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Short communication

# Reduction of erosion rate by particle size distribution (*PSD*) modification of hematite as weighting agent for oil based drilling fluids

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ABSTRACT

Natural hematite ($Fe_2O_3$) and barite ($Ba_2SO_4$) are usually employed as weighting agents for oil based drilling fluids in several venezuelan fields. Hematite has shown some physico-chemical advantages with respect to barite: a greater specific gravity and solubility in acid media and lower attrition rate. However, the most challenging issue related to hematite field applications has been to reduce its high erosive potential. Effects of particle size distribution (*PSD*) have been evaluated with four different samples of hematite (48, 38, 30 and 18 μm based on the statistical parameter $D_{(v,0.9)}$) respect to commercial barite. These samples were used to prepare fluids with a density of 1977 kg/m$^3$. An erosion test loop was used to expose different samples of *AISI* 1020 flat steel to the erosive action of jet fluid. Wear of metallic samples was measured by weight lost and wear mechanisms were identified by laser profilometry, SEM and EDS. The investigation showed that the erosion rate ($E$) produced by hematite decreases potentially with size grain reduction ($D_{(v,0.9)}$) and depends on the morphology and angularity of the particle in comparison with barite. Laboratory results were validated on field tests with drilling fluids formulated with hematite of different *PSD*.



## 1. Introduction

In the oil industry, the process of drilling a well requires the use of heavy equipment and tools which conforms the Bottom Hole Assembly (BHA), commonly used to improve geo-steering performance of the drill pipe and to acquire information from subsurface. Because this assembly is attached near the drill bit, it usually suffers some wear associated to the continuous rotation against the rock and through its internal components caused by the erosive action of drilling fluids in its external surface. Basically, drilling fluids are composed by a base fluid (water or oil), a weighting agent ($Ba_2SO_4$ or $Fe_2O_3$) and other additives to control rheological properties, fluid losses and particle suspension among others, to maintain the wellbore stability during drilling, to transport the cutting from bottom hole to the surface, cooling and lubricate the BHA. For many years, barite ($Ba_2SO_4$) has been used as the primary weighting agent for oil based drilling fluids to provide a specified density to the fluid system in order to control the formation pressure during drilling process. Nevertheless, world reserves of barite are decreasing in quality and quantity while international demand of fluid densifiers is increasing every year, associated with the increase of drilling worldwide activity [1–9]. Based on this consideration, Petróleos de Venezuela (PDVSA) as the primary Venezuelan oil industry, has carried out a project to develop alternatives to replace barite imports by hematite produced in Venezuela [1]. However, the principal barrier that has limited the massive use of hematite as weighting agent in drilling fluid systems has been its erosive and abrasive wear effect over metallic and non-metallic components of the fluid circulation system (valves, pumps, pipes) and downhole tools (directional tools, motors, turbines) of a drilling rig. This effect increases when drilling fluids are operated at high densities and high pumping rates [10,11]. Since the introduction of Brazilian hematite in South Texas in the early 1970s, several attempts have been made to reduce the wear potential of hematite [1–13], which have shown that erosive potential depends on the particle sizes, fluid densities (solid content) and rheological properties of the fluid system. In general these results agree with the classic dry and slurry erosion theories [14–23] which establishes that erosion rate ($E$) is a function of particles characteristics and the fluidynamics behavior of the system (kind of fluid and hydraulic conditions). Nevertheless, these studies consider only the $D_{(v,0.5)}$ as a primary particle sizes characteristic of a hematite *PSD*. The goal of the present research is to understand the erosion behavior of the drilling fluids weighted with barite and hematite. In this case we want to express a second goal, study the effect of *PSD* ($D_{(v,0.9)}$) modification in the abrasion response of the drilling fluids.

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**Nomenclature**

| | |
|---|---|
| *AISI* | American Iron and Steel Institute |
| $d$ | particle size |
| $D_{(v,0.5)}$ | particle size less than 50% in volume of particles distribution |
| $D_{(v,0.9)}$ | particle size less than 90% in volume of particles distribution |
| $E$ | erosion rates |
| $h$ | maximum penetration rate |
| $HV_{0.1}$ | Vickers hardness (measure at 100 gf and 11 s) |
| $k$ | erosion wear coefficient |
| $n$ | drilling fluid or jet velocity coefficient |
| *PSD* | particle size distribution |
| $v$ | drilling fluid or jet velocity |
| *VP* | drilling fluid plastic viscosity |
| *YP* | drilling fluid yield point |

