



Experimental study on the application prospects of dimethyl ether in assisted oil recovery

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SUMMARY: *Dimethyl ether (DME) is economical, safe, and environmentally friendly. However, it is gaseous at ambient temperature and pressure, which complicates experimental evaluations for its application in assisted oil recovery. Therefore, a multifunctional experimental system for gas testing was developed. Based on this system, the wax dissolution, wax inhibition, viscosity reduction, corrosivity, and recyclability of DME were tested. The experimental results indicate that DME exhibits a wax dissolution rate of 0.086 g/min, a wax inhibition rate of 89.02%, and a viscosity reduction rate of 98.8% at a mass percentage concentration of 5%. These values far exceed the performance requirements for wax inhibitors and viscosity reducers specified in industry and enterprise standards. Additionally, DME has a recovery rate of 96% at 60°C and does not corrode downhole tools under typical dosing conditions in oilfields. Comparative experiments with commonly used wax inhibitors and viscosity reducers in oilfields demonstrate that DME offers superior wax inhibition effects on high-wax crude oil from the Wushi 17-2 oilfield and viscosity reduction effects on water-free heavy oil from the Tahe oilfield. Therefore, DME holds great promise as an oil recovery aid.*

KEYWORDS: *Dimethyl ether; wax dissolution; wax inhibition; viscosity reduction; recovery; experiment.*

1 Introduction

China boasts abundant heavy oil reserves, yet the high viscosity and wax content of these resources pose significant challenges to efficient exploitation, with conventional recovery methods typically yielding low recovery rates.[1-3] Chemical viscosity reduction and chemical wax removal/prevention technologies currently represent the primary approaches to enhancing the fluidity of heavy oil and high-wax crude oil, and have been extensively studied by scholars worldwide.[4-7] Traditional chemical viscosity reducers mainly include surfactants, polymers, organic solvents, and nanomaterials,[8] while wax removal/prevention agents are categorized into solvent-based, dispersant-based, and inhibitor-based types.[9-12] However, the practical application of existing chemical agents remains hindered by several limitations, such as viscosity reduction efficiency being notably affected by water content,[13-15] insufficient temperature and salinity resistance, relatively high costs, and environmental risks associated with certain formulations.[16-19] Consequently, the development of novel, high-efficiency, cost-effective, and environmentally friendly viscosity reducers and wax removal/prevention agents remains a key research priority.

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In recent years, low-molecular-weight ether compounds have demonstrated promising potential in heavy oil recovery due to their superior solubility and recyclability. Among these, Dimethyl ether (DME) is a widely sourced, safe, and economical fuel with ultra-low pollution characteristics. Patents have disclosed methods for using liquid DME to extract crude oil, as well as processes and devices for utilizing DME to assist in the recovery of heavy oil, indicating that injecting liquid DME can reduce the viscosity of heavy oil, significantly improve pump efficiency, and enhance heavy oil recovery rates. Additionally, DME has a low saturated vapor pressure and remains liquid under pressurized wellbore conditions. On the ground, DME can be recovered through "flash evaporation," a mature method for separating and recovering petroleum products, which allows for reuse and cost reduction. These attributes highlight the potential application of DME as an oil recovery aid. However, since DME is gaseous at ambient temperature and pressure, there have been no reported laboratory experimental evaluations or field applications of DME-assisted oil recovery. Therefore, this study conducted laboratory experimental research on the feasibility of using DME as an oil recovery aid based on the developed multifunctional experimental system for gas testing. The research findings can provide a theoretical foundation and technical support for the industrial-scale application of DME in heavy oil recovery.

