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Investigation of the Applicability of Environmentally Friendly Surfactants for Oil Recovery

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Abstract

This study investigates the feasibility of producing surfactants (surface-active agents) from alternative, environmentally friendly raw materials for application in enhanced oil recovery (EOR) processes. The primary objective is to identify and evaluate sustainable feedstocks capable of replacing conventional, widely used surfactant materials that often pose environmental concerns. The paper provides a detailed overview of the analytical and physicochemical methods employed in the characterization of the synthesized surfactants, focusing on key parameters such as surface tension reduction, stability, and emulsification performance. The physicochemical properties of the newly developed surfactants are compared with those of commercially available agents currently used in EOR applications. The ultimate goal of this research is to support the development of sustainable and eco-conscious alternatives that maintain or improve oil recovery efficiency while minimizing environmental impact.

Keywords: *enhanced oil recovery, sustainability, environmentally friendly, surfactant.*

1. Introduction

In the context of global energy demands, a key ambition is to extract oil from oil fields and reservoirs with maximum efficiency. When the residual oil trapped in the reservoir rock cannot be recovered by conventional recovery methods, an Enhanced Oil Recovery (EOR) process is employed. **[1]**. This process involves the use of an additive that changes the chemical and physico-chemical properties of the oil in the porous rock (reservoirs), making it more mobile and easier to bring to the surface **[2]**. The fundamental principle underpinning the method is that the auxiliary substances employed act on the forces that hold the oil in the pores of the reservoir rock, thereby preventing it from flowing out **[3]**. EOR technologies can utilise several types of auxiliary substances, which can be thermal, gas injection, chemical or other auxiliary substances. The type of extraction process employed is contingent on the geological properties of the reservoir, the physical and chemical characteristics of the oil and the composition of the reservoir water **[4, 5, 6]**. The methods employed are delineated in **Fig.1 [7]**:

The remainder of this study focuses on the analysis of surfactants employed in chemical enhanced oil recovery (cEOR) processes. As illustrated in **Fig. 1.**, the auxiliaries of the chemical process encompass polymers, surfactants, alkalis, and foaming agents **[8]**. The concurrent utilisation of these auxiliaries can elicit synergistic effects. The present study investigates the surfactants utilised in petroleum extraction processes, with a view to replacing the conventional surfactant feedstocks with eco-friendly vegetable oil alternatives. The syntheses undertaken in this study focus on the preparation and testing of geminitype surfactants, which represent a distinct group of surfactants. Gemini surfactants are compounds that possess dimeric structures. In contradistinction to simple surfactants, gemini surfactants possess two long hydrophobic hydrocarbon chains and two hydrophilic headgroups, which are connected by a spacer. Their schematic structure is shown in **Fig. 2**.

