SPE-225819-MS
Significant Phase Behavior Changes in Chemically Treated Oil During CO2 Injection

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Introduction

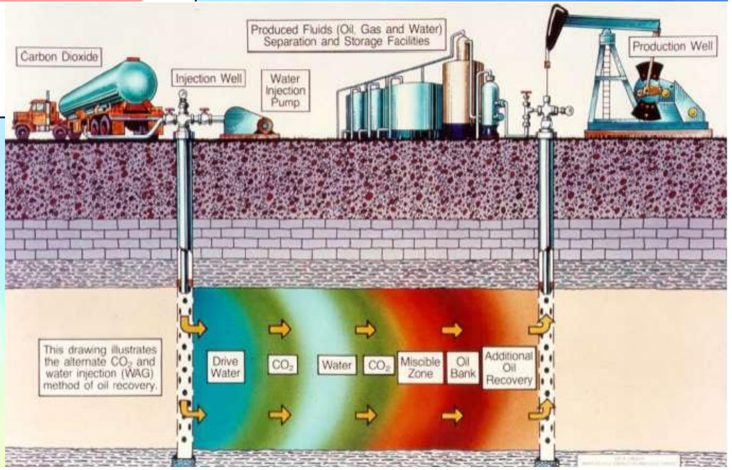
Enhanced oil recovery (EOR) can be achieved through various methods, including water flooding, gas injection, and chemical flooding. In response to climate change and the need to mitigate CO_2 emissions, Carbon Capture, Utilization, and Storage (CCUS) has emerged as a widely adopted mitigation strategy. Within this framework, CO_2-Enhanced Oil Recovery (CO_2-EOR) plays a dual role in both reducing emissions and increasing oil production. Under appropriate temperature and pressure conditions, injected CO_2 can become miscible with reservoir fluids (such as crude oil and water), enabling efficient miscible displacement and significantly improving oil recovery.

This study focuses on laboratory investigations integrating CO_2 injection with chemical additives. The effects of oil-based and water-based chemical additives on saturation pressure, CO_2 solubility, and minimum miscibility pressure (MMP) are evaluated using PVT phase behavior analysis and slim tube displacement experiments. The results demonstrate the potential of these additives to improve CO_2-EOR performance under reservoir conditions where natural miscibility cannot be achieved.

EOR Technologies

- **Mobility - Control**
  - Polymer-augmented waterflood
- **Thermal:**
  - Cyclic Steam stimulation
  - Steamflooding
  - SAGD
  - Hot waterflooding
  - In-situ combustion
- **Miscible** - CO_2, Hydrocarbon, flue gas, N2 flooding
- **Chemical**
  - Micellar/polymer flooding
  - Alkaline flooding
- **Microbial**

CO_2 Flooding （WAG）



CCUS： CO_2-Enhanced Oil Recovery (CO_2-EOR) plays a dual role in both reducing emissions and increasing oil production.

Experiments

The crude oil sample used in this study, designated as JL2, was sourced from the Karamay Oilfield, Xinjiang, China.

Additive A – an oil-soluble formulation

- # Additive B – a water-soluble formulation

1. NIRPVT-1500, Black Oil PVT System

100MPa/0.1% Full range

150°C/±1°C

250ml/0.01ml

2. ST-1000, Slimtube Apparatus

Inner diameter of 0.4 cm

Total length of 2000 cm

Pore volume of 251.2 cm^3

3. Infrared Imaging Captures Experiment

An Infrared High-Pressure Optical Cell (IRHPOC) was employed to capture infrared images of CO_2–crude oil interactions under simulated reservoir conditions.

Reservoir and Fluid Properties

Table 1. Parameters of reservoir temperature, pressure and gas-oil ratio

	Reservoir T (°C)	Reservoir P (MPa)	Bubble point P (MPa)	GOR (m^3/m^3)
J L 2 oil	97	50.12	31.09	130.3

Table 2. Composition of Natural Gas

Component	Content (mol%)	Component	Content (mol%)
Methane	93.58	i-pentane	0.16
Ethane	2.57	n-pentane	0.16
Propane	1.04	n-heptane	0.06
i-butane	0.30	N2	1.73
n-butane	0.38	CO2	0.02

Results and Discussion

Table 3. PVT analysis results of JL2 crude oil under different concentrations of injected CO_2

