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Full Length Article

Permeability evolution study after breaking of friction reducer in near fracture matrix of tightgas reservoir

Yongpeng Sun [a], Baojun Bai [b,*], Caili Dai [a], Hong Liu [c]

[a] School of Petroleum Engineering, China University of Petroleum (East China), Qingdao, Shandong 266580, China
[b] Department of Geological Sciences & Engineering, Missouri University of Science and Technology, Rolla, MO 65409, United States
[c] School of Petroleum Engineering, Chongqing University of Science and Engineering, Chongqing City, Chongqing 401331, China

HIGHLIGHTS

- Three conditions of breaking for friction reducer are proposed.
- For each breaking condition, the permeability regain in tightsand sample is carefully investigated.
- The emulsion particle size of friction reducer is analyzed, and compared with the pore size of tightsand matrix.
- The surface wettability of tightsand is measured after each treatment.

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ABSTRACT

Hydraulic fracturing is generally required for tightgas formation with low matrix permeability to achieve economic production rate. Slickwater fracturing is one of most commonly used technology. Friction reducer is the primary component of this fluid. During fracturing, million gallons of friction reducer fluid are pumped downhole to initiate fractures, and lots of fluid would filtrate into formation matrix. Due to the small pore size of tightgas reservoir, breaking of the friction reducer fluid is required to minimize formation damage and improve the conductivity in fracture. However, this performance in tightgas is not clear.

In this paper, tightsand samples were treated with a friction reducer and a breaker to simulate the filtration process during hydraulic fracturing. Three breaking scenarios were proposed and studied correspondingly. Over balance breaking resulted in higher permeability regain than balance and under balance breaking, which means less formation damage to the near fracture matrix. The short sample has a full recovery of permeability with over balance breaking and it is higher than that with balance and under balance breaking. With over balance breaking, 0.012 wt% breaker recovers 79.5% permeability, and the permeability regain increases with higher breaker concentration. The permeability regain of longer sample is improved, up to 116.3%. With under balance breaking, 0.1 vol% friction reducer shows 81.6% permeability regain. Lower concentration friction reducer achieves a higher permeability regain. The reasons can be attributed to pore blocking effect and wettability alteration introduced by the friction reducer and breaker. The emulsion particle size in the friction reducer solution is found to overlap with the pore size distribution of tightgas sandstone. Therefore, it was able to block the matrix pores in tightsand after treated with the friction reducer and breaker. The contact angle on sample surface was changed from 24.3° to 81.1° in average.

1. Introduction

Tightgas, one type of unconventional resources, possesses huge amount of reserves as green fossil fuel [1,2]. Tightgas sandstone reservoir is the most commonly seen tightgas reservoir. It features low matrix permeability and low porosity [3]. Though it may contain some inborn fissures, the gas production cannot be high enough to have an economic justification. The gas production need to be improved through horizontal well drilling combined with hydraulic fracturing technology [4,5].

Among various hydraulic fracturing methods, slickwater fracturing has been proved to be performed very well by which to increase the production rate of tightgas reservoirs [5–7]. Compared

* Corresponding author.
E-mail address: baib@mst.edu (B. Bai).

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with conventional cross-linked fracturing fluid, this fluid features to be low viscosity, low surface pumping pressure, and little formation damage [8,9]. Water is the major component in slickwater fracturing fluid. Other additives include clay stabilizer, friction reducer, breaker, flowback additive, and etc, usually less than 1 vol% [9–11]. Most of the friction reducers are polyacrylamide-based polymer, usually manufactured as water-in-oil emulsions and added to the fracturing fluids (hydration) ‘‘on the fly” [12–14]. As commonly used breaker, ammonium persulfate generates highly reactive free radicals based on the thermal decomposition of persulfates, which react and break the polymer backbone [15]. At higher temperature, the molecular reaction is faster. Generally, this reaction is faster at temperatures over 125 °F.