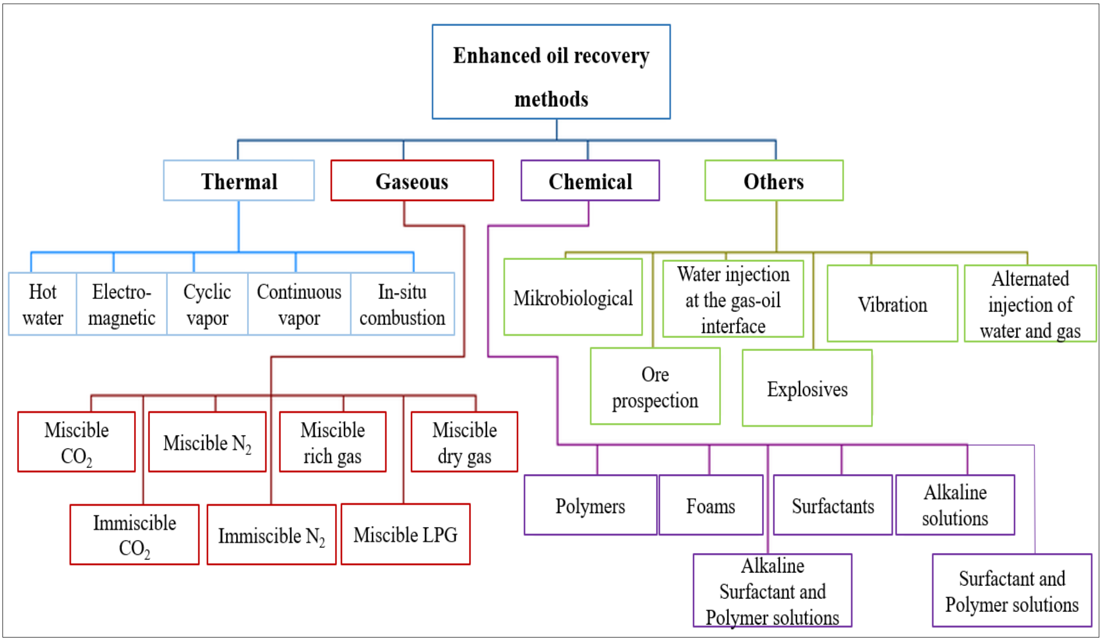

Fig. 1. *Additives used in enhanced oil recovery processes (LPG-liquefied petroleum gas)* [7]

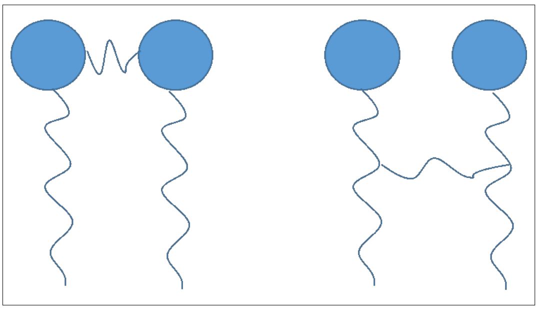
Fig. 2. *Schematic structure of gemini surfactants.*

2. Raw materials

The following paper presents the results of an experimental study into the physical and chemical properties of the plant-based surfactant KOMAD-710, developed, produced and marketed by MOL Plc., the coconut oil-based surfactant Empilan 2502, the oleic acid-based surfactant SPAN80 marketed by SigmaAldrich, and two proprietary sunflower-based experimental gemini surfactants (experimental surfactants ZMG-1 and ZMG-3).

The experimental work, which analyzes the physical and chemical properties and impact assessment of commercially available surfactants, is shown in Table 1 were analysed. All the surfactants investigated belong to the non-ionic group.

Our own experimental surfactants are gemini-type non-ionic surfactants based on vegetable oil. The synthesis of the experimental surfactants presented in the following chapters is broadly similar, the only difference being the number of carbon atoms in the spacers used, but in both cases the compound used was dibromoalkane.

The first step in preparing the experimental surfactants was to make a glycerol ester intermediate by transesterification from vegetable oil and glycerol. Then, the glycerol ester intermediate was reacted with dibromoalkane in an alkaline cyclic medium using a phase transfer catalyst. The reactions were carried out at 100-250 °C and ambient pressure. The product was dried with anhydrous sodium sulphate [9].

3. Methodology

The physical and chemical properties of the surfactants and the impact studies were evaluated and carried out using the following methods.

3.1. Density and dynamic viscosity

Density and dynamic viscosity were measured at 40 °C using an SVM 3000 Stabinger Viscometer.

Table 1. *Commercially available surfactants and their environmentally friendly base materials*

Brand of surfactant	KOMAD- 710	Empilan 2502	SPAN80
Raw material	Rapeseed oil	Coconut oil	Sorbitol
Distributor	MOL Nyrt.	Huntsman	Sigma-Aldrich

3.2. The pH value

The pH was measured in a 5 g/l distilled aqueous solution of the surfactants using a SevenCompact Duo from Mettler Toledo.

3.3. Solubility

The solubility of the surfactants in water was also tested in a 5 g/l distilled aqueous solution by visual inspection and transmittance measurement. Transmittance was measured using an Avantes AvaSpec-DUAL spectrophotometer.

3.4. Pour point

The pour point was measured with a Koehler automatic pour point and freezing point meter.

3.5. Water number

The test is used to determine the hydrophilic-lipophilic nature of surfactant compounds, thus providing information on the emulsifying effect of surfactants and their salt tolerance. The water number was determined by titration. The measurement was carried out by dissolving 1 g of surfactant in 30 cm^3 of a 4:96 mixture of cyclohexane-acetone and titrating the mixture with distilled water until turbidity was reached.