2 Experiments

2.1 Experimental Reagent

The experimental materials employed in this study encompassed: DME, toluene, xylene, petroleum ether, liquefied petroleum gas (LPG), 56# paraffin wax, diesel fuel, crude oil from Wushi 17-2 Oilfield, crude oil from Tahe Oilfield, fluorine rubber ring-346, AFLAS fluororubber, hydrogenated nitrile rubber, polytetrafluoroethylene (PTFE), and wax inhibitor YHJNZ-103 from Wushi 17-2 Oilfield. Among these, DME is a colorless gas at ambient temperature and pressure with a low saturated vapor pressure, approximately 0.5 MPa at room temperature, which facilitates flash evaporation recovery. Liquid DME exhibits unique miscibility in oil and water, enabling good adaptation to changes in the water content of oil wells. Furthermore, DME is inert at ambient temperature, is non-corrosive to metals, non-carcinogenic. As oil recovery aid, it will not affect crude oil quality, will not harm wellbore metal tubing, will not impact the health of field personnel, and is environmentally friendly. Additionally, DME has diverse sourcing channels and relatively low costs.

2.2 Experimental Equipment

As mentioned above, DME offers numerous advantages compared to commonly used benzene-based wax inhibitors and viscosity reducers in oilfields. However, the lack of equipment for conducting experimental evaluations of gaseous reagents has hindered research on the application of DME in assisted oil recovery. Therefore, a multifunctional experimental system for gas testing was developed. This experimental system primarily consists of a nitrogen cylinder, reagent tank, piston tank, measuring tank, computer, test reactor, bracket, magnetic stirrer, circulating water bath, temperature control cabinet, waste liquid tank, pressure gauge, as well as various pipelines and valves. Specifically:

- Nitrogen cylinder pressurized tanks and reactors;
- Reagent tank supplied reagent;
- Piston tank achieved phase transition of reagent;
- Measuring tank achieves precise reagent metering;
- Waste liquid tank stored experimental waste;

- Wax dissolution and corrosion test reactor is designed to perform wax dissolution and corrosion experiments;
- Wax inhibition and viscosity test reactor is used to conduct viscosity measurement and anti-wax experiments;
- Temperature control cabinet is designed to control experimental condition.

This system enables the testing of gaseous reagent under pressurized condition, including wax dissolution, corrosion, anti-wax performance, viscosity reduction, and recyclability. The schematic diagram of the entire experimental workflow is presented in Figure 1, with structural details of the wax dissolution-corrosion test reactor and wax inhibition-viscosity test reactor illustrated in Figures 2 and 3, respectively.

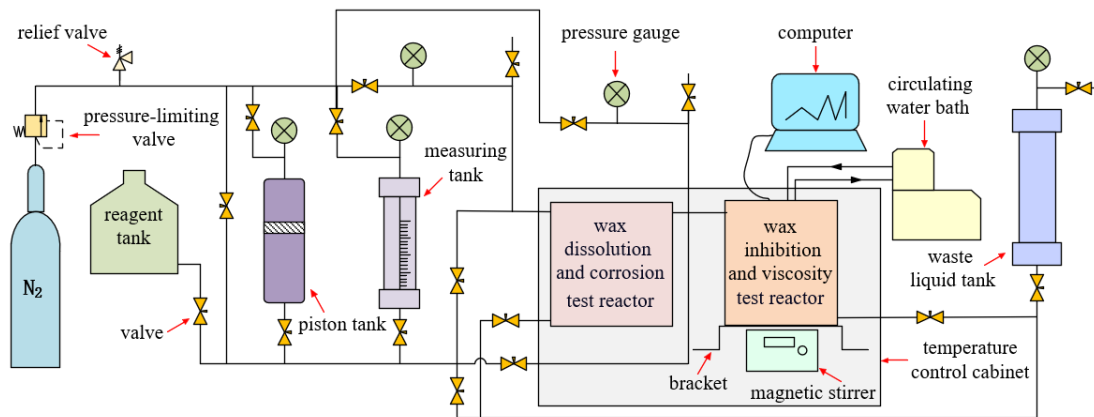


Figure 1: schematic diagram of multifunctional experimental system for gas testing