During slickwater fracturing, million gallons of friction reducer fluid is pumped downhole to initiate fractures, and lots of fluid would filtrate into formation matrix [16,17]. Due to the small pore size of tightgas reservoir [18], the fluid cannot fully flow back to the ground surface [19–22]. The remaining liquid in fractures and matrix pores has tremendous impact on the gas production [23]. Therefore, the breaking of friction reducer fluid is required to minimize formation damage and improve the conductivity in fracture [24–27]. Previous breaking evaluation of friction reducer used a viscometer to measure fluid viscosity in a beaker which could represent the fluid in bulk condition [26,28], or its behavior in fractures. With a Bossier shale fracture model, after breaking of friction reducer, it shows a permeability regain from 56 to 100% [29]. Since friction reducer works as emulsion with small particle size [8], and the pore size in tightgas sandstone is also very small [30], the friction reducer may have retention in near fracture pore matrix and cause formation damage [26,29]. However, this performance in tightgas porous media is not clear.

In this study, tightsand samples were treated with a friction reducer and a breaker to simulate the filtration process during hydraulic fracturing. Three breaking scenarios were proposed and investigated in detail: over balance breaking, balance breaking, and under balance breaking. Humidified nitrogen flooding system was used to measure the gas permeability before and after the chemical treatment for each sample. Permeability regain, the sample permeability after treated by additives divided by the permeability before that, is calculated based on the measured permeability data. Their permeability regain after each breaking conditions are compared. Various impact factors, such as friction reducer concentration, sample length, breaker concentration are all studied carefully. The emulsion particle size was measured with a dynamic light-scattering particle size analyzer. And the pore size distribution was analyzed with Mercury injection capillary pressure method. The sample surface wettability was examined with contact angle method. With the results from these methods, the reasons for different behaviors after breaking was explained from the points of pore blocking effect and surface wettability alteration.

2. Experimental

2.1. Materials

Rock sample: Sandstones were reservoir cores from tightgas reservoir at Ordos basin, China, was used in this study. In order to prevent the unexpected interaction through the periphery of core sample, epoxy was used to coat the core boundary. Their basic parameters are shown in Table 1. Sample length around 5 mm is defined as short, 10 mm as medium, and 15 mm as long.

Fluid: A commercial friction reducer: FR, a polyacrylamide-based polymer, was used in this study with three concentrations: 0.025, 0.05, 0.1 vol%. Ammonium persulfate was demonstrated to be an effective breaker for this friction reducer, and prepared with three concentrations: 0.012, 0.024, 0.048 wt%. Clay stabilizer, 2% KCl, was used to prepare the former solutions, to minimize the clay from swelling during experiment.

2.2. Equipment

A coreflooding system and a gas permeability measurement system were employed in this study, as shown in Fig. 1and 2. The system mainly consists of a piston pump, an accumulator, a coreholder, a digital pressure gauge, and a gas permeameter. The piston pump was a high-pressure ISCO 500D syringe pump (Teledyne Technologies, Thousand Oaks, CA), provided the fluid driving power, with a flow rate ranging from 0.001 to 204 mL/min. The digital pressure gauge (Keller, Winterthur, Switzerland) measured the pressure over a pressure range of 0–3.1 MPa with an accuracy of ±0.1%. The gas permeameter was an Ultraperm 600 (Corelab, Houston, TX), with permeability range of 0.01–2000 mD.

The coreflooding system was used to simulate how fluids enter formation matrix during hydraulic fracturing. With humidified Nitrogen [16,17], the permeability measurement system was used to measure the gas permeability in tightsand sample when remaining liquid saturation was attained, before and after they were treated by the friction reducer and breaker.

2.3. Procedure

In this study, we are focusing on the breaking of the friction reducer on fracture face and in near fracture matrix, and series steps are designed to simulate this process, as shown in Fig. 3.

Table 1
Basic parameter of tightsand samples and corresponding fluid concentration.

Sample type	Sample No.	Sample length (mm)	K_a (mD)	Friction reducer concentration (vol%)	Breaker concentration (wt%)
Short	TS11	4.02	0.040	0.05	No
	TS28	4.62	0.033	0.025	No
	TS20	5.39	0.039	0.025	No
	TS22	5.42	0.033	0.05	No
	TS21	4.80	0.033	0.1	No
	TS29	4.61	0.020	0.1	0.024, soak
	TS30	4.97	0.028	0.1	0.024, flooding
	TS26	5.00	0.037	0.1	0.012, flooding
	TS27	4.77	0.036	0.1	0.048, flooding
Medium	TS33	10.27	0.031	0.1	No
	TS35	9.34	0.027	0.1	0.024, flooding
Long	TS25	13.08	0.026	0.1	0.024, flooding
	TS34	13.94	0.031	0.1	No