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The Influence of Bentonite Source on the use of Mixed Metal Oxide Drilling Fluid Systems for Geothermal Drilling

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Keywords

Bentonite, loss circulation, drilling fluids, mixed metal oxides, geothermal, drilling, MMO, unconsolidated formations

ABSTRACT

Mixed Metal oxides have been used for geothermal drilling in South East Asia with great success. The MMO (Mixed Metal Oxides System) has and is being extensively used for drilling other types of wells (oil, gas, water wells, mining, river crossings, etc.) in the USA, Argentina, Brazil, Mexico, Peru, Colombia, Ecuador, etc. Sourcing the right type of bentonite is one of the critical decisions when using this system. In this paper we will show the lab results of using two types of premium bentonite and make a review of the characteristics of this system and its application on geothermal drilling. The unusual rheology of the system is emphasized as this permits high carrying capacity and suspension and greatly helps in controlling or reducing mud losses. In many cases, it is also the best available option to drill unconsolidated formations.

Introduction

Unconsolidated formations, loss of circulation, lack of pumping capacity, and high temperatures are some of the many concerns when drilling a geothermal well. The MMO system is very well suited to address those issues because of its unique rheology. MMO can help drilling unconsolidated formations typical of the upper sections and reduce losses commonly found at the deeper sections. Because MMO has a unique high rheology, marked by a high yield point (YP) and Gels, it provides good hole cleaning and suspension in all sections, especially in surface sections and helps maintain a stable wellbore. It is a very simple system to prepare with few compounds but the quality of bentonite is critical for geothermal applications. This paper presents the results of a High Temperature lab test showing that a very high quality bentonite did not meet the required YP requirements after hot rolling. The hot rolling consisted on placing the Muds in a roller oven at high temperature to simulate the heated environment downhole (in this case at 400 degrees Fahrenheit).

The MMO system is an environmentally benign, temperature-stable fluid that contains no polymers and is low in solids. The MMO system is a unique, high performance drilling fluid developed for drilling high angle or horizontal wells, for reservoir drilling, for stabilizing mechanically weak or poorly consolidated formations, and for curing losses in both seepage and highly fractured zones. MMO systems are based on a complexed group of metal oxides that reacts with bentonite to form a new compound (Figure 1). The properties obtained resemble the values typical of a flocculated system. The new compound modifies the rheology of existing bentonite systems to provide a highly shear thinning fluid with high yield point, low plastic viscosity (PV) and high, flat gel strengths (Figure 2, overleaf). A typical Mixed Metal Oxide fluid formulation and properties are shown in Table 1, overleaf.

The system is capable of remarkable solids suspension, yet it screens easily and gives low circulating pressures and high rates of penetration. The fluid behaves like an elastic solid when at rest or conditions of minimal mechanical displacement. This pseudo-solid is extremely shear thinning in nature, the high flat gels being overcome with minimal resistance, and can be transformed into an extremely low-viscosity fluid under conditions of high shear. It is this unusual rheology of Mixed Metal Oxide Fluid systems that provides superior hole cleaning, cuttings suspension, leak-off control into fractures, as well as the ability to stabilize unconsolidated formations with

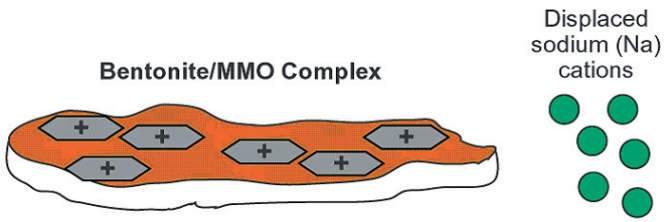

Figure 1. The Mixed Metal Oxide Bentonite Complex.

