

Comparative Analysis of A Biosurfactant with Synthetic Surfactant for Reservoir Rock Wettability Alteration

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Abstract- This study explores how different synthetic and biologically derived surfactants influence the wettability of reservoir rocks. Wettability changes were assessed using the contact angle technique, which allowed the effect of varying surfactant types and concentrations on droplet behavior to be clearly observed. Alkaline solutions, commonly used in enhanced oil recovery (EOR), were included due to their ability to interact with the natural organic acids present in crude oil and generate surface-active compounds directly at the oil-water interface. This reaction reduces interfacial tension and promotes improved oil displacement. Despite their effectiveness, the increasing cost of traditional alkaline chemicals and synthetic surfactants, along with concerns regarding environmental impact and poor biodegradability, has prompted the search for more sustainable alternatives. Bio-surfactants, particularly saponin-based compounds that naturally produce foam in water, offer a promising, environmentally friendly, and potentially more economical option for EOR processes. This work provides a comparative evaluation of these surfactants, highlighting their capability to alter wettability and supporting the development of greener chemical flooding methods.

Index Terms- Enhanced Oil Recovery, surfactant flooding, wettability, contact angle.

I. INTRODUCTION

Since energy crises are getting worse and more threatening, several countries are paying more attention to improve oil recovery (EOR) technology recently. One of the causes of this is the scarcity of available oil resources and the challenges associated with discovering new oil fields. One of the instances is Indonesia, which was an oil exporting nation before 2004 but is now an oil importing nation. The nation's demand for oil is rising while its ability to produce it is declining. In actuality, when a new oil reservoir is drilled, only 20 to 40 % of the potential oil is actually extracted, leaving 60 to 80 % of the potential oil in the reservoir. The use of EOR

technology provides an additional opportunity to extract additional oil from the reservoir, maybe another 20 %. Surfactant is the material that plays an important role in the application of EOR technology. [Abdina et. al, Osama et. al., Abass et. al.] Surfactant is injected into the reservoir to lower the interfacial tension between oil and water and to remove trapped oil from the reservoir rock and so improve oil production, is crucial to the implementation of EOR technology. Wettability of reservoir rock is identified as a parameter which controls the fluid pour in the rock porosity. In a three-phase system, wettability is defined as the greater tendency of one fluid phase to adhere to a solid surface when compared to another immiscible fluid phase. The wetting phase refers to the first fluid, and the non-wetting phase refers to the second fluid. Strongly water-wet, water-wet, neutral wet, oil-wet, and strongly oil-wet are only a few examples of the vast range of wettability that results from the interaction between the rock surface and the two immiscible fluids. The contact angle is the most practical and accurate wettability measurement method out of all the available options. According to Andrew et al. (2014), contact angle is the primary factor that encourages flow during the non-wetting period. The contact angle measurements are carried out to assess the reservoir's wettability during the last few years. Due to water's larger density than oil, the contact angle in a water/oil/rock system is determined by holding angle in water.

Introduction to Reservoir analysis and its importance in oil industry

The technique of estimating a reservoir's performance over the course of its whole production life is referred to as reservoir analysis. To produce subsurface data, it integrates the analysis of pores, rocks, and fluids from various reservoirs. Additionally, it uses optimisation methods to reduce the discrepancy

between the projected reaction and actual data while estimating the dynamic rock and fluid parameters.

In determining the fluid properties, well pressures, and hydrocarbon flow rates, reservoir analysis is crucial. Additionally, they contribute the necessary information for oil and gas project planning, engineering, construction, and completion. [Bonell et. al., Ahmed et. al., Wei et. al.]

The Process of Reservoir Analysis's Major Steps

Data collection: During this stage, major players in the reservoir analysis market and other oil businesses gather unprocessed data from a variety of sources, including well logs, fluid analyses, and routine well production tests.

Data processing: Log analyses, structural maps, geological models, cross sections, and other data are used in this reservoir analysis step.

Data Integration and Reservoir Characterization: By processing and integrating the available data, reservoir characterization strives to provide the most accurate reconstruction of a reservoir

Coal, oil, and gas reserves are investigated using reservoir analysis. These fuels and energy sources are employed in a variety of industries, including transportation, electricity production, and aviation.

Due to a significant increase in global population, there is a greater demand for oil and gas. Major oil firms are working to exploit remote oil and gas resources that were previously inaccessible due to technological limitations in order to meet the growing demand. Therefore, it has become crucial for businesses to maintain the fields' optimal performance and the necessary output. The level of energy supply has increased as a result of the escalating demand.