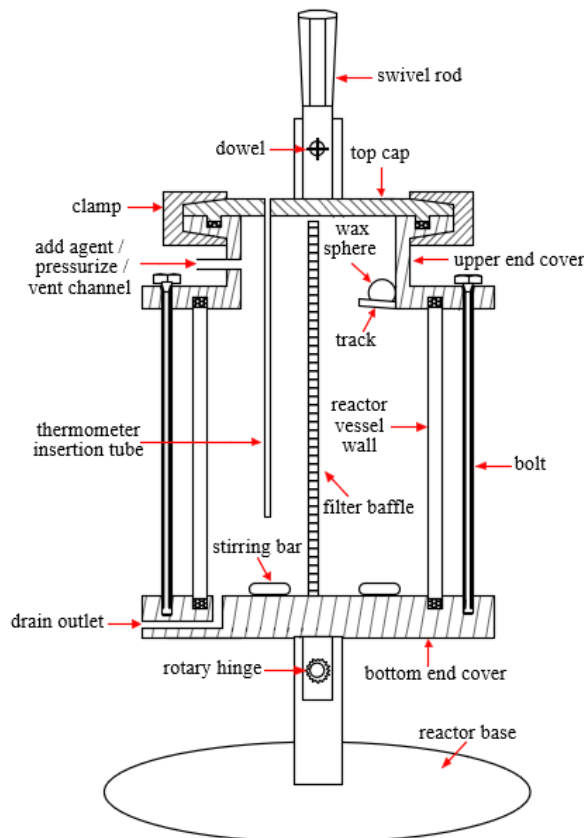


Figure 2: Structural diagram of wax dissolution and corrosion test reactor

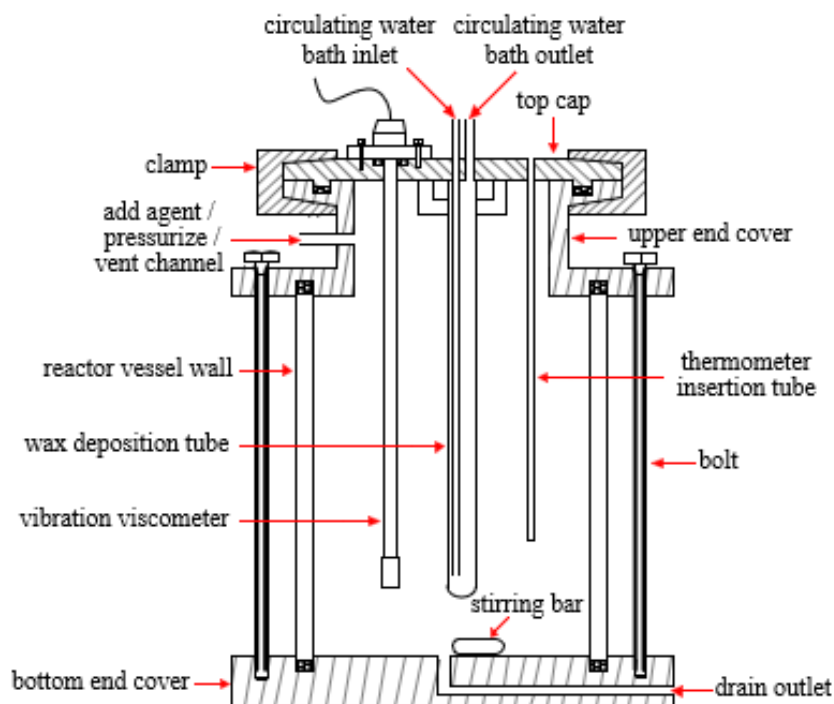


Figure 3: Structural diagram of wax inhibition and viscosity test reactor

2.3 Experimental Methods

When using DME for experiments, reagent tank contains DME. Upon opening the valve between the reagent tank and the measuring tank, DME flowed into the measuring tank driven by differential pressure. The measuring tank was pressurized using nitrogen cylinder to control the injection of DME into the test reactor in liquid form. Throughout the experiment, the system pressure was maintained above the saturation vapor pressure of DME corresponding to the experimental temperature to ensure DME remained in the liquid phase.