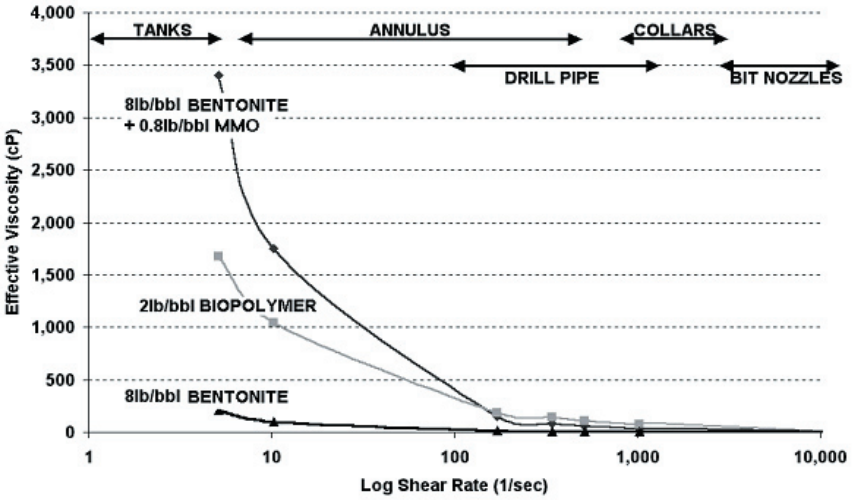

Figure 2. Shear-thinning properties of Mixed Metal Oxide Fluids Systems.

Table 1. Typical MMO Freshwater System Formulation and Properties.

Bentonite	11.0 lb/bbl	(31.4 kg/m^3)
Freshwater	1.0 bbl/bbl	(1 m^3)
Mixed Metal Oxide	1.1 lb/bbl	(3.14 kg/m^3)
Caustic Soda	0.5 lb/bbl	(1.43 kg/m^3)
Soda Ash	0.3 lb/bbl	(0.86 kg/m^3)
Plastic Viscosity	8 cP	
Yield Point	60 lb/100 ft^2	
Gels	35/40 lb/100 ft^2	
6 rpm	35	
3 rpm	34	
pH	9.5 – 11.0	

no interruptions in the drilling process and makes these fluid systems suitable for geothermal drilling.

Although the MMO system is bentonite based, it has an established cleanup procedure for eliminating the viscosity prior cementing or for reservoir clean up. MMO Systems are easily aerated and does not require degassing for reuse. The MMO system mitigates whole mud losses with its unique rheological profile. The pH profile of the fluid reduces oxygen corrosion when air drilling and it is not affected by 12+ pH. The major benefits with the MMO system are:

- Reduced number of products required in the system.
- Less reliance on standard LCM plugging materials and reduced rig time dealing with whole fluid losses.
- Better wellbore stability.
- Reduced communication with water injection wells and producing wells. No loss of steam production.
- Better bit hydraulics.
- Higher solids removal efficiencies.
- Easy de-aeration.
- Reduced well costs through savings in rig time, cementation costs, and lower mud volumes.
- Decreased formation damage and improved steam production with increased well life.

The Rheology of Mixed Metal Oxide Systems

Figure 2 illustrates the shear thinning behavior of MMO systems. In *high-shear regimes* at the bit, around heavy weight drillpipe and inside the drillpipe, the effective viscosity of all the fluids are very similar and very low. Circulating pressures and pressure losses are minimized and bit horse power is maximized for maximum rates of penetration. Conversely, in the *low-shear-rate regime*, such as in the annulus, Mixed Metal Oxide, more than other water-based drilling fluid systems, has a higher effective viscosity, that leads to more effective cuttings carrying capacity and hole cleaning efficiency.

The figure 3 shows the temperature dependence of the MMO system.

The Fann 70 rheogram in Figure 4 is of a 9.2-lb/gal Mixed Metal Oxide system tested under simulated downhole pressure and temperature conditions. The characteristic rheology of MMO systems are maintained with high low-shear-rate rheology, high yield points and low plastic viscosity, all of which ensures optimum hydraulics and hole cleaning performance.

