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# Effect of polymer on disproportionate permeability reduction to gas and water for fractured shales

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## HIGHLIGHTS

- Six shale fracture models with different fracture widths were fabricated.
- A method by which to calculate the residual resistance factor for gas was defined.
- Polymer can selectively reduce the permeability to water more than to gas.
- The $F_{rr,water}$ and $F_{rr,gas}$ tended to decrease as the fracture width grew.
- Polymer treatment does not impair gas flow, and may even improve it.

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## ABSTRACT

Large volumes of fracturing fluid are required in shale slickwater fracs, and a considerable amount of polymer friction reducer would remain in microfractures if the polymer has not been broken before gas production. It is of major interest to evaluate the effect of polymer on water/gas flow behavior in the microfractures of shale reservoirs. We fabricated six shale fracture models with different fracture widths and set up a core flooding apparatus to conduct brine/gas-injection experiments before and after polymer treatment. A method by which to calculate the residual resistance factor for gas ($F_{rr,gas}$) was defined. The experimental results illustrate that polymer can reduce the permeability to water more than to gas. In the first cycle of brine/gas injection experiments after polymer treatment, the residual resistance factor for brine ($F_{rr,water}$) and $F_{rr,gas}$ exhibited power-law characteristics through their shear rate and superficial gas velocity, respectively. The $F_{rr,water}$ and $F_{rr,gas}$ tended to decrease as the fracture width grew. Surprisingly, polymer treatment does not impair gas flow in wider fractures, and may even improve it. The mechanisms responsible for disproportionate permeability reduction (DPR) in the fractured shales were proposed in this paper.



## 1. Introduction

The great success of shale gas in the U.S. has changed the global energy situation. Accepted estimates show that shale gas production will increase from 9.7 Tcf (trillion cubic feet) in 2012 to 19.8 Tcf in 2040, acting as the largest contributor to the increase in the total natural gas production in the U.S. Correspondingly, the percentage of shale gas making up the total natural gas production in the U.S. will grow from 40% in 2012 to 53% in 2040 [1]. Because a shale matrix has low porosity and ultra-low permeability of $10^{-8}$–$10^{-4}$ mD, producing shale gas economically depends primarily upon hydraulic stimulation [2–4]. Hydraulic stimulation can generate fractures that connect with inborn fissures to create a fracture network, thereby exposing more of the shale matrix to stimulate gas production [5–7].

With the advantage of reducing both costs and formation damage, slickwater fracturing is an effective stimulation method applied most widely to improve production performance and economics in shale gas reservoirs [8–9]. In 1997, Devon Energy successfully introduced large-volume slickwater treatments into the Barnett shale, rather than cross-linked fracture treatments. Due to the lack of gel solids in the fracturing fluid, longer and more complex fractures formed, and no gel residue or filter cake was left

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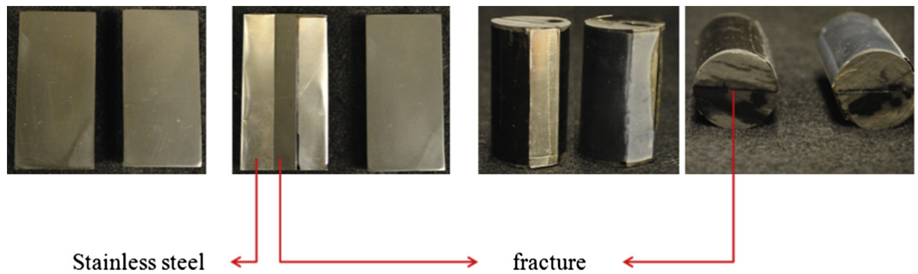


