Study on thermo-chemical impact on Crude Oil Recovery

Amte Ayesha Siddiqua Rahman and Neog Dhrubajyoti*
Department of Petroleum Technology, Dibrugarh University, Assam-786004, INDIA
*dhrubajyoti.neog@dibru.ac.in

Abstract

The conventional methods of crude oil recovery with primary and secondary measures are often found incapable in older oil-fields. Thermal-recovery is one of the most widely used EOR techniques. Many previous studies observed that an increase in reservoir temperature leads to a transition in rock wettability from an oil-wet to a water-wet state. The effect of temperature on wettability-alteration is a result of several contributing parameters that include fluid/rock and fluid/fluid interactions. This study considers a heavy crude-oil from an upper Assam oil-field to evaluate the feasibility of producing with low-salinity water flooding under thermo-chemical-mechanism.

The research work first characterizes the porous media by evaluating the petrophysical properties. Following this, crude oil has been characterized to identify the physical characteristics and for classification of crude oil. Both low-salinity and high-salinity-brine-water were then employed to undertake surface-interaction and core-flooding analysis to observe how it interacts with the heavy crude-oil. Finally, the work examines if wettability-alteration has resulted while undergoing interaction at a temperature equal to the reservoir temperature of the well from which porous- media and reservoir-fluids were acquired for the analysis. The findings of the work highlight the merits of each method and how the applied treatment can enhance oil recovery.

Keywords: Contact angle, enhanced oil recovery, rock wettability, low salinity, water flooding.

Introduction

Oil well reservoir rock wettability is defined as the tendency of one fluid to spread on or adhere to a rock surface in the availability of another immiscible liquid. There are over 500 billion barrels of heavy oil and proved and unproved reserves of extra heavy oil, bitumen and heavy oil worldwide. Of the many methods for oil recovery, a popular EOR method that has been used in oil reservoirs, is thermal recovery. In a reservoir setting, we can increase the temperature either by hot-water injection or steam injection.

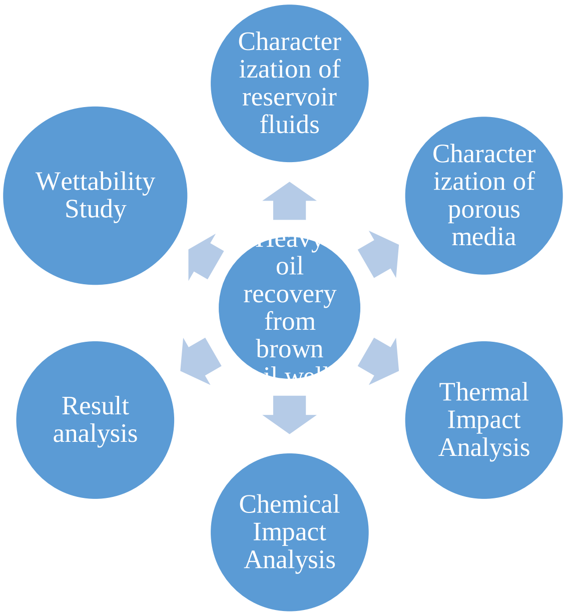
Temperature not only increases crude oil mobility but also brings about wettability alteration from oil wet to water wet, which in turn increases oil recovery[7]. In the oil industry, wettability alteration refers to the methods by which the reservoir rock can be made more water-wet. This shift in reservoir rock's wettability increases oil recovery. Two methods that are traditionally employed to alter wettability in a reservoir are thermal and chemical[9]. There are a number of factors that cause wettability alteration viz. asphaltene deposition, oil composition, pH, saturation history, clay content and initial water saturation[3].

Thermal energy that is introduced to the reservoir changes fluid properties, fluid-fluid interactions and rock-fluid interactions defined by wettability[10]. These properties change during production by different recovery processes[1]. In comparison to sandstone reservoirs, the impact of wettability change is greater in carbonate reservoirs. The hypothesis that carbonate reservoir wettability grows with injection fluid temperature is supported by numerous study findings[5,11,12]. According to Al-Hadhrami et al[2], as temperature increases, carbonates become more soluble in water.