Concentration of injected CO_2	GOR	Flash oil density	Saturation pressure	Rolling ball viscosity*	Critical temperature Tc	Critical pressure Pc
vol%	m³/m³	g/cm³	MPa	mPa·s	℃	MPa
0.0000	138.50	0.8949	45.80	6.54	333.73	45.71
4.6977	183.20	0.8924	46.20	6.41	324.77	47.10
12.5754	269.70	0.8899	47.90	6.19	295.55	52.70
17.7749	289.00	0.8874	51.90	5.98	274.01	55.33
27.0553	299.70	0.8826	55.20	5.64	234.65	57.83

Table 4. PVT analysis results of JL2 crude oil with oil-based chemical additive under different concentrations of injected CO_2

Concentration of injected CO_2	GOR	Flash oil density	Saturation pressure	Rolling ball viscosity*	Critical temperature Tc	Critical pressure Pc
vol%	m³/m³	g/cm³	MPa	mPa·s	℃	MPa
0.0000	117.70	0.8907	33.6000	5.06	338.55	34.42
11.5009	186.50	0.8880	36.2800	3.75#	315.00	45.16
27.2466	366.40	0.8855	48.9000	4.09	227.64	56.68
43.5380	599.80	0.8824	60.2200	3.78	215.18	56.36

*Rolling ball viscosity: average viscosity measured above the saturation pressure.
#Rolling ball viscosity: questionable data.

Results and Discussion

Table 5. PVT analysis results of JL2 crude oil with water-based chemical additive under different concentrations of injected CO_2

Concentration of injected CO_2	GOR	Flash oil density	Saturation pressure	Rolling ball viscosity*	Critical temperature Tc	Critical pressure Pc
vol%	m³/m³	g/cm³	MPa	mPa·s	℃	MPa
0.0000	110.90	0.8909	31.0000	5.37	365.11	30.86
13.1828	193.80	0.8898	39.8600	3.86	292.10	45.82
27.0373	318.60	0.8864	50.9000	3.91#	245.10	55.08
33.3193	390.90	0.8842	55.4000			

*Rolling ball viscosity: average viscosity measured above the saturation pressure.
#Rolling ball viscosity: questionable data.

1. Chemical Additives Alter Crude Oil Properties Prior to CO_2 Injection

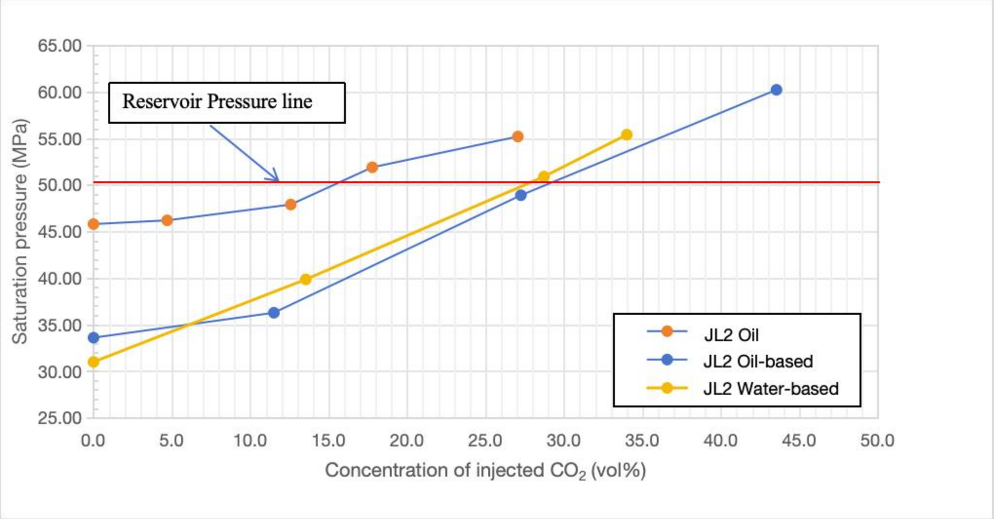


Fig. 1 Relationship of concentration of injected CO_2 with saturation pressure, JL2 oil, and chemically treated JL2 oil.

