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The damage mechanism of oil-based drilling fluid for tight sandstone gas reservoir and its optimization

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ABSTRACT

The B block is a typical tight sandstone gas reservoir in Tarim basin in the Xinjiang Uygur Autonomous Region, China. In this block, the skin factors of each well drilled by oil-based drilling fluids were high and the reservoir damage was serious. The permeability recovery rates of two kinds of oil-based drilling fluids used in site were both less than 60%. To investigate the damage mechanism, the particle size distribution was tested to analyze solids damage incorporating the pore throat radius and micro-fracture width in this block. The contact angles of deionized water on reservoir cores before and after polluted by oil-based filtrate were measured to analyze the wettability alteration. Core flow experiment was applied to evaluate oil phase trapping, and the emulsion droplets formed by mixing oil-based filtrate with formation water were observed to analyze emulsion plugging damage. Based on the test results, the factors causing damage to the tight sandstone gas reservoir included solid phase invasion to fractures, wettability alteration, oil phase trapping and emulsion plugging.

Therefore, the oil-based drilling fluids were optimized from aspects of reduction of the filtration loss, improvement of the sealing ability of the micro-fractures and reduction of the oil-water interfacial tension. A temporary plugging agent was compounded by using the Ideal Packing Theory, which could effectively plug the micro-fractures. The surfactant was optimized, and it could destroy the oil-based filtrate cake effectively and break emulsion in a short time. The permeability recovery rate of optimized oil-based drilling fluids was evaluated and the results showed that permeability recovery rate was 87.40% and 86.74%. Furthermore, cores early contaminated by oil-based drilling fluid were treated by optimized surfactant, and the tested permeability recovery rate reached more than 100%.

1. Introduction

Tight sandstone gas reservoirs are rich in resources and the world's tight gas 1 resources distributed in many basins around the world amounted to 114 trillion cubic meters. The tight gas recoverable resources in China amounted to 9–13 trillion cubic meters, accounting for about 22% of the national natural gas recoverable resources according to the data from Chinese Academy of Engineering. Tight sandstone gas reservoir is an important oil and gas exploration area in the future and has a good development prospect. However, tight sandstone gas reservoir is one type of unconventional gas reservoir where natural gas is enriched in sandstone with low porosity (less than 10%) and low permeability (less than 0.1×10^{-3} μm^2), which usually characterized by high capillary force, high irreducible water saturation, a tiny size of pore throats, severe heterogeneity and abundant micro-fractures (Reinicke et al., 2010; Geng et al., 2010; Zhang et al., 2008; Andrews et al., 2012). Thus, it is harder to develop by conventional technology and easier to be damaged during drilling and gas production. Liquid phase trapping is one of the most serious damage factors in this kind of gas reservoirs. On condition that the initial water saturation is generally lower than the irreducible water saturation in tight sandstone gas reservoirs, the serious liquid phase trapping can be formed by self-absorption and retention of the filtrate under the effect of relative permeability and potential capillary pressure. The damage degree of liquid phase trapping is influenced by the capillary pressure and the initial water saturation, and it is also related to the quality of the mud cake (Bennion et al., 1994, 2000; Rickman and Jaripatke, 2010; Bahrami et al., 2011; 2012a,b; Zhang et al., 2012). Meanwhile, tight sandstone gas reservoirs are formed accompany with

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fractures in general. Fractures are sensitive to stress and once the effective stress reaches a critical value, fractures tend to contact even close, leading to crushing of the rocks then solid plugging damage occurs with aggregation of particles in the gas flow (Oluyemi, 2011). In addition, if particles in the drilling fluids could not form bridging or shielding at the fractures entrance, solid and liquid phase would invade into reservoir through micro-fractures deeply due to leakage of drilling fluids into natural fracture system or adsorption of polymer residue on fracture surface, causing severe damage to fractures and matrix (Huang and Clark, 2012; Loghry et al., 2013).

