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Original article

Strengthening shale wellbore with silica nanoparticles drilling fluid

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ABSTRACT

Nanoparticles have been widely used to reduce wellbore instability problems of shale formation. In this paper, nanoparticle-containing water-based drilling fluids (WBDFs) and oil-based drilling fluids (OBDFs) were evaluated by running three new tests including spontaneous imbibition, swelling rate and acoustic transit time. Results showed that, for the WBDFs, nanoparticles leaded to higher plastic viscosity (PV) and yield point (YP), and lower API-filtration. Moreover, because pore throats of shale can be plugged by nanoparticles, imbibition amount, swelling rate, and Young's-modulus reduction of shale decreased significantly. Higher concentration of nanoparticles can induce better plugging effect. However, for the OBDFs, nanoparticles did not show these positive effects like the nano WBDFs, even leaded to some negative effects such as higher filtration and larger Young's-modulus reduction. The main reasons are that the silica nanoparticles can easily disperse in the WBDFs, and effectively prevent the filtrate invading into shale by plugging pore throats. But the same silica nanoparticles are difficult to disperse in OBDFs, and do not perform the expected functions. This study indicates that nano WBDFs have great potential to reduce the wellbore instability problems of shale formation.

1. Introduction

Drilling through a clay-rich shale formation often results in wellbore instability problems. It has been estimated that shale formations make up more than 75% of all drilled formations, and they account for more than 90% of all expenses associated with wellbore instability problems. The main cause of wellbore instability is drilling-fluid filtrate absorption and subsequent swelling and sloughing of the wellbore [1]. So, in order to reduce the filtrate invasion, the best possible way is to seal off exposed pore throats of shale [2].

Al-Bazali (2005) measured the shale pore-throat sizes according to the capillary pressure equation, and found that the average pore-throat sizes of a variety of shales range from 10 to 30 nm [3]. As shown in Fig. 1, compared with shale pore-throat sizes, conventional drilling fluid additives, such as bentonite and barite, have much larger particle diameters, ranging from 0.1 to 100 μm [4]. The extremely low permeability and small pore-throat size observed in shale indicate that conventional filtration additives cannot form mud-cakes on shale surface and thus not reduce filtrate invasion [5,6]. So, according to the theory of particle bridging, only nanoparticles should be used for plugging shale pore throats [7–9].

Previous investigations which based on pressure penetration experiments showed that nano-particles (particle diameters in the nano-meter range) can prevent pressure of drilling fluid from transmitting into the shale formation [4,6,10–12]. They demonstrated that nanoparticles performed well at plugging the pore throats, and significantly reducing the permeability of the shale. In addition, for the micro-cracks in shale, the nanoparticles alone cannot plug them, but nanoparticles presented a good synergic

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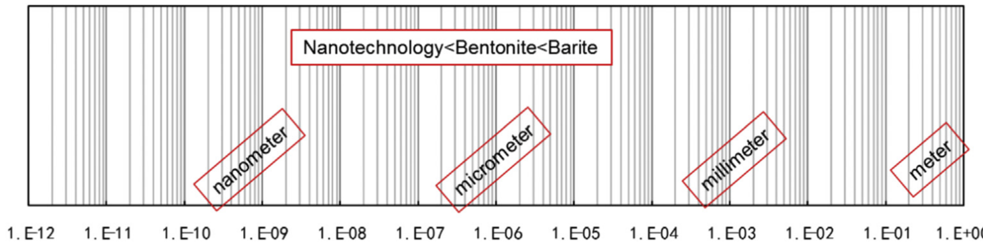

Fig. 1. Particle-size scale [4].

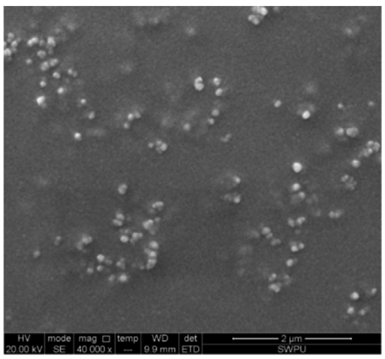

Fig. 2. SEM image of silica nanoparticles.

