Fuel 131 (2014) 28–35

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Experimental study of friction reducer flows in microfracture

Yongpeng Sun [a], Qihua Wu [b], Mingzhen Wei [a], Baojun Bai [a,*], Yinfa Ma [b]

[a] *Department of Geological Sciences and Engineering, Missouri University of Science and Technology, Rolla, MO 65409, United States*

[b] *Department of Chemistry, Missouri University of Science and Technology, Rolla, MO 65409, United States*

HIGHLIGHTS

- Micro-meter sized fracture models are successfully employed in the study.
- Flow behavior of friction reducer in microfracture is carefully investigated, and compared with that in macro-sized pipeline.
- We analyzed the friction reducer emulsion particle size.
- Fluid impact on shale matrix during slickwater fracturing is discussed.

ARTICLE INFO

Article history:
Received 4 August 2013
Received in revised form 13 April 2014
Accepted 15 April 2014
Available online 1 May 2014

Keywords:
Shale gas
Slickwater fracturing
Friction reducer
Microfracture
Flow behavior

ABSTRACT

Tight formations with extremely low matrix permeabilities, such as gas shale, can produce at economical rates is due to the inborn fissures and fractures introduced during hydraulic stimulation. These microfractures have much more contact area with the matrix and therefore hold the majority of the productivity potential of shale gas. Slickwater fracturing has been proved to be an effective method by which to increase the recovery of shale gas reservoirs. And friction reducer is the primary component of this fluid. However, the flow characteristics of this solution in microfractures are not clear.

Micro-sized fluidic chip was used to represent the microfracture. Friction reducer solution is a shear thinning fluid. Rather than reducing flowing friction, with 0.075 vol% of this fluid flowing in a 1000 μm height, 50 μm width and 4.14 cm length microfracture, the injection pressure increased more than 50%. The impact of the solution concentration was found to be more obvious at low velocities. If a flowback additive is considered for slickwater fracturing, its performance at low velocity or low shear rate would be critical. At the same shear rate, the apparent viscosity is higher in large microfractures. At the same velocity, large microfractures display higher residual resistance factors. Through the analysis of fluid emulsion particle size and gas shale matrix pore size, this friction reducer solution will not go into the matrix pores easily, but can block the pore entrance on fracture face to prevent the fluid from leak off and help pressure build up during slickwater fracturing.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Shale gas reservoir with extremely low matrix permeabilities are producing at economical rates. This can be attributed to the inborn fissures and introduced fractures. Due to the rock mechanical properties of gas shale, hydraulic fracturing can connect and generate these fractures, causing them to be a fracture network than a pair of main fractures. The fracture network will expose more matrix as the number of micro-sized fractures increases [1–5].

Among the various fracturing methods, slickwater fracturing has been proved to be an effective method by which to increase the recovery of shale gas reservoirs [6–8]. By adding a very small amount of chemical to the fluid (<1 vol% of the liquid volume), slickwater fracturing fluid can lower the surface pumping pressure below that achieved with the traditional cross-linked fracturing fluid. This fluid also demonstrates a relatively low viscosity, which significantly reduces the gel damage during hydraulic stimulation. In order to carry proppant in this low-viscosity fluid, high pump rates usually are required. Therefore, the friction along the pipeline could be significant.

Friction reducer (FR) is one of the primary components of this fluid. Most of the common FR are polyacrylamide-based polymer, usually manufactured as water-in-oil emulsions and added to the fracturing fluids (hydration) “on the fly”. Polymers disrupt the near-wall turbulence regeneration cycle and reduce the turbulent friction drag by directly interacting with the vortex, thereby

---

* Corresponding author. Tel.: +1 573 341 4016.
E-mail address: baib@mst.edu (B. Bai).

http://dx.doi.org/10.1016/j.fuel.2014.04.050
0016-2361/© 2014 Elsevier Ltd. All rights reserved.

Nomenclature

a	after FR solution flows
A	cross-sectional area (m^2)
b	before FR solution flows
D	equivalent diameter of microfracture (m)
DI water	deionized water
dP/dL	pressure gradient (MPa/m)
FR	friction reducer
F_r	resistance factor
F_{rr}	residual resistance factor
h	fracture height (m)
k	permeability (m^2)
M	fluid mobility ($m^3/(Pa \cdot s)$)
q	fluid flow rate, m^3/s
Re	Reynolds number
v	fluid velocity (m/s)
x	boundary layer development length (m)

ΔP	pressure drop (MPa)
μ	fluid dynamic viscosity (Pa·s)
γ	shear rate (s^{-1})
ρ	fluid density (kg/m^3)
η_{app}	apparent viscosity (Pa·s)
r	edge radius of the microfracture (m)
υ	fluid kinematic viscosity (m^2/s)
δ	boundary-layer thickness (m)

Unit conversion

1 in.	0.0254 m
1 μm	10^{-6} m
1 md	10^{-15} m^2

decreasing the flow friction in pipeline [9–11]. Flow loop tests in the laboratory [12–21] have addressed this phenomenon well, showing 10–82% friction reductions in the lab, compared with fresh water.

