



## Comprehensive methodology for chemicals and nano materials screening for heavy oil recovery using microemulsion characterization



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### ABSTRACT

This paper reports laboratory scale screening of different chemicals based on microemulsion generation and the feasibility to be recommended for non-thermal heavy oil recovery applications. The objective of this study is to discover optimal chemicals which can form Winsor type 4 oil in water emulsions with heavy oil. The study was performed through visualization of microemulsions generated using vials and microscopic images. The impact of brine salinity on the emulsification was studied thoroughly in order to identify the synergy between the selected chemicals and the heavy oil. An alcohol propoxy sulfate surfactant from the Alfoterra series, Alfoterra S23-7S-90, a non-commercial surfactant blend HORA-W10, performed best for emulsion formation at low salinity conditions (2.5 wt.%, 3.8 wt.%), whereas Polysorbate-type nonionic surfactant Tween 20 performed best for high salinity conditions (6.35 wt.%, 7.6 wt.%). The observed performance was obtained for an oil with a viscosity of 4.812 mPas and 11.74 °API. Moreover, the results helped creating an initial performance correlation, with dependence on two variables: crude oil composition and synthetic brines. Attempts were also made to stabilize oil-in-water emulsions formed with Alfoterra S23-7S-90, HORA-W10, Tween 20 using nanofluids (metal oxides), sodium carbonate, and an anionic polyacrylamide-based polymer (PolyFlood MAX-165). Emulsions were visualized under the Axiostar plus transmitted-light microscope and their stability was studied in order to screen the most optimal chemical (or chemical combinations) available for low cost heavy oil recovery.

### 1. Introduction

Economically recovering heavy oil is found to be challenging due to recent decline in oil prices. Thermal methods such as CSS (cyclic steam stimulation), steam flooding, SAGD (steam-assisted gravity drainage), are predominantly used in the heavy oil industry for enhanced recovery. These methods can improve the ability of heavy oil flow in reservoirs by changing the physical properties of oil such as viscosity and density (Mohsenzadeh et al., 2015). However, for thin or deep heavy oil reservoirs, steam injection methods are not economically feasible due to the heat losses to the overburden, underburden, and aquifer (Wu et al., 2012). Other drawbacks of thermal methods include high consumption of energy and fresh water as well as CO<sub>2</sub> emission. These thermal methods drawbacks led to increase in popularity of non-thermal methods such as chemical injection. Chemical methods include alkaline flooding (emulsification), surfactant flooding (IFT reduction), polymer flooding (improvement in sweep efficiency), and ASP (alkaline-surfactant-polymer) flooding. Surfactant EOR (enhanced oil recovery) technique is used to help lower IFT, which leads to enhanced oil displacement efficiency. The use and application of a suitable surfactant

could promote the generation of low enough IFT's and therefore facilitate the emulsion formation, thus, to improve the displacement efficiency. Moreover, the formation of emulsions can also help reducing water mobility and improving volumetric sweep efficiency. (Chopra et al., 2010; Sheng, 2001).

Alkaline flooding can also enhance oil-in-water emulsification between oil and brine using surfactants naturally existent in heavy oil. However, the flooding may become ineffective if the chemical is adsorbed on the rock surface or has reactions. Therefore, it is important to create emulsions that are sufficiently stable enough to eventually achieve enhanced oil recovery.

This technique might not lead to high recovery factors but it may turn out to be economically efficient due to low cost of application as long as oil-compatible (and inexpensive) chemicals such as silicon dioxide, sodium carbonate are selected. Therefore, the application of low IFT chemical flooding for heavy oil requires careful laboratory screening work. When selecting a chemical for chemical EOR, attention should be paid to the structure of the chemicals that are suitable for certain reservoir characteristics such as salinity, hardness of water (divalent ion concentration), temperature, and oil type (viscosity,

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SARA, TAN). Chemical synthesis (mixture of different chemical types such as surfactants, nanofluids, alkalis, polymers) is another option to ensure emulsion generation and, more importantly, stability.

Obtaining low IFT through visual laboratory-based oil and water phase behavior tests is often the main tool for screening suitable chemicals for emulsification at optimal application conditions (Barnes et al., 2008). This paper describes the implemented workflow for glass tube experiments, combined with the results of the visualization of the screened chemicals. Chemical structure correlations generated from the glass tube experiments with the purpose of defining optimal chemical combinations with several stabilizing agents for enhanced emulsion stability.

## 2. Materials

### 2.1. Oil

Heavy dead crude oil from an oil field in Western Saskatchewan was used throughout the experiments. Density and viscosity of the oil were measured to be 0.981 kg/m<sup>3</sup> and 4812 cP at room temperature (~25 °C). The API gravity of the oil is 11.74°. The heavy oil has a mean TAN (Total Acid Number) of 3.2 mg KOH/g.

Asphaltenes and resins play a significant role in the viscosity of heavy oil (Wu et al. 2012). Asphaltenes and resins have different molecular weights but share the same chemical composition. They both are amphiphilic, this refers to the preference to move to the water and oil interface, when in contact with water. Relatively low molecular weight resin reaches the oil and water interface faster than asphaltene and, therefore, disturbs the asphaltene solubility resulting in flocculation of asphaltene around the water droplets. The asphaltene aggregates are known to be responsible for natural emulsion stability (Daniel-David et al., 2008; Sjöblom, 2001). The asphaltene and resin content of the oil used is given in Table 1.

