Energy Proceedings
Vol 42, 2024
ISSN 2004-2965

Proposing a Novel Reusable Fracturing Fluid for Tight Sandstone Fracturing in the Changqing Gas Field: Environmental and Economic Implications

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ABSTRACT

In the Changqing gas field, fracturing fluid plays a pivotal role in the development of tight sandstone fracturing. However, its extensive usage and single-use nature have led to environmental concerns and resource wastage. Traditional fracturing fluids lack the capability for multiple recycling, underscoring the imperative for a fracturing fluid system that not only meets performance criteria but also facilitates recyclability. This study introduces a fracturing fluid formulated from exopolysaccharides complemented with Carboxymethyl Cellulose and Benzenesulfonicacid, to address this reusability challenge. Experimental evaluations were conducted on both the fresh fracturing fluid prepared with clean water and the reusable fracturing fluid formulated with returned post-fracture fluid. Results indicate that the fluid aligns with the Changqing gas field's stipulated criteria for apparent viscosity, gel breaking, and reservoir protection. A field trial involving 5,690 m³ of fracturing fluid yielded a recovery of 5,357 m³, translating to a remarkable 94.15% recycling efficiency. The potential for recycling this fluid offers substantial environmental and economic advantages, including water conservation, diminished waste fluid emissions, and the promotion of eco-friendly, sustainable production methodologies.

Keywords: Gas wells, Reusable fracturing fluid, Clean and recyclable, Fracturing

NONMENCLATURE

Abbreviations	
CMC	Carboxymethyl Cellulose
CMC_I	Critical micelle concentration

1. INTRODUCTION

Tight gas fields, characterized by their low permeability, often necessitate the application of fracturing technology to augment permeability, thereby enhancing gas flow and extraction[1]. This is particularly evident in regions such as the Changqing area. The primary reservoirs of the Changqing Sulige gas field, namely the Shanxi Formation and Changqing Shixiang Formation. Reservoir characteristics have low permeability $0.5\sim3.0\times10^{-3}$ μm², large porosity change 4.0 %~13.0 %, low pressure coefficient 0.8~0.9 MPa/100m, reservoir depth 2500~3700 m, the formation temperature is high 76-113 °C[2].

Fracking fluid plays a pivotal role in the fracking process, serving as a medium for rock transportation and pressure transmission. However, it also presents challenges. Notably, the fluid can introduce reservoir contamination[3], leading to complications such as water lockup[4]. A pressing concern is the voluminous quantity of fracturing fluid utilized, typically employed for a singular use, after which it is discarded. This practice results in substantial environmental contamination. Therefore, it is hoped that as much of the fracturing fluid can be recovered from the formation as possible and can be put into use to reduce pollution.

Dai et al. endeavored to optimize the conventional guar gum fracturing fluid, primarily emphasizing the enhancement of the fracking fluid backflow rate. However, their approach did not encompass the reuse of the fracturing fluid post-reflow[5,6]. Conversely, Wan et al. employed catalysts to treat fracturing wastewater, an approach that inadvertently escalates treatment expenditures[7,8]. Some better examples of recovered fracturing fluids include Wood achieved a recovery rate

This is a paper for 15th International Conference on Applied Energy (ICAE2023), Dec. 3-7, 2023, Doha, Qatar.

of 9% to 35% for recycled fracturing fluids. Yoxtheimer reported an average well recovery rate of 10% for return fluids in the Marcellus. In the Eagle Ford, the recovery rate of fracturing fluids is less than 15%. In summary, the existing recovery rate for recyclable fracturing fluids is not high, and there are requirements for fracturing performance to be met when fracturing fluids are recycled for reuse. Some catalysts are used to adjust the water quality to ensure that the recovered fracturing fluid can be reused.

Given these challenges, this article utilizes a composite of two exopolysaccharides sourced from Pseudomonas adaceae to develop a type of reusable fracturing fluid, characterized by low damage and high recovery rates. This colloidal removes the water quality requirements for the recovered fracturing fluid. The formulation and deployment of reusable fracturing fluids offer significant environmental and economic advantages. The reuse of fracturing fluids can mitigate environmental hazards while simultaneously offering cost-effective solutions for the petroleum industry.