During wax dissolution experiment, pre-weighed wax sphere was placed on the track within the wax dissolution and corrosion test reactor. The reactor was filled with DME to a level sufficient to submerge the wax spheres. The DME was heated to the desired experimental temperature using the temperature control cabinet. The reactor was then rotated leftward, allowing the wax sphere to slide along the track to the reactor bottom. After completion of the experiment, the reactor was rotated leftward to the horizontal position, and filter baffle was employed to separate the wax sphere from the reagent. Nitrogen pressurization was utilized to purge the waste liquid from the reactor into waste liquid tank. Subsequently, the reactor was depressurized, and the wax sphere was retrieved. Following air-drying, the wax sphere was weighed. Based on the mass loss of the wax sphere and the reaction time, the wax dissolution rate of DME was determined as

$$v = \frac{w_0 - w}{t} \quad (1)$$

where v is the wax dissolution rate (g/min), w_0 is the initial mass of wax sphere (g), w is the post-reaction mass of wax sphere (g), t is the reaction time (min).

During corrosion experiment, pre-weighed corrosion materials were loaded into the wax dissolution and corrosion test reactor and fully submerged in the reagent. All other procedures

are as the same as the wax dissolution experiment. The corrosion behavior of the materials were evaluated by comparative analysis of morphological alterations and mass variations between pre- and post-reaction states. The mass increase percentage was determined as

$$f_n = \frac{n-n_0}{n_0} \times 100 \quad (2)$$

where f_n is the mass increase percentage (%), n_0 is the initial mass of material (g), n is the post-reaction mass of material (g).

During viscosity test experiment, crude oil and DME were introduced into the wax inhibition and viscosity test reactor at the predetermined ratio. The mixture was homogenized using magnetic stirrer and heated to the target experimental temperature via temperature control cabinet. Viscosity data were recorded and stored in real-time by computer. Post-experiment, nitrogen pressurization was applied to purge the waste liquid into waste liquid tank. After measuring crude oil viscosities with and without DME, the viscosity reduction efficiency of DME was calculated as

$$f_\mu = \frac{\mu_0 - \mu}{\mu_0} \times 100 \quad (3)$$

where f_μ is the viscosity reduction efficiency (%), μ_0 is the pre-additive viscosity (mPa·s), μ is the post-additive viscosity (mPa·s).

During wax deposition experiment, crude oil and DME were introduced into the wax inhibition and viscosity test reactor at the predetermined ratio. The mixture was homogenized using magnetic stirrer and heated to the target experimental temperature via temperature control cabinet. Circulating water bath controlled temperature of the wax deposition tube, inducing wax crystallization from crude oil under temperature gradient. Following reaction completion, nitrogen pressurization was employed to purge the waste liquid into waste liquid tank. The reactor was depressurized, and the wax deposition tube was disassembled, air-dried, and weighed. Wax deposition mass was calculated as the difference between the post-reaction mass and the inherent mass of the tube. After measuring wax deposition masses with and without DME, the wax inhibition efficiency of DME was determined as

$$f_m = \frac{m_0 - m}{m_0} \times 100 \quad (4)$$

where f_m is the wax inhibition efficiency (%), m_0 is the pre-additive wax deposition amount (g), m is the post-additive wax deposition amount (g).

During recovery experiment, the wax inhibition and viscosity test reactor headspace was connected to the lower section of the piston tank via valve switching. Vaporized DME from the reactor entered the piston tank, where a nitrogen cylinder-driven piston pressurized and liquefied the recovered DME, subsequently displacing it into a measuring tank. This cycle was repeated until the reactor pressure equilibrated to atmospheric conditions. The DME recovery volume was quantified by reading the liquid level in the measuring tank. Comparing the recovered volume to the initial injected volume, the recovery efficiency was calculated as

$$f_v = \frac{V}{V_0} \times 100 \quad (5)$$

where f_v is recovery efficiency (%), V_0 is initial injected volume (mL), V is the recovery volume (mL).