Chalk exhibits oil-wet behavior above a certain temperature, as indicated by a shift in the intersection of the oil-water relative permeability curves towards lower water saturation[6,7]. In a wettability alteration study on temperature effects in carbonate reservoirs by Hamouda and Gomari[8], it was concluded that there is a critical temperature for which wettability alteration is maximum. There will be no further alteration in wettability if the temperature exceeds this critical value[8]. An increase in temperature in thermal recovery processes changes crude oil viscosity by many orders of magnitude[1]. High temperatures cause a considerable reduction to the viscosity of oil (in comparison to water viscosity) and cause a decrease in residual oil saturation at higher temperatures[4].

The current study presents a thermochemical mechanism employing temperature and salinity effects that have a direct or indirect role on heavy oil recovery. The impact of reservoir rock temperature on crude oil recovery is the key issue, which is understood differently by researchers. Many previous research studies highlight two contrasting schools of thought: one that endorses the impact of reservoir temperature on reservoir rock wettability and the other that infers no impact on crude oil recovery.

This study brings to notice the different opinions in this regard in the subsequent analysis involving characterization of reservoir fluids, porous media, wettability measurement and dilution achieved with low salinity and polymer-enriched low brine salinity water. Finally, this study draws a conclusion favouring the impact of reservoir temperature and low salinity of brine water on crude oil recovery.



Work design for heavy oil recovery analysis

Material and Methods

The experimental work was conducted on a core plug sample that represents the part of an actual crude oil-producing porous medium belonging to a tipam sandstone formation in the upper Assam basin. The core plug was used for the petrophysical property determination as well as for wettability measurement. These informations are very much essential to know the feasibility of the porous media to respond to the low salinity and polymer-augmented brine water flooding for heavy oil recovery. The heavy oil was collected from an oil well belonging to the same porous medium. Reservoir fluid analysis was done employing the heavy oil. Low salinity was prepared in the laboratory using NaCl salt solutions. Polymer flood solutions were prepared using polyacrylamide polymer in this analysis.

For measurements of specific gravity, API gravity and density of crude oil, a glass hydrometer was used. Pour point apparatus was used for determination of pour point of crude oil and ASTM distillation analysis was conducted for classification and determination of correlation index (CI) of crude oil. The saturation method was employed for measurement of porosity and an air permeameter was used for evaluation of the permeability of the porous media under study. Finally, wettability measurement was carried out using a contact angle measurement system.

Results and Discussion

Petrophysical properties: Using the saturation method, the porosity of the porous media was ascertained by first washing the core plug sample with chemical solvents. In this experiment, two solvents, toluene and xylene were blended in a 1:1 ratio using a Soxhlet device. After that, solvents were used to clean the core plug sample and the mantle temperature was adjusted to 40 °C. All greasy impurities inside the core plug helped to disappear throughout the cleaning procedure. In this investigation, the Soxhlet apparatus's solvent cleaning process lasted for 70 hours. After cleaning, the core plug sample was placed in an ultrasonic cleaner to remove surface contamination. This process continued for half an hour.

Then, for 65 hours at 72°C in a humidity control oven, the cleaned core plug was placed. Next, the dry sample was placed in the desiccator for saturation of the core plug in vacuum. In this analysis, the dry core plug was saturated with NaCl brine solution. Based on the porosity and permeability values determined in the above analysis, it is apparent that for heavy oil recovery, EOR methods will be required for enhancing crude oil recovery.

Reservoir fluid analysis: The specific gravity, API gravity and density of crude oil were determined using a glass hydrometer. The results are displayed in table 2.

Acid No: The acid no. of the crude sample was determined in the current work and is presented in table 4.

Pour Point: The pour point of the crude oil was determined in this study using a pour point apparatus. Table 4 displays the results of pour point.

ASTM Distillation: The results of the ASTM distillation that determined the UOP characterization factor, correlation index and class of crude are reported in table 5.

Thermal and salinity effect on crude oil recovery: The results of crude oil recovery with respect to two different temperature and salinity were compared. The results are presented in figures 2, 3, 4 and 5. Based on the above flooding process conducted with low salinity water (1000 ppm) at two different temperatures (65°C and 75°C), it is observed that oil recovery is high in cases of low salinity water flooding.