Tight sandstone gas reservoirs are susceptible to various damages while oil-based drilling fluids are widely used in tight sandstone gas reservoir in Tarim basin in recent years, because oil-based drilling fluids possess the advantages of strong inhibition of shale, high temperature resistance, low formation damage, good lubrication performance and strong corrosion resistance (Zhang et al., 2015). At present, there are several main types of the oil-based drilling fluid including whole oil-based drilling fluid, low toxicity oil-based drilling fluid, high temperature resistant oil-based drilling fluid, and reversible emulsion drilling fluid. Many studies on oil-based drilling fluid treating agents have been conducted aimed at issues of oil-based drilling fluid such as sedimentation stability, emulsion stability and contamination of drilling cuttings to drilling fluid (Wang, 2011; Pan et al., 2014). Nevertheless, more and more researches' results show that oil-based drilling fluid can also cause some damage to the oil and gas reservoirs. The basic compositions of oil-based drilling fluid are base oil, emulsifier, wetting agent, water phase and lipophilic colloid which are all potential factors causing reservoir damage. The organic bentonite is a lipophilic bentonite modified from bentonite by surfactant, so it presents as finely dispersed particle in oil phase that can easily invade into pore throats and seepage channel (Thomas et al., 1984). The wetting agent can cause wetting reversal and transform wettability on rock surface from hydrophilicity to lipophilicity, accordingly, the oil phase and lipophilic colloid are more easily attached to the surface of the pore throats, reducing effective gas flow area (Cui, 2012; Qutob and Byrne, 2015). The formation water and oil phase can easily form emulsion under the effect of emulsifier that may damage reservoirs by plugging pore throats and fractures (Wang, 2012; Qutob and Byrne, 2015). Currently, there are a few researches on damage mechanism of oil-based drilling fluids in tight sandstone gas reservoirs. Bahrami et al. (2012a,b) believed that the filtrate of oil-based mud might result in introduction of an immiscible liquid in tight gas reservoir drilled by oil-based drilling fluids, causing entrapment of an additional third phase in the porous media that would exacerbate formation damage effects. And Zhang et al. (2015) attributed the main factors of oil-based drilling fluids damaging tight gas reservoir to solids plugging, multi-phase flow effect, wettability reversal and emulsion plugging through laboratory experiments. Similarly, Kang et al. (2013) evaluated the damage of oil-based drilling fluid to a shale gas reservoir and confirmed the primary damage mechanisms of oil-based drilling fluid were solid phase invasion, oil trapping, alkaline damage, stress sensitivity. Summarily, Wang et al. (2014) proposed the protection status of tight gas reservoir as follows: ①although the surface tension of oil is lower than that of water, oil-based drilling fluid filtrate could be also adsorbed and retained after entering the gas reservoir; ②the change in wettability would increase the flow resistance of natural gas in the percolation channel, adversely affecting gas well production; ③oil-based filtrate invasion resulted in the change of reservoir from the original gas and water flow to gas, water, oil three-phase flow, and oil is a non-wetting phase, gathering into a mass in the middle of the percolation channel, reducing gas effective permeability.

The B block is located in the Kelasu tectonic belt of Kuche depression in Tarim basin where the reservoir porosity is distributed between 1% and 9.4% with an average of 6.8% and the permeability is distributed between 0.011×10^{-3} μm^2 and 8.56×10^{-3} μm^2 with an average of 0.19×10^{-3} μm^2. The B block belongs to a typical low permeability tight gas reservoir with low porosity, low permeability and serious heterogeneity. The skin factors of each well drilled by oil-based drilling fluids were high generally distributed between 5 and 20 and the reservoir damage was serious according to well testing interpretation. Thus, the objective of this study is to investigate main damage mechanism of oil-based drilling fluid in a certain tight sandstone gas reservoir in the B block, through testing permeability recovery rates of reservoir cores and analyzing the effect of solid phase and liquid phase on reservoir. Eventually, the oil-based drilling fluids are optimized from the aspect of ideal packing technology, oil-based filtrate cake removal, and demulsification of oil-based filtrate.

2. Experimental methods

2.1. Equipment and materials

Experimental equipment includes drilling fluid pollution instrument YBH-1 manufactured by Meter Factory of University of Petroleum, low permeability core flow testing apparatus DSRT-II developed by Yangtze University, laser particle size analyzer Bettersize2000 produced by Bettersize Instrument Co., Ltd, scanning electron microscope S-4800 produced by HITACHI, polarizing microscope ISH500 produced by FENYE Optoelectronic Equipment Co., Ltd, surface tension detector BZY-1 produced by PINGXUAN Scientific Instrument Co., Ltd, contact angle tester JC2000D5M produced by POWEREACH Industrial Limited.

Two kinds of experimental oil-based drilling fluids were respectively INVERMUL oil-based drilling fluid collected from Well B2-2-20 and traditional oil-based drilling fluid collected form Well B105. The important mud properties of two oil-based drilling fluids were listed in Table 1.

Natural cores were collected from Well B2 at depth of kelly bushing between 6781.5 m and 6865.5 m and rock fragments used for analysis of mercury, surface properties and scanning electron microscope were collected from Well B1 at depth between 6917.5 m and 6924.2 m as well as Well B2 at depth between 6770 m and 6773 m.

Table 1
Properties of two kinds of oil-based drilling fluids.

Type Properties		INVERMUL oil-based drilling fluid		traditional oil-based drilling fluid	
		Before aging	After aging(140°C/16 h)	Before aging	After aging(140°C/16 h)
Plastic viscosity (mPa·s)		70	69	56	38
Yield point (Pa)		7.5	5.5	7	3
Gel 10″/Gel 10′(Pa)		3.5/8	3.5/8.5	3/6	2.25/2.5
FL_{API}(mL)		0.1	0	0	0
FL_{HTHP}(mL)		3		1.2	
ρ(g/cm^3)		1.91		1.81	
pH		8		8	
lubricating property	Sticking factor of mud cake	0.0262		0.0349	
	Lubrication factor	0.1322		0.1325	
Sedimentation stability	Density difference (g/cm^3)	0.021		0.009	
	Note	Let drilling fluids stand for 24 h and test density upper and lower layers			