Table 1
Composition of Yanchang shale.

X-ray diffraction/wt%								Total organic carbon/wt%
Quartz	Anorthose	Siderite	Pyrite	Illite	I/S	Kaolinite	Chlorite	
32.5	3.4	3.9	2.4	37.7	5.4	9.7	5.0	6.1

Table 2
Main additives and properties of WBDF.

Bentonite	K-PAM	NH_4HPAN	LV-CMC	Density	PV	YP	API-FL[a]	pH
3 wt%	0.8 wt%	0.5 wt%	0.5 wt%	1.0 g/cm^3	14 mPa.s	1.1Pa	12 ml	9

[a] API-FL = fluid loss under standard API test conditions in cm^3.

Table 3
Main additives and properties of OBDF.

Bentonite	Water	White oil	Oxidized asphalt	Density	PV	YP	API-FL	pH
3 wt%	15 wt%	70 wt%	12 wt%	1.4 g/cm^3	68 mPa.s	59 Pa	5 ml	11

effect with other materials in drilling fluid [13–16]. In conclusion, combination of properly formulated drilling fluid and appropriate nanoparticles are keys of preventing water invasion. OBDFs have been widely used to reduce the wellbore instability problems because OBDF contains a litter water (less than 20 wt %). But recent investigations indicated that OBDFs can still lead to wellbore instability due to filtrate invasion. For example, filtrate invasion into shale can increase lubrication of bedding planes, and generate alkali erosion [17–20]. These negative effects can lead to reduction of shale strength.

Previous investigations mainly paid close attention to pressure transmission in shale exposed WBDFs, and did not evaluate the applicability of the nanoparticles in OBDFs. In this paper, some new experimental methods, such as spontaneous imbibition, swelling rate, and acoustic transit time test, were adopted to evaluate applicability of the silica nanoparticles in WBDFs and OBDFs. Experimental results can provide some evidences to reduce the wellbore instability problems using nano drilling fluids.

2. Samples and experimental methods

2.1. Samples used

2.1.1. Nanoparticles

As shown in Fig. 2, the nanoparticles discussed in this paper were 10–20-nm diameter silica spheres, and were non-modified. They had excellent ion compatibility, temperature stability, and no adverse effect on drilling fluid properties [11,13].

2.1.2. Shale properties

Yanchang shale was used in this study. And this shale consists of quartz, feldspar, dolomite, clays and other silicate and carbonate minerals (Table 1). In addition, this shale has the contact angle of 60.5° and 4.5° under contacting with water and oil, respectively. Permeability ranges from 0.00015 to 0.037 mD,

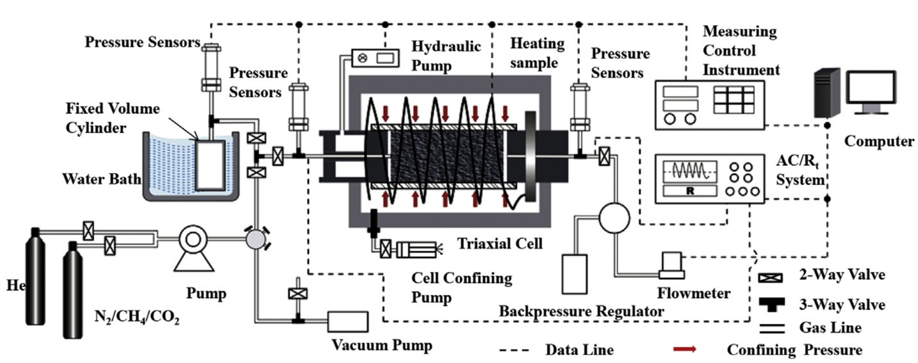

Fig. 3. Schematic diagram of acoustic transit time testing system.