Results and Discussion

2. Improved Asphaltene Stability Under CO_2 Exposure

Table 6. Data Comparison of Continuous CO_2 Injection into Oil Without and With Chemical Additives

JL2 Oil	Reservoir P (psi)	Oil vol (ml)	Injection CO2 vol (ml)	Injected Vol (%)	Max Injection Vol (ml)	Max Vol (%)
Without chemical additive	7267	33.89	4.65	12.07	7.35	17.82
5% oil-based additive	7267	30.09	9.50	24.00	13.50	30.97
30% water-based additive	7267	30.24	8.60	22.14	10.10	25.04

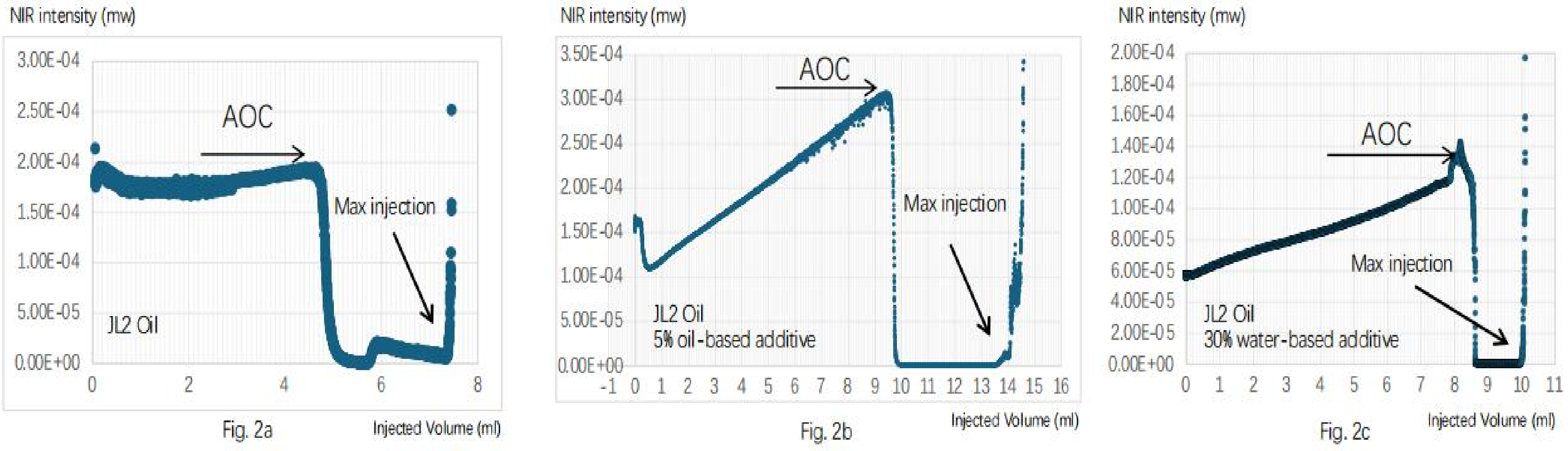
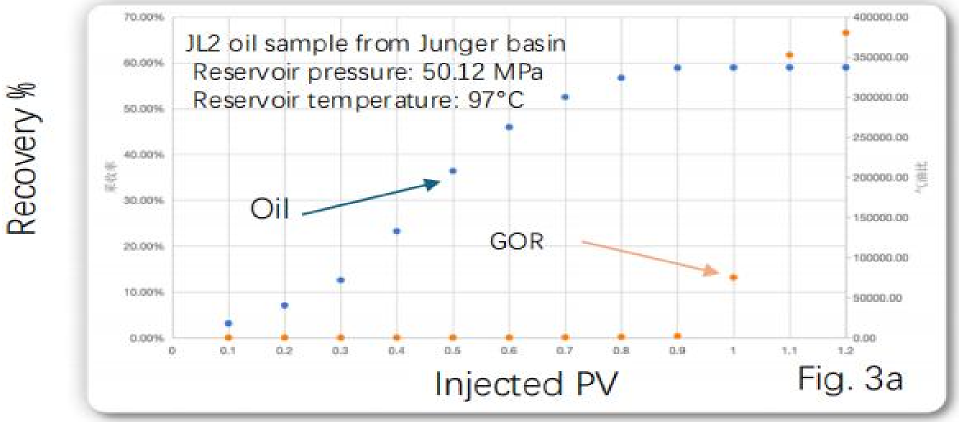
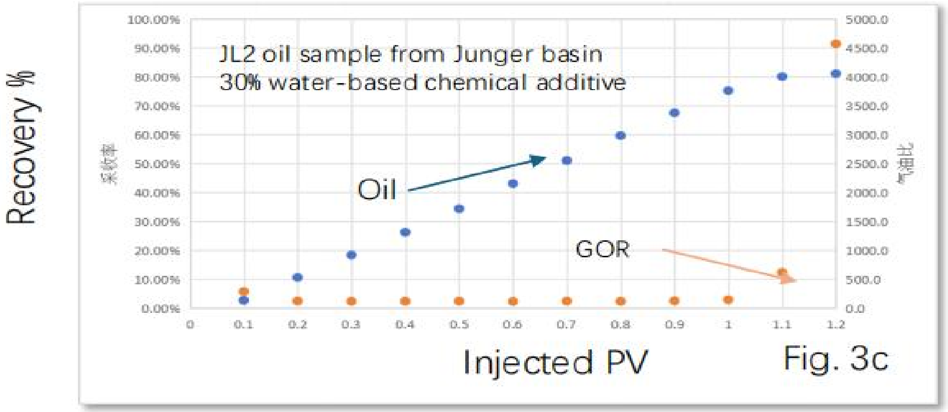