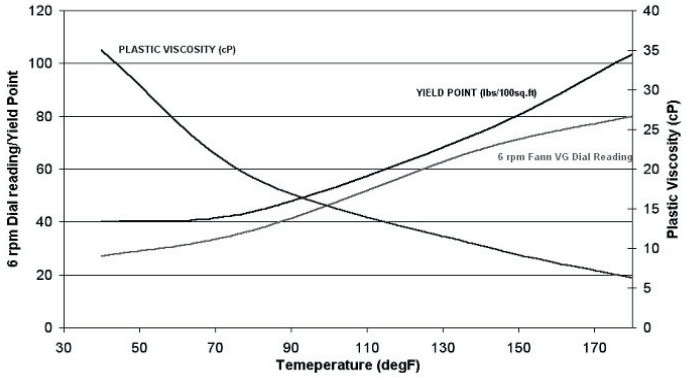

Figure 3. Temperature dependence on the MMO Rheogram.

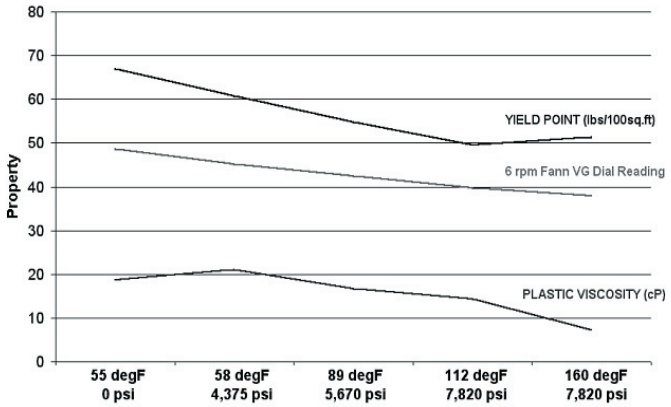

Figure 4. Simulated downhole rheology of Mixed Metal Oxide Systems.

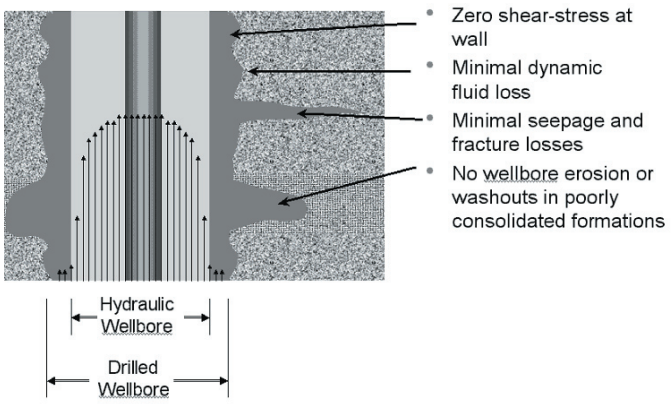

Figure 5. Schematic Diagram illustrating the annular velocity profile of MMO systems and the 'Hydraulic Wellbore'.

Hole Cleaning and Stabilizing Poorly Consolidated Formations

The consequence of shear thinning fluids of low plastic viscosity and high yield point is that the velocity profile is 'plug' flow. Normal fluids exhibit a parabolic velocity profile. In areas of low shear, the annular velocity is low, and conversely, in regions of high shear, the annular velocity is high. When drilling fragile, poorly consolidated formations, the wall shear stress is near zero and hole erosion is significantly reduced. Furthermore, we believe that a thin and near stationary fluid forms adjacent to the wellbore and we term this the 'hydraulic wellbore' (Figure 5).

