Using transparent gelatin as a reservoir analogue in laboratory experiments on hydraulic fracturing

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1 Introduction

Gelatin in its solid state can be used as a rock analogue for studying hydraulic fracture growth in reservoir formations. A polypeptide formed through the hydrolytic degradation of collagen, gelatin is classified as a “physical gel” (Kavanagh et al., 2013). Van der Waal’s forces (reversible by temperature and pH changes) lead to the development of a complex lattice of interconnected macromolecules, responsible for a viscoelastic behavior during deformation (Kavanagh et al., 2013). Hence, gelatin displays an elastic behavior when subjected to high-stress loads over a short time-period and viscous behavior when low-stress loads are applied over a longer time-period. In Michael (2021), laboratory testing was performed on specimen blocks of edible Knox® Gelatin mixed with water in high concentrations (7-8%-by-weight). Gelatin’s properties under the experimental design used made it comparable to rock formations, considering the physics of fracture propagation, as determined by analog scaling, with its transparency enabling visual observation of fracture growth.

2 Mechanical Properties and Specimen Preparation

Gelatin is brittle, with low Young’s modulus, E , which results in low formation breakdown pressures making fracture initiation in gelatin specimens fairly easy. Kavanagh et al. (2013) developed empirical correlations for estimating some of the mechanical properties of gelatin at various mixing concentrations. Table 1 displays key mechanical properties for 7-8%-by-weight gelatin at 10°C, as used in Michael (2021) – shown on Figure 1.

The mechanical properties summarized on Table 1, allow gelatin to be adequately scaled with reservoir rock, considering governing equations for fluid-driven, tensile fracture propagation in a solid, linearly-elastic medium (de Pater et al., 1994). Additionally, gelatin’s transparent color allows observation of the fracture growth, (driven by a distinctly-colored fluid) giving insights on hydraulic fracturing mechanics in reservoir rocks.

Fig. 1: Hydraulic fracturing experiment on a gelatin block (from Michael, 2021).

Table 1: Mechanical properties of 7-8%-by-weight gelatin at 10°C (after Kavanagh et al., 2013).

	Symbol	Value	Unit
Young’s modulus	E	37.2	kPa
Poisson’s ratio	ν	< 0.5	[-]
Critical stress intensity factor (Mode I)	K_{IC}	274	$\text{Pa}\sqrt{\text{m}}$

3 Analog Scaling with Field Operations

Laboratory experiments are ideally made using analogue material which obeys geometric, kinematic and dynamic similarity with its natural counterpart (Hubbert, 1937). Hence, results from such experiments can be used to understand and predict the behavior of the natural system. A set of dimensionless groups was developed by de Pater et al. (1994) to enable comparisons between lab and field-scale. Eq. (1) through (4) describe four such dimensionless groups:

- (1) Experimental time, $N_t = \frac{qt}{r_w^3}$
- (2) Crack formation energy, $N_r = \frac{K_{IC}^2}{4G^2 r_w}$
- (3) Elastic deformation, $N_G = \frac{Gr_w}{q\mu_{eff}}$
- (4) Confining stress, $N_{\sigma_c} = \frac{\sigma_c}{G}$

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where q is the fluid injection flow rate, t is the injection time period, r_w is the wellbore radius, K_{IC} is the Mode I fracture toughness, $G = \frac{E}{4(1-\nu)}$ is the shear elastic modulus, μ_{eff} is the effective viscosity and σ_c is the confining stress. The closer the lab-to-field ratio for each dimensionless group is to one, the better the scaling is in terms of the physics of fracture propagation. When compared with a typical field-scale crosslinked gel hydraulic fracture treatment, scaling analysis using Eqs. (1) through (4) yields reasonable lab-to-field dimensionless group ratios for N_{σ_c} and N_t (Table 2). However, these experimental results may be slightly biased towards emphasizing the effects of fracture toughness over the viscous fluid effects, due to poorer scaling ratios for N_r and N_G (Table 2) with μ_{eff} and K_{IC} imposing respectively lower and higher impacts in laboratory conditions used in the experiments, compared to field-scale operations.

4 Comparison Against Other Transparent Reservoir Analogue Materials

Transparent urethane plastic was considered for specimen material in Michael (2016), but was rejected due to its high K_{IC} value, which makes it less brittle for the purposes of the study. Polymethyl methacrylate (PMMA) was also rejected due to its high tensile strength (70 MPa), which exceeded the capabilities of the lab equipment. Michael (2016) noted that from the preliminary testing comparisons, gelatin showed better adhesion to the aluminum “wellbore” tube than PMMA and urethane plastic, suppressing leakages along the interface between the specimen and the wellbore. Table 3 compares urethane plastic, PMMA, and gelatin (7-8%-by-weight) as reservoir analogues.

References

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Table 2: Scaling analysis between laboratory testing on gelatin (Michael, 2021) and a typical field-scale hydraulic fracture treatment with crosslinked gel.

Dimensionless group	Experimental time, N_t	Confining stress, N_{σ_c}	Elastic deformation, N_G	Crack formation energy, N_r
Lab-to-field ratio	0.01	6.0	1.1×10^{-4}	8.5×10^4
Magnitude orders apart	2 (good)	1 (better)	4 (poor)	5 (poorer)

Table 3: Relative comparison between urethane plastic/PMMA/gelatin (7-8%-by-weight) as reservoir analogues in hydraulic fracture lab tests (from Michael, 2016).

	Transparency	Low fracture toughness (K_{IC})	Low tensile strength	Price affordability
Urethane plastic	✓	✗	✓	✗
PMMA	✓	✓	✓	✗
Gelatin (7-8%-by-weight)	✓	✓	✓	✓