2. MATERIAL AND METHODS

2.1 Design principles of reusable clean fracturing fluid

The study introduces a clean fracturing fluid formulation, which utilizes a composite of exopolysaccharides derived from Pseudomonas adaceae in conjunction with Carboxymethyl Cellulose (CMC) and Benzenesulfonicacid as its primary thickening agent. Upon interaction with water, the fracturing fluid transforms into a colloid. This transformation is driven by a combination of primary valence forces, secondary valence forces, electrostatic forces, and mechanical forces at the molecular level[9]. As the concentration of the thickener increases, there is a marked escalation in the viscosity and elasticity of the solution, enabling it to form a sand-carrying colloid. This colloid can be reconstituted multiple times. The underlying mechanism of the thickener's interaction with water is illustrated in Fig. 1.

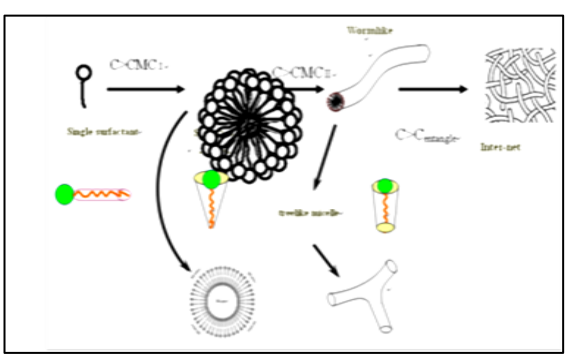

Fig. 1. Thickening mechanism of the thickener

Post-fracturing, a process termed "glue breaking" is necessitated. The glue breaker is formulated from hydrolyzed polysaccharides specific to the thickener and is a blend of natural and molecularly modified enzymes. This agent induces targeted mutations in the molecular structure of the thickener, prompting enzymes to undergo specific reactions. This results in the formation of novel, non-native disulfide bonds, ensuring complete glue degradation without compromising the cross-linked structure of the thickener. This facilitates the re-gelling of the broken solution, allowing for its reuse. Moreover, by modulating the quantity of the glue breaker, the glue breaking duration can be precisely controlled, catering to on-site operational requirements.

2.2 Experimental verification method

Key attributes of the fracturing fluid, such as its thickening duration and apparent viscosity, are fundamental to ensure its efficacy in rock carrying and energy transfer. The glue breaking capability, residual content, and potential reservoir damage are critical metrics to assess the likelihood of reservoir contamination by the fracturing fluid.

For the reusable fracturing fluid delineated in this study, a pivotal evaluation criterion is its ability to be reconstituted post-use, maintaining its original performance characteristics. Consequently, the backflow fluid, post-collection, was reconstituted and its performance re-evaluated.

3. RESULTS AND DISCUSSION

3.1 Performance of fresh fracturing fluid

To ascertain that the reproducible fracturing fluid aligns with fracturing requirements when using the clean water configuration for the first time, we evaluated its thickening time, apparent viscosity, gel breaking performance, and residue content

3.1.1 Fundamental performance

A clean fracturing fluid at a concentration of 3.0% was prepared and rapidly agitated. The resultant fluid exhibited a thickening time of 10 seconds and appeared as a viscous, milky-white liquid with a pH of 7. Using a six-speed rotational viscometer at ambient temperature, the apparent viscosity of the fluid was determined to be 48.0 mPa·s at 100 r/min.

3.1.2 Gel breaking performance

The efficacy of fracturing and subsequent production enhancement is intrinsically linked to the timely breaking and drainage of the injected fluid. We experimentally assessed the viscosity and surface and interfacial tensions of the gel-breaking liquid at 90℃ with varying concentrations of gel-breaking agents. The results are tabulated in Table 1.

Table 1 *Viscosity of the gel-breaking solution with different concentrations of gel-breaking agent.*

Time/min	Viscosity under different mass /mPa·s			
	0.4%	0.6%	0.8%	0.9%
30	4.39	3.38	3.85	3.35
60	4.15	2.85	2.08	1.92
90	4.15	2.47	1.36	1.30
120	4.01	2.01	1.37	1.16

3.1.3 Solid residue content

The particle size distribution in the fracturing fluid (glue breakage) after measuring the broken glue is shown in Fig. 2.