II. APPLICATION OF SURFACTANT IN ENHANCED OIL RECOVERY

Surfactant flooding is an Enhanced Oil Recovery technique in which the mobility of residual oil in the reservoir is increased by reducing the Interfacial

Tension (IFT) between the injected fluid and the reservoir oil. It is a chemical Enhanced Oil Recovery technique (CEOR) in which a small amount of surfactant (0.3 to 1.0 volume %) is mixed with the injected fluid (water) to sweep the reservoir oil. Surfactants are blended with co-surfactants which acts as active agents to enhance the properties of surfactant solution and helps to sustain optimal conditions with respect to pressure, temperature and salinity. The presence of surfactants also improves the wettability (oil-wet to water-wet) of reservoir rock to enhance the recovery of oil. Surfactants also improve the recovery of residual oil through other mechanisms like micro-emulsification of trapped residual oil and by changing the interfacial rheological properties. Sometimes, the surfactants and cosurfactants, along with other components of the aqueous solution form a micro emulsion. In primary and secondary recovery less than 50% of the oil can be produced and the residual oil gets trapped in the pores due to capillary forces. Therefore, in chemical enhance oil recovery (cEOR), surfactant solution is injected into the reservoir which reduces the capillary forces by greatly lowering the interfacial tension. [Kazarika et. al., Massarweh et. al., Gbadamosi et. et. al]

Wettability & Contact angle

Wetting is the ability of a liquid to maintain contact with a solid surface, resulting from intermolecular interactions when the two are brought together. This happens in presence of a gaseous phase or another liquid phase not miscible with the first one. The degree of wetting (wettability) is determined by a force balance between adhesive and cohesive forces. Wetting is important in the bonding or adherence of two materials. Wetting and the surface forces that control wetting are also responsible for other related effects, including capillary effects. There are two types of wetting: non-reactive wetting and reactive wetting.

Wetting deals with three phases of matter: gas, liquid, and solid. It is now a center of attention in nanotechnology and nanoscience studies due to the advent of many nanomaterials in the past two

decades (e.g. graphene, carbon nanotube, boron nitride nanomesh)

Adhesive forces between a liquid and solid cause a liquid drop to spread across the surface. Cohesive forces within the liquid cause the drop to ball up and avoid contact with the surface.

The contact angle is the angle, conventionally measured through the liquid, where a liquid vapor interface meets a solid surface. It quantifies the wettability of a solid surface by a liquid via the Young equation. A given system of solid, liquid, and vapor at a given temperature and pressure has a unique equilibrium contact angle. However, in practice a dynamic phenomenon of contact angle hysteresis is often observed, ranging from the advancing (maximal) contact angle to the receding (minimal) contact angle. The equilibrium contact is within those values, and can be calculated from them. The equilibrium contact angle reflects the relative strength of the liquid, solid, and vapour molecular interaction. [Taylor et al., Kamal et. al.]

The contact angle depends upon the medium above the free surface of the liquid, and the nature of the liquid and solid in contact. It is independent of the inclination of solid to the liquid surface. It changes with surface tension and hence with the temperature and purity of the liquid.

The objective of this paper is to analyze reservoir rock wettability alteration using different types of surfactants such as Sodium Lauryl Sulphate (SLS), Sodium Dodecylbenzenesulphate (SDBS) and biosurfactant (Soapnut fruit or Reetha seeds powder). Contact angle studies were done to select suitable concentration of the surfactants for surfactant flooding and determine the recovery of oil from that suitable concentration of surfactants.

III. EXPERIMENTAL ANALYSIS

Material used

Synthetic surfactant - Sodium Lauryl Sulphate (SLS), Sodium Dodecylbenzenesulphate(SDBS) and biosurfactant – reetha seeds powder.

Methods employed

a. Core cleaning

The core is cleaned using the soxhlet apparatus. The samples are placed in the extractor and cleaned by refluxing solvent. The solvent in this closed system is externally heated and vaporized continuously in a flask, flow through the samples in the extraction tube, condenses at the top of the assembly. The condensate falls back into the sample chamber.

b. Grain size analysis

Equipment used are Balance, set of sieves, Cleaning brush, Sieve shaker, Beaker. The grain size distribution of core samples was carried out by sieve analysis method. For this purpose, core samples were cleaned, dried and crushed using pestle and mortar. Care was taken not to break the grains. Sieves of different US standard mesh sizes were racked on a sieve shaker with bottom pan and top cover. 100 grams of the prepared sample was poured onto the top sieve and the sample was sieved for ten minutes. The sieves were removed and unloaded and were brushed thoroughly to remove each grain. The sand in each sieve and in the bottom pan was measured accurately. The percentage by weight of the total sand sample retained on each sieve and in the pan was calculated. Sieving is commonly used in determining the grain size distribution of a particular core sample. The dried sample is placed in the uppermost sieve in a set of stacked sieves. The stack of sieves arranged in order so that the coarsest sieve is at the top with finer ones below (with a pan at the bottom to catch any sediment that passes through the lowest and finest sieve) is placed on a shaking machine. After ten minutes of shaking, 25 samples collected from each sieve and from pan are weighed and further calculations and graphical analysis are done to study grain size analysis.