3 Results and Discussion

3.1 Analysis of Wax Dissolution Performance of DME

To evaluate the wax dissolution efficacy of DME, comparative experiments were conducted using toluene, xylene, petroleum ether, LPG, and DME under the same conditions (temperature: 45°C, pressure: 1.5 MPa, dissolution time: 20 min) on 56# paraffin wax, following the industry standard "SY/T 6300-2009 Technical Specifications for Wax Removal and Inhibition Agents in Oil Production". The dissolution phenomena and calculated dissolution rates are presented in Figure 4 and Figure 5, respectively.

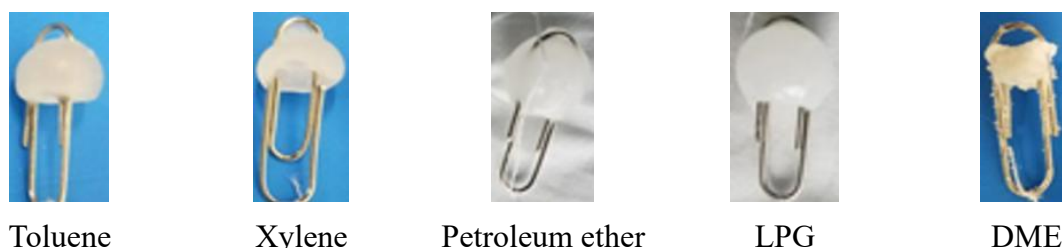


Figure 4: The phenomenon of dissolution wax of each reagent

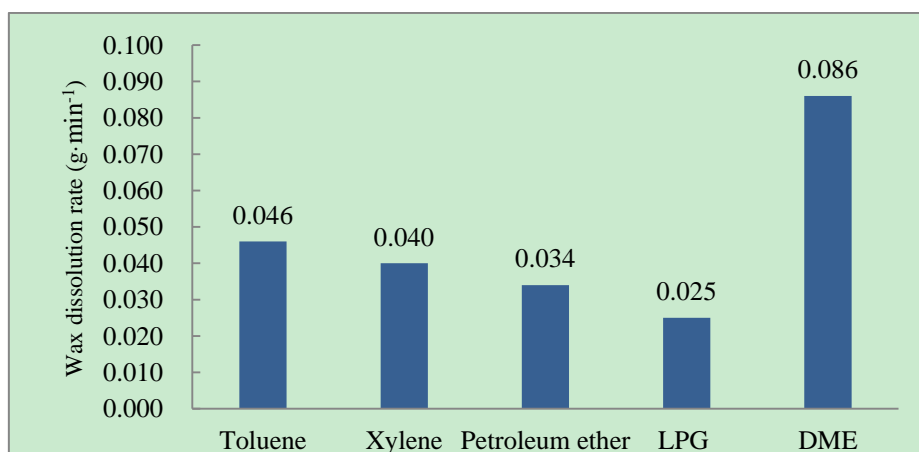


Figure 5: Comparison of wax dissolution rates of each reagent

Fig. 5 reveals that DME exhibited a remarkable wax dissolution rate of 0.086 g/min, significantly exceeding the rates of other tested reagents and the minimum requirement of 0.016 g/min specified in the industry standard. Literature surveys indicate that conventional oilfield wax removers typically achieve dissolution rates between 0.045–0.072 g/min. These results collectively demonstrate the superior wax solubilization capacity of DME.