Table 1
Petrophysical Properties

Core ID	Porosity, ϕ, %	Permeability, k, mD	Grain Density, ρ_{mg}, gcm^{-3}	Rock Type, RT
GPS1	12.76	87.65	2.76	Sandstone

Figure 1: DNS1 Tipam core plug sample

Table 2
Specific gravity, API gravity and density of crude oil

Crude Sample ID	°API	Density, g/cc	Crude Oil Type
GCS2	18	0.952	Heavy Oil

Since the crude oil °API gravity falls <20° API, the oil sample is observed to be heavy oil.

Table 3
Pour point

Crude Sample ID	Pour Point (°C)
GCS2	27

Table 4
Acid No

Property	Value
Acid No (mg KOH/g of oil)	6.97

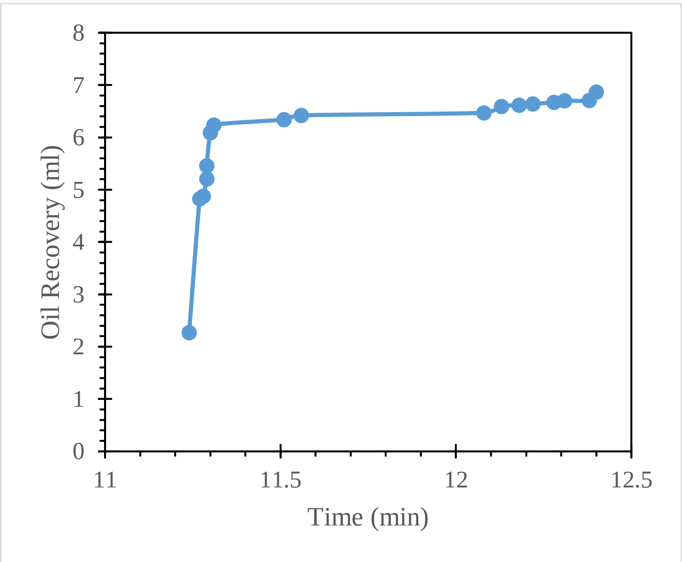


Figure 2: Oil recovery with low salinity (1000 ppm) at temperature 65°C

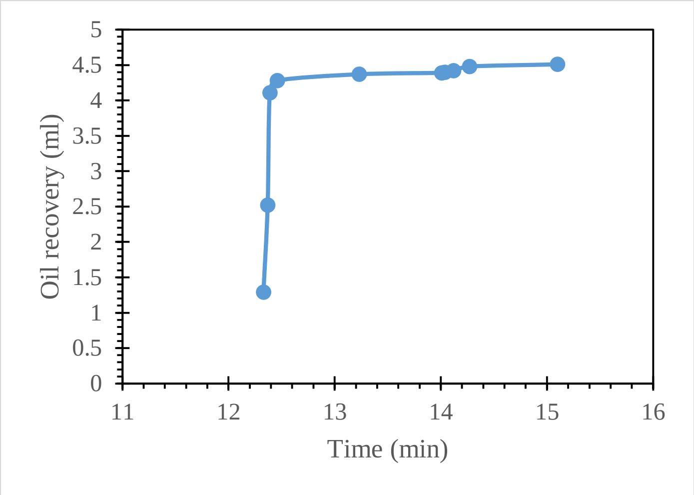


Figure 3: Oil recovery with low salinity (1000 ppm) at temperature 75°C

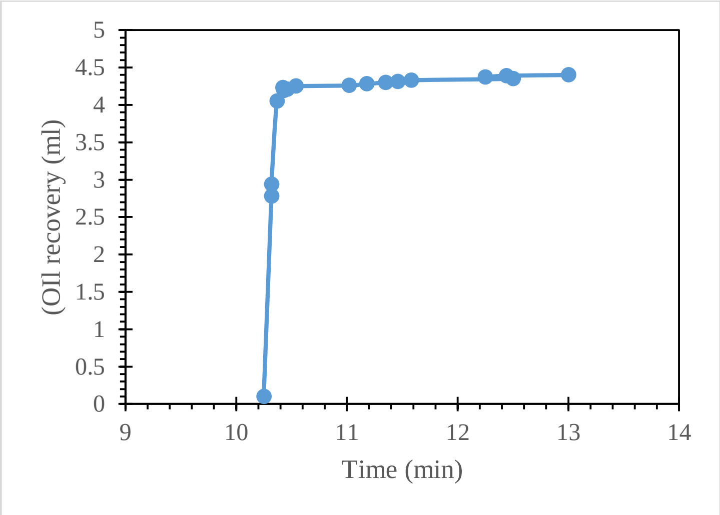


Figure 4: Oil recovery with increasing salinity (8000 ppm) at temperature 65°C

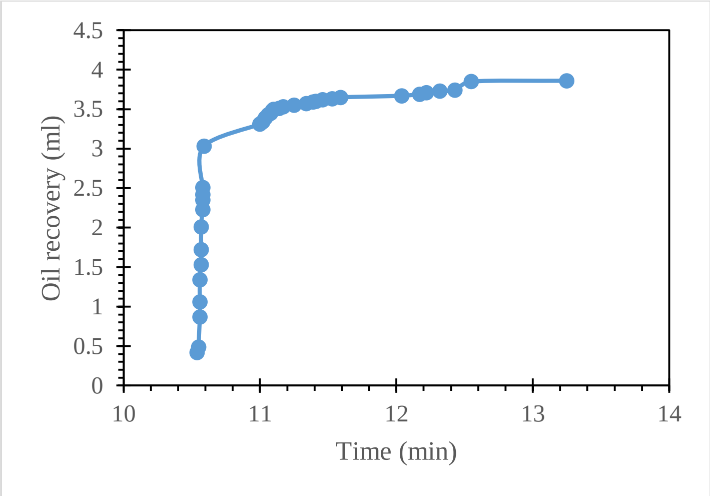


Figure 5: Oil recovery with increasing salinity (8000 ppm) at temperature 75°C

Table 5
Crude Classification

Crude Sample ID	Class of crude	Type
GCS2	Mixed crude with aromatic component	Naphthenic

Figure 6: Wettability w.r.t salinity 65°C (CA:69.8°)

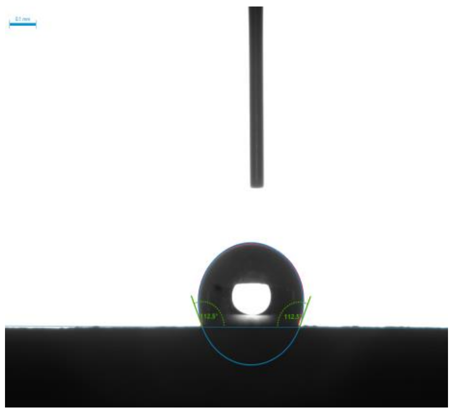


Figure 7: Wettability w.r.t salinity 65°C (CA: 112.5°)

However, when the salinity is increased to 8000 ppm and the temperature is kept constant at 65 °C for the same porous media, water flooding results in higher recovery in the case of a low-temperature water flooding process. Likewise, when temperature was raised to 75 °C and salinity was kept constant at 8000 ppm, higher oil recovery was obtained in the case of a low-temperature reservoir. This study observes that when salinity and temperature roles are compared, the effect of salinity is dominant over temperature, even though raising temperature helps increase oil recovery but is prominent when a specific temperature range is obtained.

Wettability analysis: Wettability analysis was conducted in this work using a contact angle measurement system. To conduct the measurement, first of all, the core plug sample was aged in crude oil for about two weeks. Following this, a drop of brine water solution was released on the surface of crude oil-aged core plug samples. The spread of droplets on the solid rock surface was measured using advanced software of the CA measurement system. This process of determination of wettability employed the sessile drop method. Figure 6 and figure 7 present the wettability of the measured core samples at two different salinities, 1000 ppm and 8000 ppm at 65°C temperature of the reservoir.

Conclusion

The present study observed that in order to produce heavy crude oil from a less porous and permeable reservoir rock, the thermal EOR method can be a feasible option. However, to be successful, thermal EOR alone cannot help to increase oil recovery. This finding establishes that low temperature and low salinity flooding help in the recovery of heavy oil for a specific salinity and temperature range.

It is therefore required to study each well condition independently to select the appropriate temperature and salinity for water flooding to perform in such wells. To sustain or enhance oil recovery from such porous media, salinity plays a very vital role. Low salinity brine water flooding, supported with thermal assistance, can improve oil recovery significantly.

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