Another feature of MMO systems is the gel strength development of the system. When static, the MMO/Bentonite complex provides a fluid with viscoelastic properties that is reversible with the onset of an applied shear stress. Under static conditions therefore, this behavior provides additional support, not only to stabilizing fragile wellbore formations, but also suspended solids and cuttings. The gelling behavior of MMO fluids is instantaneous, but non-progressive, meaning that the gelling properties do not continually increase with time, but reach a maximum after 10 seconds and remain constant thereafter. Uniquely, it requires only very low shear stresses applied to static MMO system to break the gel strengths resulting in low swab and surge pressures. The hole cleaning capabilities of MMO system are therefore exceptional and ideally suited to geothermal

Lost-Circulation Control with MMO Systems

The unique rheology of MMO systems also provide for improved lost circulation control. High effective viscosities at low shear rates (Figure 6) mean that whole fluid lost into a fracture will invade less with MMO systems than with other fluid systems. Whole fluid will flow into this existing open fracture if the hydrostatic pressure exceeds the formation pressure. Because of the shear thinning nature of MMO systems, the greater the volume of fluid that flows into fracture, the greater the pressure required to maintain that flow rate into the fracture. Since the hydrostatic pressure is constant, the flow rate into the fracture will decline. As the flow rate (shear rate) declines, the effective

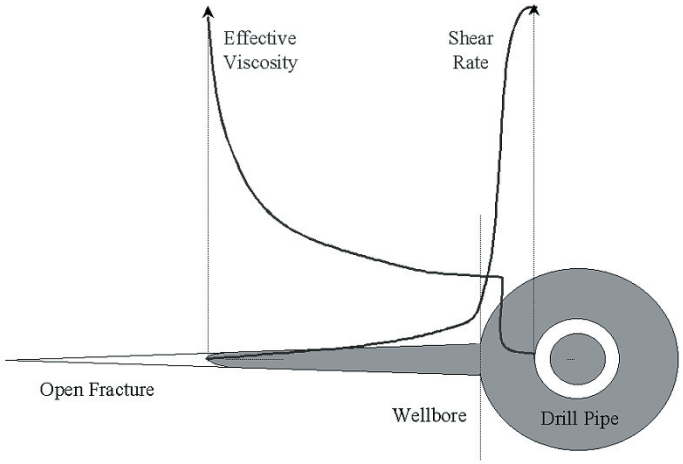

Figure 6. Schematic diagram illustrating the lost-circulation-control mechanism of MMO systems.

viscosity increases and as the effective viscosity increases, the loss rate declines further, until there comes a point when the loss rate falls to zero and losses to the fracture cease. This mechanism applies to all drilling fluids, but because of the highly shear thinning nature of MMO systems, losses into fractured formations will be significantly less than conventional fluids.

Most geothermal wells require extensive laboratory testing to optimize fluid design. The testing is often complicated by poor reproducibility and skilled interpretation of results is required. Critical factors include:

- Equipment calibration (including oven temperatures)
- Test methodology needs to be precise and repeatable. This includes mixing, shearing, pressurizing and cooling of aging cells, pH adjustment etc.
- Material selection - results are very sensitive to the quality of barite and bentonite.
- Equipment design - the standard HTHP fluid loss cells are not designed for operation above 350ºF and reproducibility at this temperature is poor.
- High-temperature/high-pressure viscometers assists in the design of geothermal fluids and permit the measurement of fluid viscosity up to 480°F (250°C) and 20,000 psi and also allow measurement of long-term gel strength under HTHP conditions.

Bentonite Performance Testing in MMO Systems

The performance of MMO systems in general is dependent on the choice of bentonite, which becomes more critical for high temperature geothermal applications. A premium grade untreated sodium bentonite is required for MMO systems in order for the bentonite and MMO complex described previously to be formed. In the series of laboratory tests presented in this paper, two top quality bentonite sources that both pass the API 13B specification for untreated bentonites are compared.