Fig: Core Sample



Fig: Pestle and mortar

Choice of Grade Scale: In general, a grade scale should form a useful basis for description and comparison of results; it should not be affected by the technique of measurement and preferably it should have some physical justification. On the basis of these criteria few of the grade scales proposed are justified. By far the most useful and accepted scale is the one proposed by Wentworth.

Fig : Set of sieves in Mechanical shaker

Fig: Samples retained

c. Determination of Porosity

There are four methods to measure porosity namely: mercury porosimetry, helium pycnometry, image analysis and liquid saturation method. In this project, the Liquid saturation method is used to determine the porosity.

Liquid Saturation method

The objective of this method is determining the bulk volume, pore volume and effective porosity of a core sample Procedure: First, take a cylindrical shaped dry core. weight of the dry core (W1) is measured with the help of a weighing machine. Saturate the core sample in brine solution. The brine solution along with the core sample is placed inside a vacuum desiccator with vacuum pump. This is done to let the air bubbles come out of the core and completely saturate it. Measure the weight of the saturated core (W2). The pore volume (PV) can be determined by the formula:

$$PV = \frac{w_2 - w_1}{\text{density of the fluid}}$$



Fig: Core sample



Fig : Fruit pericarp

Then, the length and diameter of the core is measured with the help of a Vernier calliper. The bulk volume (BV) of the core is measured with the help of the formula for cylinder volume . The porosity of the core sample is measured by the formula:

$$\phi = \frac{\text{Pore volume}}{\text{Bulk volume}}$$

d. Preparation of synthetic surfactant

Surfactant used are SLS (sodium lauryl sulphate) , SDBS (Sodium Dodecyl benzenesulfonate) and bio surfactant.)

Preparation of SLS (sodium Lauryl Sulphate)

The surfactant is prepared in distilled water with concentrations of 0.1 to 0.5 M. Each sample is well mixed with distilled mixture using a magnetic stirrer. The sample is stored in the conical tubes.

Preparation of SDBS (Sodium Dodecyl benzenesulfonate)

The surfactant is prepared in distilled water with concentrations of 0.1 to 0.5 M • Each sample is well mixed with distilled mixture using a magnetic stirrer. The sample is stored in the conical tubes.

e. Preparation of biosurfactant

Soapnut fruit was collected from a nearby area. The samples were collected randomly from the stock. The fruit pericarps were dried in an oven at 500C for 36 h. The dried pericarp shells were crushed to a fine powder, which was added to distilled water. The mixture was mixed using a magnetic stirrer. The sample was stored in conical tubes. [Shetty et.al]



Fig: Soapnut fruit

f. Determination of wettability

FAMAS (InterFace Measurement and Analysis System) software measures and analyzes the surface phenomena of solids and liquids, and present physical properties of contact angles in static and dynamic ranges, liquid surface/interfacial tension, and surface free energy. When measuring contact angles, most tools show images in black and white, not grayscale. FAMAS, however, uses a unique algorithm to creates a rich silhouette of the droplet, the most important object in the image, allowing the outline of the droplet to be measured correctly to produce more accurate data.



Fig: Contact angle meter (FAMAS)

IV. RESULTS AND DISCUSSIONS

a. Grain size analysis

Sieve Size	Weight (g)
0.045	3.11
35	34.054
45	10.1
75	4.1
85	33.2
120	14.2
pan	0.8

b. Determination of Porosity

Liquid Saturation Method

$$\phi = \frac{\text{Pore volume}}{\text{Bulk volume}} * 100$$

Dry weight of core sample = 70.624g

Wet weight of core sample = 75.021g

Main Scale Reading of core sample = 38 mm

Vernier Scale Reading = 7*0.05 = 0.35mm

Diameter of the core sample = 38+0.35 = 38.35 mm = 3.835 cm

Radius of the core sample = 38.35/2 = 19.175 mm = 1.9175 cm

Height of the core sample

Main Scale Reading = 28 mm

Vernier Scale Reading = 8*0.05 = 0.4 mm

Height of the core sample = 28+0.4 = 28.4 mm = 2.84 cm.