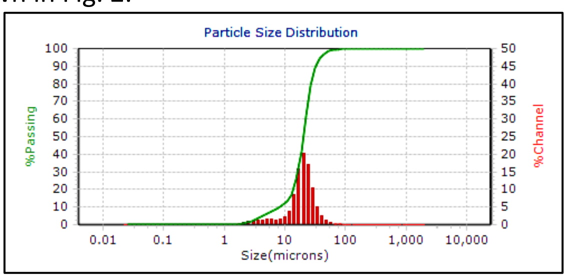

Fig. 2 Particle size distribution of fresh gel-breaking solution.

Data indicates a median particle size of 19.46 μm for the broken gel, with 95% of particles measuring less than 40 μm. This suggests minimal risk of reservoir blockage due to fracturing fluid residues. Additionally, the measured residue content was a mere 16 mg/L, significantly lower than conventional guanidine gel-breaking solutions, implying minimal reservoir impact.

3.2 Performance of reproducible fracturing fluids

Post-fracturing, the backflow fluid was collected and assessed for its reusability.

3.2.1 *Fundamental performance of reproduced fluid*

Upon agitation of the returned fluid, Fig. 3 illustrates that the agitated fracturing flowback fluid is a yellow, turbid liquid. Typically, such fluids from fracturing operations require treatment through flocculation and the addition of water quality regulators before they can be repurposed for fracturing fluids. However, in this study, as depicted in Fig 4, the fracturing flowback fluid is directly utilized for preparing new fracturing fluids.

Fig. 3 *Appearance of fracturing fluid post-gel breaking*.

Fig. 4 Clean fracturing fluid with a glue breaker configuration

Samples were formulated into a bio-clean fracturing fluid at concentrations of 3.0% and 4.5%. Both formulations exhibited a pH of 7, with apparent viscosities of 43.5 mPa·s and 57.0 mPa·s, respectively.

3.2.2 Gel breaking performance of reproduced fluid

Reproduced fracturing solutions at concentrations of 3.0% and 4.5% were evaluated. Within 30 minutes, the viscosity of both solutions reduced to below 5.0 mPa·s, indicating the reconstituted fracturing fluid's capability to effectively break the gel[10].

3.2.3 Solid residue content of reproduced fluid

The residue content of the reconstituted fracturing fluid at concentrations of 3.0% and 4.5% is illustrated in Fig. 5 and Fig. 6.

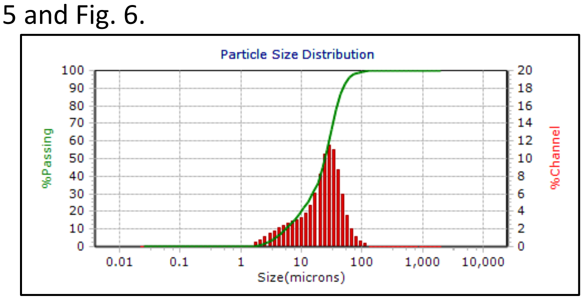

Fig. 5 *Particle size distribution for 3.0% concentration post-gel breaking.*

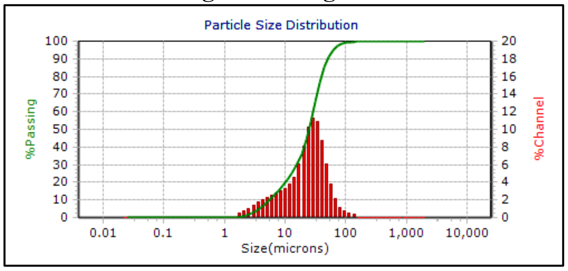

Fig. 6 *Particle size distribution for 4.5% concentration post-gel breaking*

The solid content measured 145 mg/L and 157 mg/L, with median particle sizes of 24.12 µm and 24.41 µm, respectively. 90% of the residue particles were below 50 µm. These metrics, albeit slightly elevated compared to the fresh fracturing fluid, suggest that residues from the reconstituted fluid can be efficiently expelled from the reservoir[11].

To compare the performance of this paper, compared with the existing fracturing fluids, as shown in Table 2, the fracturing fluids in this paper have more advantages in terms of glue breaking time and reduce the degree of frictional resistance. In terms of residue content and median particle size, xytj-1 and xyzc-6 residues have lower content and smaller particle size. One of the reasons for this is that both fracturing fluids need to be adjusted with a water conditioner, which has removed impurities from the water. The fracturing fluids in this paper are not treated, but the purpose of discussing the degradation residues is to discuss whether the residues are causing reservoir damage. Compared with the reservoir protection capacity, the fracturing fluid in this paper has the characteristics of low damage.

