. The "slurry" showed elastic properties at low strain values and a propensity to "snap" at some critical displacement value. In short, the "slurry" could be characterized as a solid when zero or low strain was applied. When displacement was increased, a critical point was reached at which the solid instantly changed to a low viscosity liquid state. Cessation of displacement caused extremely fast reversion to the solid state (in milliseconds).

Field and Laboratory Observations

Fraser[5] presented field evidence showing that less than 100% of the fluid volume in the wellbore was in motion during drilling operations. Further, he observed that close to the wellbore wall, the "fluid" was either immobile or close to it, indicating that away from the influence of the drillpipe motion, the "fluid" probably existed in its solid state. Even at that time (early 1990's) there was speculation that the fluid's characteristics might cause it to impede injection into fractures and porous media. The application of this fluid type to control losses was championed by Gilmour, who with Hore,[6] published the results of mathematical modeling, laboratory testing and field application of an MMH fluid in formations which traditionally presented problems in maintaining a circulating system. The modeling work supported the contention that the MMH-type of fluid would lose less volume along a fracture before a steady state was reached than was the case with other fluids which might reasonably be used for drilling such formations. They also reported partial or complete success in arresting losses to formations varying from unconsolidated sands to fractured limestone reefs in locations ranging from North America, West Africa to the Far East.

Santarelli, *et al*.[7] published in 1992 on optimizing fluid design for drilling through highly fractured formations, from an operational perspective. They used core analysis and numerical modeling to tackle (and overcome) a specific field problem. Amongst the conclusions they drew on fluid design to minimize the probability or extent of losses were that the fluid should exhibit minimal erosion at the wellbore while maintaining good carrying capacity in the annulus. MMH and MMO fluids provide these elements of performance.

Fraser and Aragaol[8] in 2001 reported a further field example of the ability of this fluid type to facilitate maintenance of circulation when total losses are expected. The fluid was used to drill an ultra deepwater well offshore Brazil (Campos Basin) where the ECD was predicted to exceed the fracture pressure by ~0.5 lb/gal equivalent over an interval of a few hundred feet. The rationale was that the formation would inevitably be fractured so the route to maintaining a circulating system should be sought through the fluid properties. The problem section was drilled without any reported loss of fluid volume.

In support of this well, some simple injection work was carried out in the lab. Fluids were pumped at 50 mL/min. into a sleeved PPA cell containing a constrained, water-wet, frac-sand column using a pump with a 250-psi shut off limit. (See Fig. 1) While high viscosity bentonite and xanthan slurries passed through the column, an MMO slurry failed to penetrate more than ~35% of the column length before the pressure rose sharply and shut down the pump.

While carrying out Fann 70 analysis of fluids formulated for the well, it was further observed, that the fluid demonstrated an unusual relationship between rheology and temperature. The rheology of a low-density MMO fluid trended sharply upward with increasing temperature (Fig. 2). Similar analysis of the fluid from the well showed the tendency to be reduced when drill solids and weight material were present (due to competition from conventional mechanisms.) Nevertheless, in a situation where the viscosifying mechanism of the MMO fluid is operating efficiently, some advantage may be gained in loss zones. The temperature of invading fluid increases as it equilibrates with the formation, causing the fluid's rheology and gelation tendencies to rise, further hindering the invasion tendency.

Case History 1

The MMO fluid was programmed to drill the 28-in. section of a well in Tartagal, Salta, Argentina. The history of the area is one of massive whole fluid losses, often resulting in inability to maintain a full circulating system.