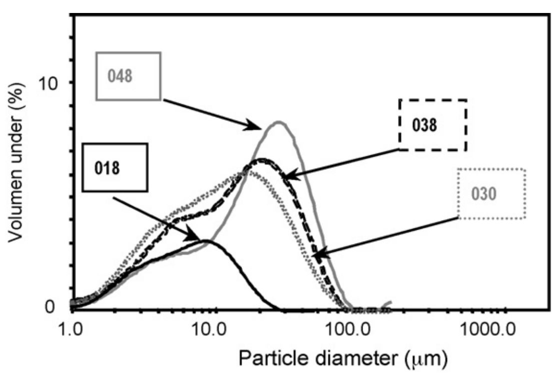


**Fig. 1.** *PSD* of hematite tested as weighting agent of oil based drilling fluid.

## 2. Experimental procedure

### 2.1. Materials

Four different samples of natural hematite ($Fe_2O_3$) were obtained through a *PSD* modification based on the $D_{(v,0.9)}$ statistical parameter: 48, 38, 30 and 18 μm, measured by laser diffraction using ISO-13320 standard procedure [24] (Fig. 1 and Table 1). Each sample of hematite was used to prepare a specified volume of oil based drilling fluid with a density of 1977.1 kg/m$^3$ (16.5 lbm/gal), as well as two commercial formulations of oil based fluids weighted with barite (Tables 1–3). Properties and general morphology of the weighting agents are shown in Table 1 and Fig. 2. Target samples were cylindrical flat and made of *AISI* 1020 steel with 235 ± 12 $HV_{0.1}$, density of 7.86 g/cm$^3$ and a nominal chemical composition of: 0.19 C, 0.45 Mn, 0.030 P, 0.025 S, with a typical microstructure illustrated in Fig. 3.

**Table 2**
Chemical compositions of evaluated drilling fluids (1977.1 kg/m$^3$).

| Additive | Barite fluid | Hematite fluid |
|---|---|---|
| Aromatic free oil base (m$^3$) | 0.097 | 0.108 |
| Organophilic clay (modified montmorillonite) (kg/m$^3$) | 19.97 | 25.68 |
| Liquid surfactant (polyacrilamidic polymers) (kg/m$^3$) | 28.53 | 37.09 |
| pH control (natural grinded CaO) (kg/m$^3$) | 11.41 | 11.41 |
| Solid dispersing agent (modified carbon lignosulfonate) (kg/m$^3$) | 22.82 | 22.82 |
| Weighting agent ($Fe_2O_3$ or $Ba_2SO_4$) (kg/m$^3$) | 1406.53 | 1349.76 |

**Table 3**
Physical properties of evaluated oil based drilling fluids.

| Drilling fluid | Weight (kg/m$^3$) | VP[a] (Pa s) | YP[a] (N/m$^2$) |
|---|---|---|---|
| Barite 1 | 1977.1 | 0.030 ± 0.001 | 7.2 ± 0.5 |
| Barite 2 | 1977.1 | 0.025 ± 0.001 | 6.2 ± 0.5 |
| Hematite 18 | 1977.1 | 0.023 ± 0.001 | 8.2 ± 0.5 |
| Hematite 30 | 1977.1 | 0.020 ± 0.001 | 3.8 ± 0.5 |
| Hematite 38 | 1977.1 | 0.019 ± 0.001 | 4.8 ± 0.5 |
| Hematite 48 | 1977.1 | 0.023 ± 0.001 | 7.7 ± 0.5 |

[a] Measured at 65.56 °C (150 F) using the procedures API RP 13B-2 [26].

### 2.2. Erosion test

The volume of drilling fluid was prepared in the test tank and pumped during 3 h (stationary erosion period) through the erosion

**Table 1**
Properties and main parameters of the *PSD* of barite and hematite as weighting agents of oil based drilling fluids.

| Weighting agent | Density [25] (g/cm$^3$) | Mohs hardness [25] | Vickers hardness [4] ($HV_{0.1}$) | $D_{(v,0.5)}$ (μm) | $D_{(v,0.9)}$ (μm) |
|---|---|---|---|---|---|
| Barite 1 ($Ba_2SO_4$) | 4.25 | 3–4 | 451 ± 190 | 18.0 ± 1.5 | 50.5 ± 2.5 |
| Barite 2 ($Ba_2SO_4$) | 4.21 | 3–4 | 579 ± 200 | 21.0 ± 1.3 | 53.0 ± 1.5 |
| Hematite 18 ($Fe_2O_3$) | 5.15 | 5–6 | 820 ± 153 | 5.5 ± 0.5 | 20.0 ± 1.3 |
| Hematite 30 ($Fe_2O_3$) | 5.15 | 5–6 | 886 ± 221 | 10.0 ± 0.5 | 29.3 ± 1.5 |
| Hematite 38 ($Fe_2O_3$) | 5.20 | 5–6 | 892 ± 105 | 15.0 ± 0.5 | 38.6 ± 0.9 |
| Hematite 48 ($Fe_2O_3$) | 5.20 | 5–6 | 865 ± 237 | 20.0 ± 1.5 | 48.0 ± 2.0 |

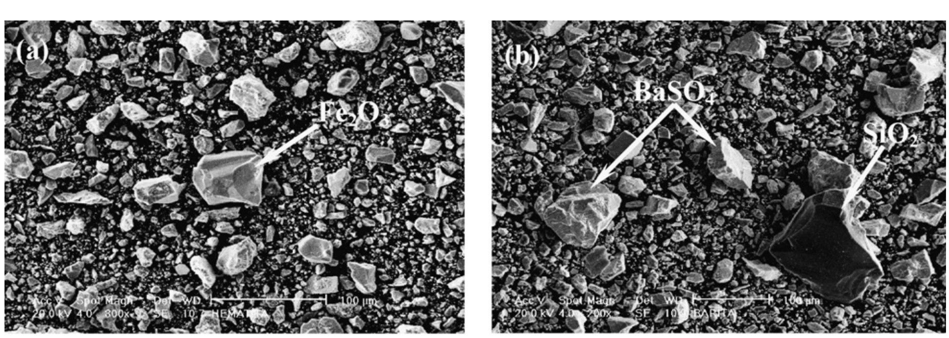


**Fig. 2.** SEM images of particle morphology of barite and hematite weighting agent.