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ORIGINAL RESEARCH

Preformed particle gels of sulfonated polyacrylamide: preparation, characterization, and application as permeability modifier

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Abstract

In this study, a preformed particle gel (PPG) was synthesized from sulfonated polyacrylamide and chromium metal cross-linker with specific concentration. The main characteristics of PPG, such as gelation time, gel fraction, swelling properties and salt sensitivity factor were investigated. The gel fraction of 94.1% practically indicated an appropriate conversion of gelant to the gel. The equilibrium swelling ratios of particle gels in distilled water and formation water at 80 °C were 470.49 and 12.61, respectively. Additionally, the rheological properties of gel were studied by a dynamic rheometer. The ultimate storage modulus of gel was measured 35.4 kPa. The linear viscoelastic behavior was observed at strain between 1 and 82.6% and gel structure was stable up to strain of 1120% with small reduction of storage modulus. The kinetics of gelation were also studied at different temperatures and tested against Avrami equation to determine the kinetic parameters. The Avrami exponents for two kinetic steps were about 2.29 and 0.80, respectively, indicating the rapid formation of the gel network at first step due to nucleation and two-dimensional growths of gel nuclei. Furthermore, a core flooding experiment was conducted to study PPG performance in porous media. The residual resistance factor of water and oil was 41.58 and 12.91, respectively. A value of 3.22 for the ratio of these two factors indicated the ability of the synthesized PPG to decrease water-effective permeability compared to oil-effective permeability in porous media.

Keywords Preformed particle gels · Swelling · Gelation kinetics · Rheology · Conformance control

List of symbols

C	Inverse of the initial swelling rate (s/g)
D	Inverse of the maximum water uptake (1/g)
DPR	Disproportionate permeability reduction index
D_{th}	Pore throat diameter (μm)
E_a	Activation energy (cal/mol)
ESR	Equilibrium swelling ratio in distilled water (g/g)
ESR_e	Equilibrium swelling ratio in formation water (g/g)
G^*	Complex modulus (Pa)
G'	Storage module (Pa)
G''	Loss module (Pa)
K	Overall gelation rate constant ($1/s^n$)
K_{abs}	Absolute permeability (D)
K_s	Kinetic rate constant of swelling (1/g s)
k_o	Oil-effective permeability (D)
k_w	Water-effective permeability (D)
M	Water uptake at time t (g)
n	Avrami exponent
R	Universal gas constant (cal/mol K)
RRF	Residual resistance factors
SSF	Salt sensitivity factor
T	Absolute temperature (K)
t	Time (s)
W_0	Mass of the dry gel (g)
W_s	Mass of the swollen gel (g)
X	Conversion
μ	Viscosity (Pa s)
μ^*	Complex viscosity (Pa s)
ω	Frequency (rad/s)
φ	Porosity

Introduction

Excess water production is an important problem in mature oil fields that increases the capacity of fluid handling equipment and the levels of corrosion. It also results in

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