The results of testing are shown in Table 2, overleaf, where the effect of heating on the formulation becomes apparent. The MMO formulation with Bentonite A for example at 10 lb/bbl

Table 2. MMO Geothermal System Formulation and Properties

Fluid Formulation	**1**		**2**		**3**			**4**	
Fresh Water, bbl	0.664		0.599		0.664			0.599	
BENTONITE A lb/bbl	10		12		10			12	
MMO, lb/bbl	1.2		1.2		1.2			1.2	
SODA ASH, lb/bbl	0.25		0.25		0.25			0.25	
CAUSTIC SODA, lb/bbl	0.1(pH=9.5)		0.1(pH=9.5)		0.1(pH=9.5)			0.1(pH=9.5)	
Mud Properties	***Initial***	***Aged***	***Initial***	***Aged***	***Initial***	***Aged***		***Initial***	***Aged***
Heat Aging Temp, °F		400		400		400			400
Heat Aging Hours		16		16		16			16
Static/Rolling		R		R		R			R
Mud Weight, lb/gal		8.5		8.5		8.5			8.5
Rheology Temp, °F	120	120	120	120	120	120		120	120
600 rpm	72	94	120	150	71	38		126	64
300 rpm	60	85	108	136	67	30		120	48
200 rpm	55	83	102	132	64	28		118	45
100 rpm	49	80	93	130	61	28		112	44
6 rpm	32	58	70	115	44	28		82	44
3 rpm	29	43	65	103	42	20		76	35
PV, cps	8	9	12	14	4	8		6	16
YP, lbs/100 ft²	52	76	96	122	63	22		114	32
10 Seconds Gel	25	31	54	93	28	12		62	27
10 Minutes Gel	35	39	60	66	49	17		74	32
pH @22-24°C	8.45	9.39	8.22	9.0	8.65	9.23	10.1	8.5	9.1

exhibits excellent fluid stability with a slight increase in the overall rheological properties. In the same formulation, but using Bentonite A, a decrease in rheology is exhibited which may be detrimental to the performance of the system in the field. Increasing the concentration of Bentonite A to 12 lb/bbl minimizes the rheology decrease.

From a fluid engineering perspective, Bentonite B would be the bentonite of choice for reasons of fluid stability, tolerance to contaminants and ultimate rheological control

Conclusions

We conclude from this study that the choice of untreated sodium bentonite is crucial to the successful planning and execution of MMO systems for geothermal applications. Even though the bentonites may pass the relevant API specifications for untreated bentonite, this is not a reliable indicator for performance in MMO systems, especially for extreme temperature geothermal applications. Qualifying the bentonite in the MMO fluid formulation before the job commences is a prerequisite for success.

Geothermal drilling places great stress on the design of drilling fluids to meet the combined challenges of minimizing drilling fluid losses in surface zones, drilling fluid losses in steam producing fractures, hole cleaning and cuttings suspension, wellbore enlargement in poorly consolidated zones, and thermal stability. MMO system combined with a carefully selected bentonite can provide an excellent system suited to geothermal drilling.

1. The few number of products needed to build a MMO system adds to the ease of engineering in remote locations.

2. All products required for the MMO system pass the strictest environmental regulations and are environmentally benign. In addition, the MMO system is thermally stable to temperatures in excess of 250 ºC - suitable for most geothermal applications.

3. The interaction between MMO and Bentonite provides a unique rheological profile that is highly shear thinning. This is highly desirable for:

- Higher fluid velocities in the annulus for improved hole cleaning ability.
- Cuttings cleaning and suspension in horizontal and highly deviated wellbore sections.
- Reducing whole fluid losses into fractures and a porous matrix.
- Lower frictional pressures and pump pressures for a given flow (pump) rate.
- Lower ECD's minimizing the risk of formation breakdown
- Improved bit hydraulics in hard rock formations
- Low fluid velocities at the wellbore, minimizing erosion of mechanically weak formations.
- Thin rheologies at low temperature mud line and flow lines
- Optimum hole cleaning capability under downhole conditions

The MMO has a successful track record of success in geothermal drilling, mostly confined to the Far East at present. However, the MMO system is widely used in South America as a conventional drilling fluid in areas of low geothermal gradients.

Acknowledgments

The authors wish to thank the management of ThermaSource and M-I SWACO for permission to present this paper and all the individuals who assisted in its preparation.

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