Fig. 2. Continuous CO_2 injection under reservoir conditions (97 ℃ /7267psi) at a flow rate of 0.1 mL/min: (2a) without chemical additive, (2b) with 5% oil-based chemical additive, and (2c) with 30% water-based chemical additive.

Results and Discussion

3. Enhanced Oil Recovery Efficiency and Favorable Phase Behavior





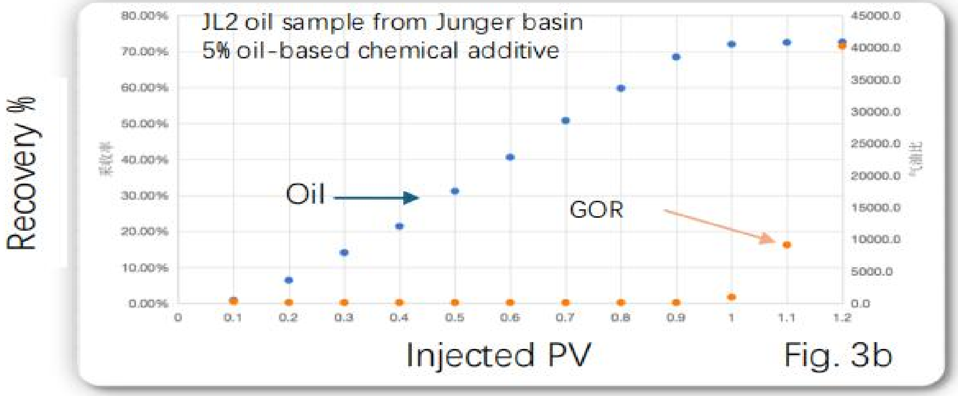


Fig. 3. Effect of various chemical additives—including oil-based and water-based amphiphilic surfactants—on CO_2 injection into oil. These additives significantly enhanced oil recovery (EOR) and increased CO_2 solubility. (3a) without chemical additive, (3b) with 5% oil-based chemical additive, and (3c) with 30% water-based chemical additive.