The section was TD'd with a total of 5,069 bbl of fluid lost compared with an average of 8,810 bbl lost on three offset wells, representing over 40% reduction in losses. Fluid densities were in the 9.3 to 9.6 lb/gal range and only seepage and drilling break losses were recorded. Most of the losses occurred while drilling the interval comprising highly permeable sands between 600 and 630 m and while carrying out operations at TD (including running casing). The hole remained full during trips. Based on past experience, the operator had air equipment on location to address the traditional occurrence of total losses. When losses occurred, air assist was used and the fluid provided an ideal vehicle through which to apply such an approach. It was easily aerated and the gas broke out at surface when the fluid was run over screens. Table 1 illustrates the thixotropic nature of the fluid and reference to the discussion on physical characteristics can be made to understand how easily the fluid can be screened. (The mechanical displacement encountered on contact with the vibrating screen causes the "fluid" to change to its low viscosity liquid state making screening particularly easy.)

In retrospect, the operator concluded that the use of air assist had been unnecessary and that the cost of the equipment could have been saved had it been understood how well the fluid would handle drilling the loss zones. Losses at TD were instigated by use of a packed hole assembly as attempts were made to correct some micro-doglegs and spirals which had been caused by the non-rotating vertical assembly. This assembly packed off and 694 bbl of fluid were pumped away before corrective action was taken. It is suspected that this event opened up a substantial fracture in the formation.

ROPs were documented as having exceeded plan and also exceeded values recorded in bit records for offsets. Cavings, which had caused tripping and disposal problems in earlier wells, were almost completely eliminated. (The problem had occurred consistently in the past even when oil-based muds were used.) Solids removal efficiencies as high as 95% were documented (these being calculated from fluid densities and volumes added since retort values would be suspect in such a low-solids environment.) The fluid's propensity to exist in its low viscosity liquid state during solids removal processing allowed for use of very fine screens on both scalpers and linear shakers. None of the commonly encountered problems of poor hole cleaning, fill, torque and drag, and back reaming on trips were reported. Offsets were plagued with some or all of these problems.

The problems experienced at TD resulted in several hundred barrels of cement slurry being pumped into the hole and left to cure. The fluid was converted to a lime system while drilling out the cement.

Based on the successes achieved on the 28-in. section, the operator changed the drilling program which had called for a low-fluid-loss polymer fluid to drill the 22-in. section. The reasons cited were the improvements in ROP, a previously unseen level of wellbore stability, and new levels of control over whole fluid losses. Initially it was decided to use the MMO fluid to drill through the Las Penas formation in an attempt to identify previously reported sulfate and carbonate contamination coming from this formation. Such was the performance of the fluid to this depth that the decision was taken to continue its use to the end of the section at 2,210 m.

A leakoff test performed after drilling out the cement resulted in whole fluid losses and indicated that the MMO fluid had held sufficient hydrostatic pressure to drill and cement with returns even though the fluid density was calculated to be 2-3 lb/gal over the pore pressure and very close to the fracture pressure.

The fluid's performance on the 28-in. section provided the operator enough confidence to rig down and back load the air assist equipment.

Once again the fluid outperformed others used on offsets in respect of ROPs, cavings, differential sticking, viscosity fluctuations and disposal costs. LCM (lost-circulation-material) pills were mixed to address apparent losses to fractures but in some instances, the problem was cured before the pill left surface. Once losses to any identified thief zone had ceased, no further problem was encountered with that particular zone. Most of the losses recorded coincided with drilling breaks in highly permeable sands and in faults. Tripping was carried out without need of backreaming, which was unheard of in this area. Of the 60 days spent on the section, 10 were the result of waiting on directional tools and 10 for premature directional tool and motor failures.

A total of 3,270 bbl of fluid was lost on this section compared with an average of 71,858 bbl on the three offsets. If the well with the worst losses is excluded from the calculation, the average losses on the two better wells was 8,962 bbl which represents more than 2.5 times the losses seen when the MMO fluid was used. More footage was drilled on the MMO well than on either of these offsets.

The section was successfully logged and the gauge was found to be 23 – 24 in. for most of the interval. The previous well gauge was 28 – 30 in. which represents around 1,400 bbl additional solids to dispose of. After running and setting the $18^5/_8$-in. casing, the annulus was used for water disposal which was achieved at a very low injection pressure of 90 psi.