**Fig. 1.** Shale fracture models used in the experiment.

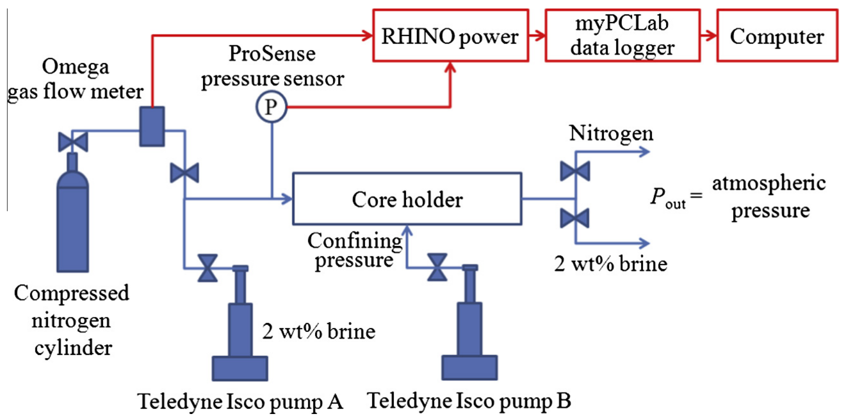


**Fig. 2.** Diagram of shale fracture model experimental setup.

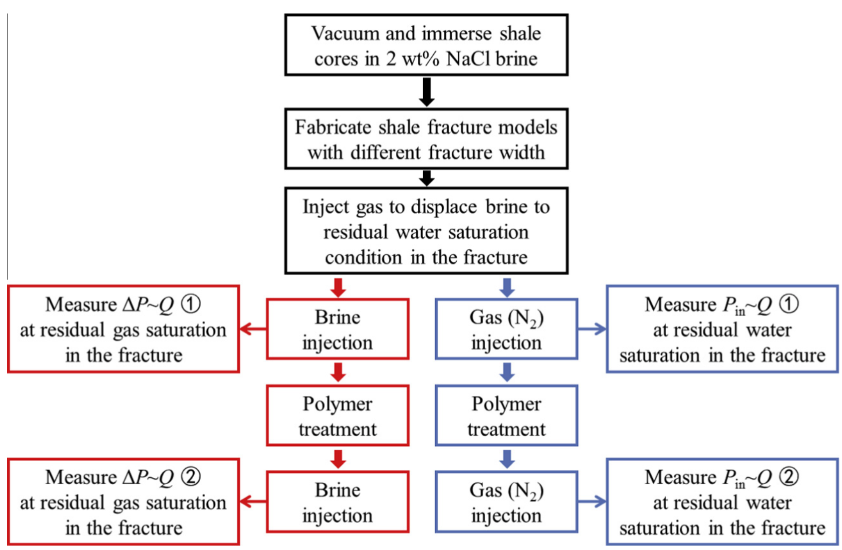


**Fig. 3.** Flow chart of experimental procedure.

to damage the fracture conductivity [10]. However, slickwater fracturing provides poor proppant transport and limited stimulated reservoir volume due to the low viscosity of the fracturing fluid. To compensate for this disadvantage, high pump rates that may exceed 100 bbl/min are usually required to carry proppant in the fracturing fluid. A considerable amount of energy loss occurs due to the turbulence of the fracturing fluid, and additional pumping pressure is required to achieve the desired treatment [11–16]. Therefore, friction reducers serve as one of the primary additives in slickwater fracturing fluid to reduce the fluid friction associated with high pump rates.

The most common friction reducers are polyacrylamide based and usually are anionic, cationic or nonionic [17–18]. A friction reducer can modify the mean velocity profile in pipelines and redistribute the shear in the boundary layer. As a result, the near-wall structure of the turbulent boundary layer changes significantly to minimize energy loss via the polymer friction reducer interacting with eddies of turbulent flow [19–22]. The friction reducer is loaded into the slickwater fracturing fluid at a concentration of 0.25–2 gpt (gallon per thousand gallons), thereby reducing the friction in the wellbore by as much as 80% compared with fresh water [20,21,23–26]. The current practice is to use breakers