Results and Discussion

4. Infrared Imaging Captures Transient Fluid Dynamics

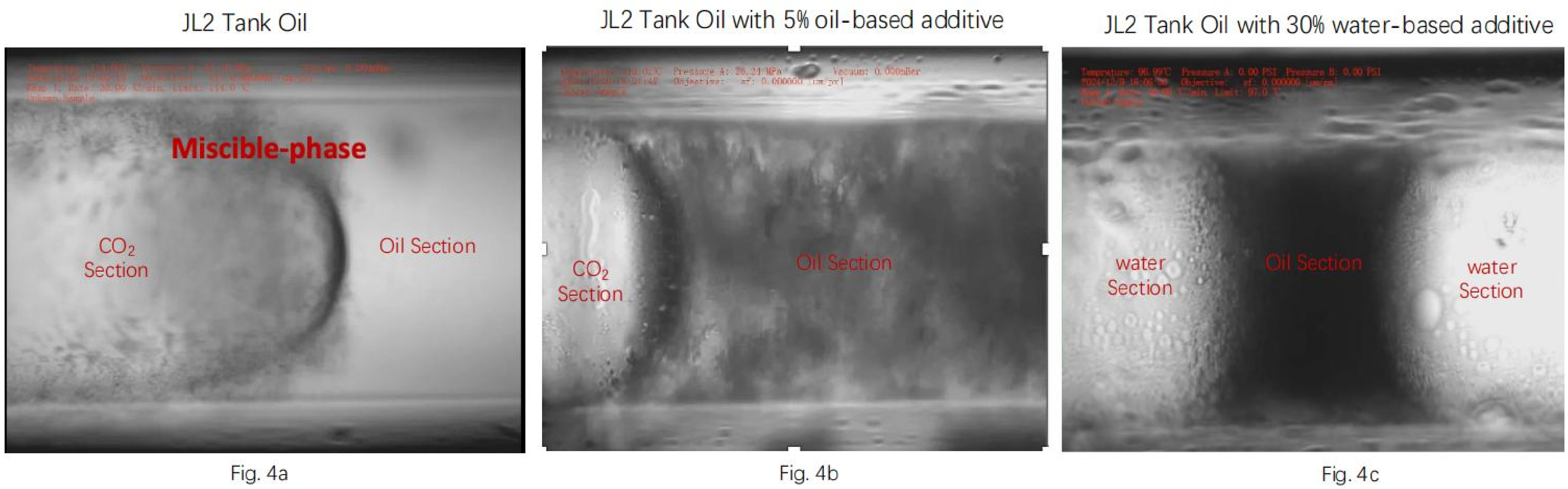


Fig. 4. Interaction between CO_2 and oil under reservoir temperature and pressure observed using the IRHPOC Raman microscope: (a) without chemical additive, (b) with 5% oil-based chemical additive, and (c) with 30% water-based chemical additive.

Conclusion

Key findings include:

① Improved Pre-Injection Fluid Properties: Chemically treated JL2 crude oil exhibited notably lower saturation pressure and reduced viscosity even before CO_2 injection, suggesting structural alterations in the oil phase due to additive interactions. These changes facilitate better CO_2 diffusion and enhanced mobility, which are critical to achieving efficient displacement.

② Enhanced CO_2 Solubility and Miscibility Potential: The treated oils showed increased CO_2 solubility under reservoir pressure, promoting more favorable phase behavior and lowering the threshold for miscibility. This enhances the effectiveness of CO_2 injection in reservoirs where natural miscibility is not attainable.

③ Higher Asphaltene Onset Concentration (AOC): Continuous CO_2 injection tests revealed elevated AOC values for chemically modified oils, indicating delayed onset of asphaltene precipitation. This improved stability is essential for minimizing formation damage and maintaining injectivity during long-term CO_2 operations.

④ Improved Oil Recovery Efficiency: Slim tube experiments confirmed the performance gains, with chemically treated samples achieving an additional 10% to 20% oil recovery compared to untreated crude. These results demonstrate the additive's ability to enhance sweep efficiency and displacement effectiveness in CO_2-EOR applications.

⑤ Direct Visualization of Altered Phase Dynamics: High-pressure infrared imaging captured real-time evidence of improved CO_2-oil interactions, including accelerated CO_2 diffusion, delayed phase separation, and the absence of gas fingering in treated systems. These visual observations support the hypothesized mechanisms behind the improved performance metrics.

Collectively, these results highlight the potential of chemical additives to address two major challenges in CO_2 -EOR: achieving miscibility in sub-optimal reservoirs and mitigating asphaltene-related risks. The ability to tailor fluid properties and control phase behavior offers a promising pathway to improve oil recovery while reducing operational uncertainties.

Acknowledgements / Thank You / Questions

1. Two chemical additives were selected through a preliminary screening process conducted by Karamay Xinyitong Biotechnology Co., Ltd, **Lei. Shi**

2. All experimental work was conducted at the Karamay XianBo Technology Innovation and Incubation Co., Ltd, where controlled laboratory facilities enabled high-precision testing under reservoir-simulated conditions， **Yao. Ge**