### 2.2. Brines and chemicals

Synthetic brine was used in the aqueous phase. 2.5%, 5.1%, and 7.6% brine samples (NaCl) were prepared to represent different salinity conditions and were dyed with a water-based tracer IFWB-C7 fluorescent dye for enhanced visualization. Fluorescent-dyed brine samples were used for glass tube tests. 3.8% and 6.35% brine samples without the fluorescent dye were used for stability experiments where stabilizing agents were added in order to enhance emulsion stability. The pH of the brine solutions of different salinities was measured to be 6.7. The list of chemicals for the glass tube tests are presented in Table 2.

## 3. Glass tube test

### 3.1. Glass tube test methodology

Glass tubes and their caps were prepared and held in a rack for stability. Brine solutions/oil mixtures with oil-brine ratio of 1:1 (2 g each) were made up in different tubes and the concentration of the surfactant solution was kept at 1.5 wt.% for the initial glass tube test. 1.5 wt.% concentration was chosen based on the preliminary screening of chemicals. Preliminary screening displayed that for most chemicals

**Table 1**  
Chemical properties of oil.

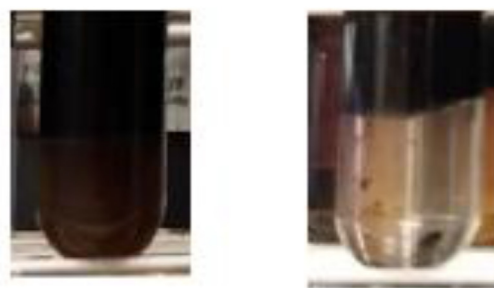
Specification	Unit	Value	Test method
Saturates	Wt.%	29.36	SARA
Aromatics	Wt.%	25.65	SARA
Resins	Wt.%	29.51	SARA
Asphaltenes	Wt.%	14.78	SARA

**Table 2**  
Chemicals Screened and Evaluated in this Study.

Chemicals	Type	Abbreviation	Active matter (%)
AAS J13131	Alcohol Alkoxylate Sulfate (or alkyl ether sulfate)	AAS 1	29.1
AAS J11111	Alcohol Alkoxylate Sulfate (or alkyl ether sulfate)	AAS 2	27.67
AAS J771	Alcohol Alkoxylate Sulfate (or alkyl ether sulfate)	AAS 3	29.7
Alfoterra 145-8S-90	Alcohol Propoxy Sulfate	APS 1	89.2
Alfoterra 145-4S-90	Alcohol Propoxy Sulfate	APS 2	82.2
Alfoterra S23-7S-90	Alcohol Propoxy Sulfate	APS 3	85.1
IOS 0332	Internal Olefin Sulfonate	IOS 1	27.99
IOS 0242	Internal Olefin Sulfonate	IOS 2	18.99
IOS 0352	Internal Olefin Sulfonate	IOS 3	69.4
LTS-18	Alkyltoluene Sulfonate	LTS	14.27
Arquad 2C-75	N/A	Arquad	N/A
[BMIm] + [BF4]-	Ionic liquid	IOL	N/A
Tween 20	Polysorbate 20	PSB 20	N/A
Tween 80	Polysorbate 80	PSB 80	N/A
WITCONOL NP-40	Nonylphenol (4) ethoxylate	NP	N/A
DES 1 (Reline)	2 hydroxyethyl trimethyl ammonium chloride, urea	DES 1	N/A
DES 2 (Ethaline)	Hydroxyethyl trimethyl ammonium chloride, 1,2,3 Propane triol	DES 2	N/A
DES 3	Sodium carbonate, 1,2,3 Propane triol	DES 3	N/A
HORA-W10	Non-commercial surfactant blend	HORA	N/A
SDS	Sodium Dodecyl Sulfate	SDS	N/A
Na <sub>2</sub> CO <sub>3</sub>	Sodium Carbonate	Na <sub>2</sub> CO <sub>3</sub>	N/A
C <sub>18</sub> H <sub>29</sub> NaO <sub>3</sub> S	Sodium Dodecylbenzenesulfonate	C <sub>18</sub> H <sub>29</sub> NaO <sub>3</sub> S	N/A
NaC <sub>12</sub> H <sub>25</sub> SO <sub>4</sub>	Sodium Dodecyl Sulfate	NaC <sub>12</sub> H <sub>25</sub> SO <sub>4</sub>	N/A

listed in this research, the concentration of chemicals lower than 1.5 wt.% could not lead to any type of observable emulsification. Emulsions were observed and analyzed at distinct times (after 1, 6, 24 h, and 7 days). At various time intervals, emulsion quality was tested by naked-eye observation and light manual agitation and the results were recorded.

Barnes et al. (2008) addressed in their study that promising behavior is the smooth movement of uniform oil-in-water emulsions while less promising behavior is the formation of viscous gels or oil globules. Promising systems are kept for several weeks for further observation (Fig. 1). For unstable emulsion systems, a rapid phase separation between the oil and brine is observed. For stable emulsions, the emulsion samples in the tubes are uniformly black and a Winsor type 4 emulsions are formed. It is common to calculate the ESI (emulsion stability index) using an Eq. (1) (Wang et al., 2017) to determine the stability of the emulsions in an emulsion stability study. However, due to the high viscosity of heavy oil used and possible attraction forces caused by chemicals causing emulsion or oil to spread on the inner surface of the



**Fig. 1.** Left: promising system; Right: less promising system.

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