During slickwater fracturing treatment, a pair of main fractures firstly is generated perpendicular to the wellbore direction. As the fluids continue to pump, more microfractures are generated near the main fractures. These microfractures have much more contact area with the shale matrix and therefore hold the majority of the productivity potential of shale gas [1,2,5,22]. However, the flow characteristics of FR solution in these microfractures are not clear.

Microfluidic chips have been widely used in the area of chemistry, biology, microelectromechanical systems, etc. The flowing channel in the microfluidic chip could be manufactured from micrometer to nanometer depth. Therefore, a single straight channel in microfluidic chip with micrometer width and height would act like a microfracture.

The present study investigates how the friction reducer solution flows in microfractures by employing the microfluidic chip model. The fluid flow in microfracture had been extensively examined. A commercial FR was prepared with deionized water at various concentrations. FR solution concentration effect, microfracture size effects, and residual resistance factor to water were investigated in detail. The fluid shear rates and Reynolds number in microfractures also were studied. Then the microfracture experimental results were compared with that in macro tubing. FR solution impact on fracture face, which is shale matrix, also was analyzed. The emulsion particle size in FR solution was analyzed from micrometer to nanometer scale. Then it was compared with the pore size of typical gas shale.

2. Experiment

2.1. Materials

A commercial friction reducer, FR, a polyacrylamide-based polymer, was used in experiment. Four concentrations, 0.025, 0.05, 0.075, and 0.1 vol% were prepared according to industry practice. Deionized (DI) water was used to prepare the FR solution. Microfluidic chip (Micronit, The Netherlands) was bonded with two pieces of glass of 145 μm and 1.1 mm thick, respectively. The channel was etched in the later one with a quarter circles of 50 μm radius on top and bottom of the fracture. Each chip contains 3 separated microfractures with 50 μm width, 1500 μm, 1000 μm, and 500 μm heights, respectively. Fig. 1 shows the microfluidic chip with micro-sized fractures (a) and cross-sectional view of a single fracture (b).

In order to calculate Reynolds number and shear rate, equivalent diameter was introduced. The area of equivalent circle is the same with the microfracture cross-sectional flowing profile. Equivalent diameter is the diameter of this circle, as listed in Table 1. Since microfractures were not of equal length, pressure gradient is used in the Results and Discussion part.

2.2. Equipment

The apparatus used in the experiment consisted of a pump, a digital pressure gauge, two non-piston accumulators, microfluidic chip inlet assemblies, and a data acquisition system, as shown in Fig. 2. 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 microfracture inlet pressure over a pressure range of 0–3.1 MPa with an accuracy of ±0.1%. To minimize the friction in the flow line, two non-piston accumulators (Swagelok, Solon, OH) were used. Decane (Fisher Science, Waltham, MA), a nonpolar liquid that will not dissolve in water, was employed to fill the pump so that it could work as a driving fluid to push the DI water and FR solution, respectively, from the accumulators into the microfractures. A 250 μm inner diameter capillary was used to connect the 1/8″

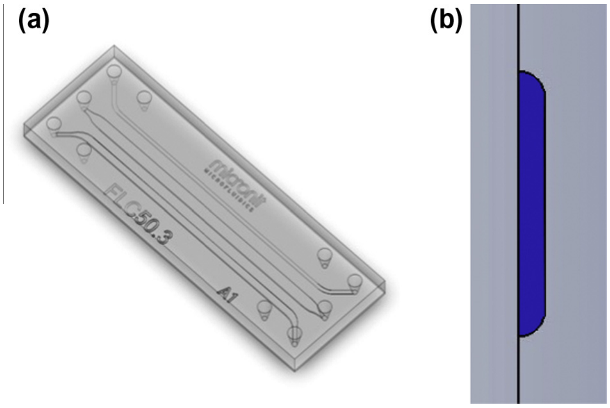

Fig. 1. Microfluidic chip with microfractures (a) and cross-sectional view of a single fracture (b).

Download English Version:

https://daneshyari.com/en/article/206218

Download Persian Version:

https://daneshyari.com/article/206218

Daneshyari.com