3.6. Oil displacement test

The oil displacement test is performed by thin film chromatography. To prepare for the test, we dipped a clean, dry glass plate into a chloroform suspension of the powdered rock material from Algyő. This caused a thin layer of powdered rock to form on the glass plate after it dried. We applied a droplet of Algyő 892 petroleum about 2 cm from the bottom of the glass plate. We made a solution of the surfactants in Algyő filtered brine water that had 5 g/l of it. Then we measured out 15 cm^3 of the prepared solution and put it into test tubes. We put the prepared glass plates inside the test tubes and sealed the test tubes. We then placed the samples in a drying oven at 60 °C for 3 hours. At the end of the test, the distance between the oil spot and the edge of the plate was measured. The result is given in millimetres.

3.7. Emulsifying (solubilising) effect test

The emulsifying effect was tested using an ADEM automatic emulsifier. During the test, 40 cm^3 of a 5 g/l concentration of a surfactant solution prepared with filtered brine water from Algyő was measured into the measuring cylinders of the device, and 40-40 cm^3 of Algyő 892 oil was added to each sample. The samples were stirred at 1500 rpm (revolutions per minute) for 2 minutes. After half an hour, the resulting emulsion (mixture) was analysed.

3.8. Interfacial tension (IFT) test

The interfacial tension (the force that keeps water and oil apart) was measured using a special tool called a Krüss SDT Spinning Drop Tensiometer. This tool has a thin glass tube (called a capillary) that is spun around a central axis. The radius of the oil droplet in the capillary is measured from the axis of rotation. This allows us to calculate the interfacial tension between the surfactant solution in the capillary and the oil droplet. In this study, we also used Algyő 892 oil and a solution of the surfactants in 5 g/l Algyő filtered brine water.

4. Results

The values obtained from analysing the surfactants physically and chemically are shown below **Table 2** shows the physical and chemical properties of the surfactants that were tested. **Table 3** shows the results of the impact tests.

5. Conclusions

The aim of this experimental work was to produce surfactants from renewable raw materials that are less harmful to the environment and can be used in petroleum extraction, to replace surfactants that are already commercially available.

The results of the measurements show that the experimental surfactant ZMG-1 has the highest oil displacement efficiency measured by thin-layer chromatography, the highest emulsification efficiency compared to all commercially available surfactants, and the interfacial tension test is in

Table 2. *Physical and chemical properties of the tested surfactants*

Properties/Sign of surfactant	KOMAD- 710	Empilan 2502	SPAN80	ZMG-1	ZMG-3
Density (g/cm^3) 40 °C	0.9701	0.9800	0.9860	1.2201	1.2223
Dynamic viscosity (mPa·s) 40 °C	148.8	450	1285	1.6570	1.5947
pH-value	11.21	9.74	Not measurab-le	12.83	11.83
Pour point (°C)	–25	9	1	–15	–16
Solubility	Soluble	Partially soluble	Non-soluble	Soluble	Soluble
Transmittancy (%)	34	51	69	23	28
Water number (cm^3)	10.3	13.5	4.30	13.0	11.65

Table 3. *Results of the impact assessments of the tested surfactants*

Properties/Sign of surfactant	KOMAD- 710	Empilan 2502	SPAN80	ZMG-1	ZMG-3
Oil displacement test, (mm)	21	12	10	26	20
Emulsifying (solubilising) effect test, (V/V%)	30	22	23	41	63
IFT (mN/m)	6.18	8.67	10.2	7.14	5.3

the order of magnitude of the other surfactants.

The oil displacement test of the experimental surfactant ZMG-3 showed that the oil droplet „ran" almost twice as far as Empilan 2502 and SPAN80, and performed similarly to KOMAD-710. In the emulsifying effect test, the experimental surfactant ZMG-3 showed the highest result. The value of interfacial tension is also more favourable compared to the interfacial tension measured for the other tested surfactants.

Overall, the preliminary efficacy assessment of the surfactants suggests that the experimental surfactants have similar or even superior efficacy to the existing surfactants on the market.

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