3.2 Analysis of Wax Inhibition Performance of DME

Drawing reference from the industry standard "SY/T 6300-2009 Technical Specifications for

Wax Removal and Inhibition Agents in Oil Production", comparative experiments on wax inhibition for simulated oil were conducted using toluene, xylene, petroleum ether, LPG, and DME. The simulated oil was prepared by mixing 100 g of wax with 300 g of diesel oil, and the dosage of reagents was set at a mass concentration of 1%. Additionally, comparative experiments on wax inhibition for high-paraffin crude oil from the Wushi 17-2 Oilfield were carried out using DME and commonly used wax inhibitors in the Wushi 17-2 Oilfield. The reagent dosage was set at the commonly used level in offshore oilfields, 200 ppm, equivalent to a mass concentration of 0.02%. The wax inhibition efficiencies were measured under the conditions of an oil temperature of 40°C, a wax deposition tube temperature of 30°C, a pressure of 1.5 MPa, and a wax deposition time of 30 min, and the results are presented in Tables 1 and 2, respectively.

Table 1: Experimental Data of Wax Inhibition Using Simulated Oil

Reagent	Dosage (%)	Wax deposition tube mass (g)	Sum mass of wax and wax deposition tube (g)	Wax deposition (g)	Wax inhibition efficiency (%)
Control	0	42.37	49.20	6.83	-
Toluene	1.00	42.37	43.71	1.34	80.38
Xylene	1.00	42.37	43.92	1.55	77.31
Petroleum ether	1.00	42.37	44.33	1.96	71.30
LPG	1.00	42.37	44.86	2.49	63.54
DME	1.00	42.37	43.12	0.75	89.02

Table 2: Experimental Data of Wax Inhibition Using WS17-2 Crude Oil

Reagent	Dosage (%)	Wax deposition tube mass (g)	Sum mass of wax and wax deposition tube (g)	Wax deposition (g)	Wax inhibition efficiency (%)
Control	0	42.77	46.10	3.33	-
YHJNZ-101	0.02	42.77	45.74	2.97	10.81
YHJNZ-102	0.02	42.77	45.59	2.82	15.32
YHJNZ-103	0.02	42.77	45.07	2.30	30.93
YHJNZ-104	0.02	42.77	45.28	2.51	24.62
DME	0.02	42.77	44.89	2.12	36.34

As shown in Table 1, DME achieved the highest wax inhibition efficiency (89.02%) among all tested reagents, surpassing the minimum requirement of 50% stipulated in the industry standard. For WS17-2 crude oil (Table 2), DME outperformed the field-conventional inhibitors (YHJNZ-101–104) with an efficiency of 36.34%. These findings confirm the exceptional wax inhibition performance of DME.

3.3 Analysis of Viscosity Reduction Effect of DME

The experiments were conducted using water-free heavy oil from Tahe Oilfield. A comparative study was performed using diesel (as a conventional viscosity reducer) and DME as viscosity-reducing agents. The viscosity reduction efficiencies were obtained at 10 wt% diesel and 5 wt% DME addition levels, as shown in Table 3.

Table 3: Viscosity Reduction Data for Water-Free Heavy Oil from Tahe Oilfield

Temperature (°C)	Initial viscosity (Pa.s)	10% Diesel added		5% DME added	
		Viscosity (Pa.s)	Viscosity reduction efficiency (%)	Viscosity (Pa.s)	Viscosity reduction efficiency (%)
40	609.3	28.9	95.3	7.2	98.8
45	283.6	15.6	94.5	3.5	98.8
50	135.6	8.5	93.7	1.6	98.8
55	61.2	4.5	92.6	0.7	98.9
60	31.2	2.7	91.3	0.3	99.0
65	18.5	1.8	90.3	0.2	98.9
70	13.8	1.4	89.9	0.1	99.3
75	8.1	0.9	88.9	0.1	98.8
80	6.6	0.8	87.9	0.1	98.5
85	4.8	0.5	89.6	0.1	97.9
90	2.6	0.3	88.5	0.1	96.2
95	1.9	0.2	89.5	0.1	94.7
100	1.5	0.2	86.7	0.1	93.3

"Q/SH1020 1519-2016 The Enterprise Standard for Heavy Oil Viscosity Reducers" stipulates that oil-soluble viscosity reducers must achieve a viscosity reduction efficiency $\geq 85\%$ at 10 wt% addition and 50°C. As shown in Table 3, 5 wt% DME demonstrated superior viscosity reduction performance compared to 10 wt% diesel, with a viscosity reduction efficiency of 98.8% at 50°C, exceeding the standard requirement. Thus, DME exhibits excellent viscosity-reducing properties.