Case History 2

Historically wells drilled in S.E. Gueydan Field, Vermillion Parish, Louisiana, have presented problems with mechanical wellbore instability and whole fluid losses in the 20-in. section (which is usually TD'd around 6,000 ft). On the Hardee, *et al*. #1 well, 24-in. pipe was driven to 355 ft. The MMO fluid was selected to drill the 20-in. section with the objective of avoiding lost time due mainly to losses.

While washing out the drive pipe, lignite was encountered and the fluid rheology dropped significantly (as is traditional for fluids of this type, particularly when they are in virigin state, *i.e.*, containing little or no drill solids.) The potential for such an occurrence had been anticipated and reserve fluid was used to recover the properties.

Pea gravel was encountered soon after drilling out (at ~400 ft and continuing to ~1,000 ft) and whole fluid losses sustained initially at around the rate of 400 bbl/hr at a controlled drilling rate of 50 ft/hr. If the formation is assumed to have a uniform and connected void volume fraction of 0.4 (or 40%) and washout was assumed to be absent, these data would suggest that whole fluid was invading the pea gravel to a depth of ~6 ft around the wellbore.

It was noted on the section that when losses were experienced, picking up the bit and circulating off bottom resulted in a reduction and finally cessation of losses. Resumption of drilling caused losses also to resume, but when the loss zone was exited, losses subsided and ceased. It is postulated that the mechanism by which the fluid operates requires it to invade the highly porous (or fractured) formation to a substantial depth before a steady state is achieved and losses cease. It certainly appears that we are not dealing with a mechanism which is localized to the wellbore surface and near-wellbore region, but rather depends on invasion to function.

Partial losses continued through massive sands (1,000 to 2,600 ft) and some lessons were learned about selection of LCM materials, in light of the fluid's sensitivity to anionic additives. Additions of nut hulls resulted in a loss of rheology (which exacerbated the problem which the additions were meant to alleviate) due to tannins and other anionic agents on the surface of the hulls. Cellulosic materials had a similar effect due to their anionic nature. Additions of bentonite and MMO were made to reverse the loss of rheology and recover programmed drilling properties.

Drilling continued through gumbo and sand to 4,835 ft at which depth the bit was tripped. Losses through this section were controlled to ~50 bbl/hr and incorporation of gumbo caused the drill solids content to rise from 2% to 4% and the MBT to reach 22.5 lb/bbl (the highest value encountered on the section).

Some problems were experienced with bridges and ledges on the trip in, but no fill was encountered and the problems were ascribed to a "corkscrew" trajectory caused by major fluctuations in formation type and hardness.

Penetration of the oyster beds below 5,000 ft caused resumption of losses at significant rates. Nevertheless, the commonly experienced scenario of full losses through this formation never materialized. Losses were sustained to a depth of 5,800 ft where the oyster bed limit was reached and drilling continued to casing point at 6,055 ft. Ledges were again encountered on a wiper trip but a hole-opener run was made and casing run without further incident and with the hole full of MMO fluid.

This well represented the first occasion when the 20-in. section had been drilled without complete losses of returns being encountered. Consequently it was never necessary to drill blind. The commonly experienced occurrences of the pea gravel running and the oyster beds collapsing were notably absent on this well.

At a flow rate of 900-1000 gal/min, the pump pressure was 2,700 psi and hole cleaning was very efficient (as assessed by both observation and modeling). The section was drilled and cased in a total of 11 days. Table 2 contains properties for the fluid on this well.

Conclusions

1) A simply formulated bentonite/MMO slurry has proven effective at enabling drilling to continue through loss zones.
2) The mechanism by which the fluid operates in limiting invasion appears, itself, to depend on a certain depth of initial invasion.
3) Care must be taken in selection of lost circulation materials to add to the system.