Therefore, Bulk Volume = 32.8 cm³

$$\text{Pore volume} = \frac{w_2 - w_1}{\text{Density of fluid}} = 4.397 \text{ cm}^3$$

$$\text{Porosity} = \frac{\text{Pore Volume}}{\text{Bulk Volume}} * 100 = \frac{4.397}{32.8} * 100 = 13.4\%$$

c. Determination of wettability

For SLS

Concentration	Contact Angle
0.1 M	44.8
0.2 M	41.8
0.3 M	38.8
0.4 M	36.3
0.5 M	33.3

For SDBS

Concentration	Contact angle
0.1 M	35.8
0.2 M	32.8
0.3 M	29.8
0.4 M	26.8
0.5 M	23.8

For bio surfactant

Concentration	Contact angle
0.1 M	26.2
0.2 M	21.2
0.3 M	16.4
0.4 M	11.4
0.5 M	6.4

d. Determination of contact angle and wettability

- Contact angle (degree) vs SLS concentration (M)

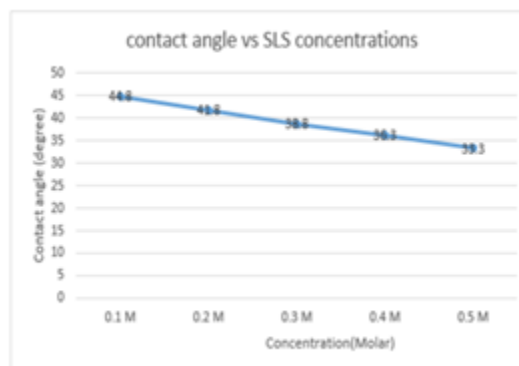


Fig: Contact angle (degree) vs SLS concentration (M)

- Contact angle (degree) vs SDBS concentration (M)

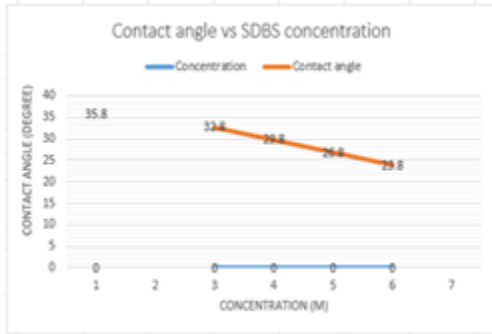


Fig: Contact angle (degree) vs SDBS concentration(M)

- Contact angle (degree) vs Bio surfactant concentration (M)

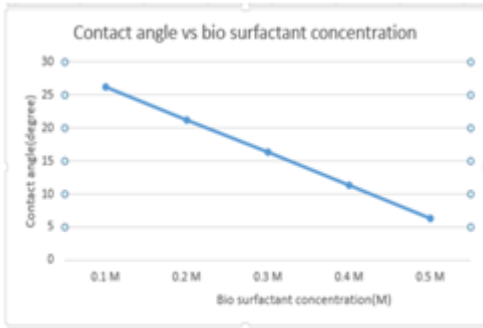


Fig: Contact angle(degree) vs biosurfactant

Observations

- Graph 1 depicts that contact angle decreases with increasing concentration of SLS surfactant.
- Graph 2 depicts that contact angle decreases with increasing concentration of SDBS surfactant and it is less as compared to SLS surfactant.
- Graph 3 depicts that contact angle decreases with increasing concentration of bio surfactant and it is less compared to both SLS and SDBS.
- Moreover, bio surfactant is cost effective since it is natural as compared to the other synthetic surfactants.

V. CONCLUSION

The special effects of different concentration of three type surfactants on wettability alteration were designated in this study. The ideal concentration of each surfactant to changing the wettability of the rock was also specified. Based on this work, the following attentions are made:

- As the surfactant concentration increases, the wettability of rock changes. Contact angle decreases with increasing concentration of surfactant.
- SLS and SDBS almost had the same effect on sandstone rock.
- Bio surfactant prepared from soapnut fruit had the finest effect on wettability alteration.
- By contrasting between used surfactants, the greatest contact angle lessening and altering wettability was made by bio surfactant.
- By considering these results and the literature-presented results, among all types of surfactants, bio surfactant had the best effect on the wettability of rock.
- In countries like China, India and Indonesia, the Soapnut trees are abundant. Due to the biodegradability, neutrality, low price, suitable effects on the wettability of rocks and environmentally friendly properties of this surfactant, it can be suggested for chemical oil recovery process.

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