3.4 Recyclability Analysis of DME

In a viscosity reduction experiment, 80 mL of DME was used. Post-experiment, recovery test was conducted using the experimental system and method described in Section 2. Table 4 presents the DME recovery efficiencies at different temperatures.

Table 4: DME Recovery Data

Temperature (°C)	Cumulative DME recovery (mL)	Recovery efficiency (%)
25	49.48	61.85
45	69.24	86.55
60	77.3	96.63
70	78.85	98.56

Table 4 indicates that DME is highly recoverable, achieving 86.55% recovery at 45°C. In practical production, 100% recovery is unnecessary, appropriate residual DME is more conducive to the transportation of heavy oil or waxy oil in surface pipelines, that further enhancing the feasibility of DME-assisted oil recovery.

3.5 Corrosion Analysis of DME

While DME is non-corrosive to metals, downhole tools often rely on rubber seals. Therefore, comparative corrosion tests were conducted between DME and YHJNZ-103 wax inhibitor on common oilfield materials: fluororubber O-ring (FKM-346), fluororubber (AFLAS),

hydrogenated nitrile rubber (HNBR), and polytetrafluoroethylene (PTFE). The Corrosive mediums included pure DME, YHJNZ-103, and crude oil containing 200 ppm DME or YHJNZ-103. Experiments were conducted at 50°C for 40 h. Material corrosion is illustrated in Figure 6, and mass changes are summarized in Table 5.



Figure 6: Comparison of materials appearances before and after corrosion

Table 5: Mass Changes of Corroded Materials

Corrosive medium	Mass increase (%)			
	FKM-346	AFLAS	HNBR	PTFE
Pure DME	1.13	10.32	2.71	0.00
YHJNZ-103	1.41	15.08	3.57	0.00
DME-containing oil	0.00	0.00	0.00	0.00
YHJNZ-103-containing oil	0.00	0.00	0.00	0.00

Figure 6 and Table 5 reveal that all materials except PTFE experienced swelling corrosion by DME and YHJNZ-103, with greater mass increases in YHJNZ-103. However, under typical oilfield dosages, the corrosion of DME and YHJNZ-103 on downhole rubber materials is negligible.

4 Conclusion

(1) A multifunctional experimental system for gas testing was developed, enabling integrated evaluation of DME's wax dissolution, wax inhibition, viscosity reduction, corrosivity, and recyclability.

(2) Comparative studies validated DME's feasibility as an oil recovery aid, achieving a wax dissolution rate of 0.086 g/min, wax inhibition efficiency of 89.02%, and viscosity reduction efficiency of 98.8% at 5 wt% addition, that surpassing industry and enterprise standards. DME outperformed conventional wax inhibitors and viscosity reducers in Wushi 17-2 and Tahe Oilfields. Additionally, its 96% recovery efficiency at 60°C reduces operational costs, and it exhibits negligible corrosion under typical oilfield dosages. Thus, DME holds significant potential for auxiliary oil recovery.

Data Availability Statement

The data used are not confidential.

Author Contributions

L.K.: writing-original draft, data analysis. H.L.: literature research, experiment. Z.Y.: writing-review and editing, methodology. Y.Y.: development of experimental equipment. H.Y.: data processing.

Notes

The authors declare no competing financial interest.

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Abbreviations

DME, dimethyl ether; LPG, liquefied petroleum gas; YHJNZ-101–104, oilfield-conventional inhibitors; FKM-346, fluororubber O-ring; AFLAS, fluororubber; HNBR, hydrogenated nitrile rubber; PTFE, polytetrafluoroethylene.

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