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Nomenclature

ECD	*equivalent circulating density*
Fann 70	*rheometer with high temperature/high pressure capability*
MBT	*methylene blue equivalent*
MMH	*mixed metal hydroxide*
MMO	*mixed metal oxide*
PPA	*permeability plugging apparatus*

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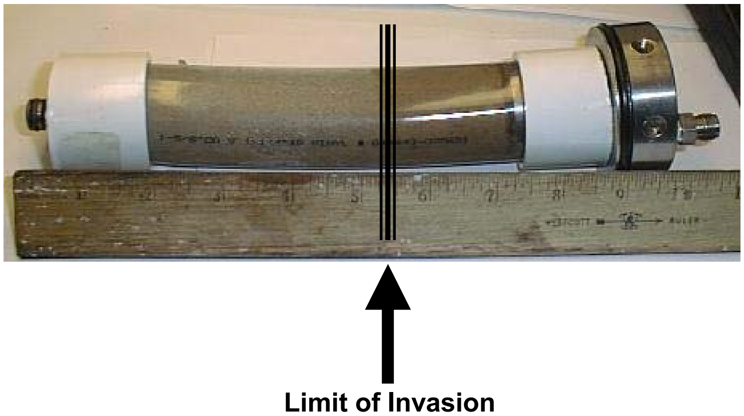

Fig. 1 - MMO slurry resistance to efforts to pump it through a wet, constrained sand pack

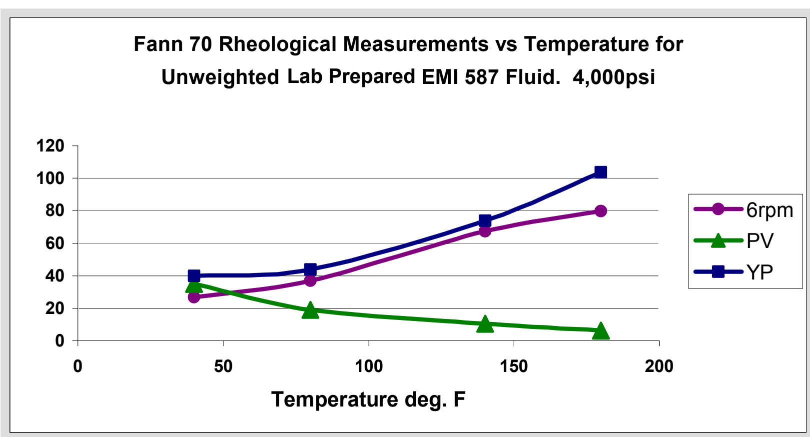

Fig. 2 - Unconventional temperature/viscosity relationship for simple, unweighted MMO slurry (ref. SPE/IADC 67734).

Table 1 - Drilling data from TECPETROL Well

Properties	
Mud density (lb/gal)	8.7-9.3
Funnel Vis (sec/qt.)	45-60
PV (cP)	2-8
YP (lb/100 ft^2)	30-40
R6 (Fann units)	20-28
R3 (Fann units)	20-28
G 10sec (lb/100 ft^2)	20-24
G 10min (lb/100 ft^2)	75-90
G 30min (lb/100 ft^2)	80-100
G 60min (lb/100 ft^2)	100-110
pH	11-11.2
API fluid loss (ml/30 min)	16-30
MBT (lb/gal)	7.5-16
Solids (%)	3-4
Other Data	
Ann. Press. Loss (psi)	15-50
Press. to break circ. (psi)	300-500
Soilds Removal Eff.(%)	90-92

Table 2 - Initial fluid properties from Dominion well

Properties	
Mud density (lb/gal)	8.5
Funnel Vis (sec/qt.)	75
PV (cP)	3
YP (lb/100 ft^2)	61
R600/300 (Fann units)	67/64
R200/100 (Fann units)	58/52
R6/3 (Fann Units)	34/32
Gels 10-sec (lb/100 ft^2)	30
Gels 10-min (lb/100 ft^2)	29
API Fluid Loss (mL/30 min)	NC
MBT (lb/gal)	7.5
pH	11.5