Table 2. Swept area variation of the first-round implementation for the PWIS method

Types of fracturing fluids	Gel breaking ability	Reduce the degree of frictional resistance	Residue content	Median particle size	Reservoir protection capacity	Whether water quality needs to be adjusted
XYTJ-1	60min	67%	12mg/L	34.08µm	6.7	need
XYZC-6	60min	—	2mg/L	18.63µm	7.55	need
Hydroxypropyl guar	—	\	243mg/L	—	27.93	—
EM50	—	19%			11.48	need
Fracture fluid in this article	30min	87%	151mg/L	24.27µm	5.03	no

4. APPLY EFFECTS ON THE OIL FIELD

In Changqing Oilfield, the fracturing fluid proposed in this paper is used for fracturing operations, and the fracturing fluid is prepared to other wells for fracturing after flowback. Table 3 shows the statistics of the use of the fracturing fluid in the field, in which the field application is mainly divided into three blocks. In the Su-central and Su-west blocks, the recovery rate is high, reaching more than 60%, and all the recovered fluid can be used for fracturing fluid preparation. However, in Su-east, due to the acidification engineering process in the fracturing process, such as SD1SD2SD3 wells, part of the fluid flowback after acidification is acidified liquid, which cannot be used, resulting in a decrease in recovery rate and reuse rate. A cumulative volume of 5,690 m^3 of backflow fluid was recovered, out of which 5,357 m^3 was successfully repurposed, resulting in a recovery and reuse efficiency of 94.15%.

Compare the use of other types of fracturing fluids on site. A total of 30,300 m^3 of EM50 fracturing fluid was injected in Changqing area, with a cumulative recovery volume of 12,470 m^3 and a Flowback rate of 41.15%. The fracturing fluid has a reusable volume of 11,540 m^3 and a reuse rate of up to 92.50%. XYZC-6 has a better recovery rate, injecting 13,200 m^3 in Changqing area, recycling 7,814 m^3, with a recovery rate of 59.20%, However, only 6,832 m^3 of fracturing fluid can be reused, its reuse rate is about 87%. Comparatively, the fracturing fluid in this paper has better performance in terms of recovery and reuse rate. At the same time, the absence of water treatment agents also reduces the treatment process of the recovered liquid, further simplifying the procedure.

Table 3. The application and recovery of the fracturing fluid in oilfield blocks

Region	Well	Injected volume/m^3	Recovery volume/m^3	Flowback rate/%	Reuse volume/m^3	Reusability /%
Su-east	SD1	721	320	44.38	320	100
	SD2	842	450	53.44	320	71.11
	SD3	712	320	44.94	242	75.6
	SD4	835	410	49.10	285	69.51
	SD5	611	250	40.92	250	100
Su-central	SZ1	550	300	54.55	300	100
	SZ2	2574	1910	74.20	1910	100
Su-west	SX1	2552	1730	67.79	1730	100
Total	\	9397	5690	60.55	5357	94.15

5. CONCLUSIONS

Upon evaluating laboratory-based fluid performance metrics and field construction data, the following conclusions have been deduced:

The formulated clean fracturing fluid exhibits prompt gel-breaking capabilities and minimal reservoir damage potential. Field trials have demonstrated that the bio-clean fracturing fluid, at a concentration of 3.0%, possesses commendable rheological attributes, sand suspension stability, and reduced operational friction. These characteristics render it suitable for the specific demands of fracturing operations in the Changqing gas field. Furthermore, The fracturing fluid has a recovery rate of more than 60% and a reuse rate of 94.15% in practical applications, and does not require other treatment measures, which is environmentally friendly.

The recyclable nature of this fluid presents significant environmental and economic benefits. It can contribute to water conservation, diminish waste fluid discharge, and promote cleaner, more sustainable production practices. Given these advantages, the fluid holds substantial promise for broader adoption and application in the industry.

Future research endeavors should focus on enhancing the long-term preservation of the clean fracturing fluid, bolstering its resistance to acidic contaminants, and ensuring its immediate readiness for deployment in any requisite fracturing well.

ACKNOWLEDGEMENT

Thanks to China National Petroleum Corporation for providing on-site technology application opportunities.

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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