IMPROVING ENHANCED HEAVY OIL RECOVERY BY PAIRING HOT WATER WITH SURFACTANT

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ABSTRACT

In the industry of oil and gas, the most important aspect that needs to pay attention is the production of oil and natural gas to maximize the profit of the well. However, it is a challenging process as the mobility of the crude oil is the main aspect that needed to deal with. Although the heavy oil can be recovered through water and surfactant injection, it is still not economically viable as the recovery rates are very low. In the present study, by pairing hot water with three type of surfactants, preferably alphaolefinsulfonates (AOS) and sodium dodecyl sulfate (SDS) of anionic group, a greater increase in the mobility of oil was seen, thus, increasing the recovery of the heavy oil. The first objective is studying the effect of pairing hot water and three type of surfactants to the viscosity and IFT by static condition tests. The second objective of this study is investigating the effect of pairing hot water with the surfactant in enhancing the heavy oil recovery by studying interfacial tension of heavy oil, surfactant and the reservoir rock thus determine the recovery rates of heavy oil when the interfacial tension decreased caused by the temperature of hot water and the presence of surfactants. Static tests were conducted to get a clear understanding on the mechanism by measuring the viscosity and interfacial tension between the heavy oil and injection fluid against heat (from room temperature to 60^{o}C) and time and it is determined that the best surfactant between AOS and SDS is the first one. The recovery volume was measured at the dynamic condition by injecting the best saturation for each surfactant from the static test, with hot water into a core. This study showed that the maximum oil recovery for AOS is when the hot water temperature paired with AOS was at 50°C with 43.2% of oil recovery. Meanwhile, the maximum recovery for SDS is when the hot water temperature paired with SDS was at 60°C with 27.2% of oil recovery. In conclusion, it is shown that the heavy oil recovery of this mechanism is higher than that of pure hot water flooding or the surfactant flooding process.

ABSTRAK

Dalam industry minyak dan gas, banyak tumpuan diberikan kepada kaedah penghasilan minyak dan gas secara konvensional yang menghasilkan pulangan yang lumayan. Salah satu faktor besar yang menyumbang kepada kadar penghasilan petroleum ialah mobiliti minyak. Dan faktor ini menjadi punca utama dalam menentukan tahap kelangsungan banjiran di kala lapangan minyak berada dalam fasa kematangan.Walaupun pelbagai kaedah seperti suntikan selangan air dan surfactant telah diaplikasikan untuk menangani masalah penghasilan minyak yang berketumpatan tinggi, hasil daripada analisis ekonomi mendapati bahawa kadar penghasilan minyak mengikut kaedah ini tidak mendatangkan keuntungan kepada syarikat ikutan daripada kadar penghasilan yang terlampau rendah. Kajian ini dilakukan bertujuan untuk menilai kesesuaian cara suntikan air yang dipanaskan pada suhu tertentu dan surfactant; alphaolefinsulfonates (AOS) and sodium dodecyl sulfate (SDS) yang termasuk dalam kumpulan anionic group. Static tests were conducted to get a clear understanding on the mechanism by measuring the viscosity and interfacial tension between the heavy oil and injection fluid against heat (from room temperature to 60^{o}C) and time and it is determined that the best surfactant between AOS and SDS is the first one. The recovery volume was measured at the dynamic condition by injecting the best saturation for each surfactant from the static test, with hot water into a core. Kajian ini mendapati bahawa pennyuntikan air pada suhu 50°C bersama AOS telah menghasilkan perolehan minyak tertinggi iaitu sebanyak 43.2% pada fasa perolehan Tertier. Hasil kajian juga mendapati bahawa penghasilan perolehan minyak tertinggi bagi suntingan SDS bersama air panas adalah pada suhu 60°C dengan kadar 27.2%. Sebagai rumusan, suntikan air panas bersamasurfactant mempunyai potensi yang lebih baik dalam process perolehan minyak berbanding dengan kaedah suntingan air panas sahaja dan kaedah banjiran surfactant.

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LIST OF ABBREVIATIONS

AOS	-	Alpha Olefin Sulfonates
API	-	American Petroleum Institute
BAC	-	Benzalkonium Chloride
BZT	-	Benzethonium Chloride
CHOPS	-	Cold Heavy Oil Production with Sand
CPC	-	Cetylpyridinium chloride
CTAB	-	Cetrimonium Bromide
DODAB	-	Dioctadecyldimethylammonium Bromide
EOR	-	Enhanced Oil Recovery
HLB	-	Hydrophile-lipophile Balance
HWWS	-	Hot Water with Surfactants
IFT	-	Interfacial Tension
PFO	-	Perfluorononanoate
PV	-	Pore Volume
PVT	-	Pressure Volume Temperature
RF	-	Recovery Factor
SAGD	-	Steam-assisted Gravity Drainage
SDS	-	Sodium Dodecyl Sulfate
SLES	-	Sodium Lauryl Ether Sulfate
SLS	-	Sodium Lauryl Sulfate
THAI	-	Toe-to-heal air injection
USGS	-	U.S. Geological Survey
VAPEX	-	Vapor-assisted Petroleum Extraction

LIST OF SYMBOLS

%	-	Percent
°C	-	Degree Celsius
°F	-	Degree Fahrenheit
cm	-	Centimetre
cm3	-	Centimetre Cubic
cP	-	Centipoise
g	-	Gram
m	-	Meter
md	-	miliDarcy
min	-	Minutes
mL	-	Millilitre
mm	-	Millimetre
mN/m	-	Mili Newton per meter
sec	-	Second
T	-	Temperature

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

In the industry of oil and gas, the most important aspect that needs to pay attention is the production of oil and natural gas to maximize the profit of the well drilling. In extracting the oil, there are several stages need to be done to maximize the production of oil. These stages are separated into three different recovery oil stages which are the primary, secondary and tertiary. The primary oil recovery stage is where the hydrocarbons is obtained when the hydrocarbons rise to the surface naturally with the help of the reservoir drive that occurs from various natural mechanisms. Some of the natural mechanisms that naturally drive the oil out of the reservoir are oil displaced downward into the well by the natural existed water, natural gas that has expanded at the top of the reservoir, gas that initially dissolved in crude oil and has expanded, and oil movement from upper to lower parts where wells are located within reservoir that results in gravity drainage.

Concurrently, there are also other factors of the formation and fluid properties that disrupt the flow of oil to the surface as pressure, permeability, viscosity and water saturation. Therefore, sometimes artificial lift mechanisms like electrical submersible pumps, beam pumps and pump jacks, that are being used to drive the oil out and up to the surface and hence extract the limited hydrocarbons during this stage. Typically, varying up to 15%, only a limited, minute fraction of the original oil in place is recovered during the primary recovery phase. This is illustrated in Figure 1.1 below that was obtained from the Petroleum Geology website of Chulalongkorn University, www.petgeo.weebly.com.

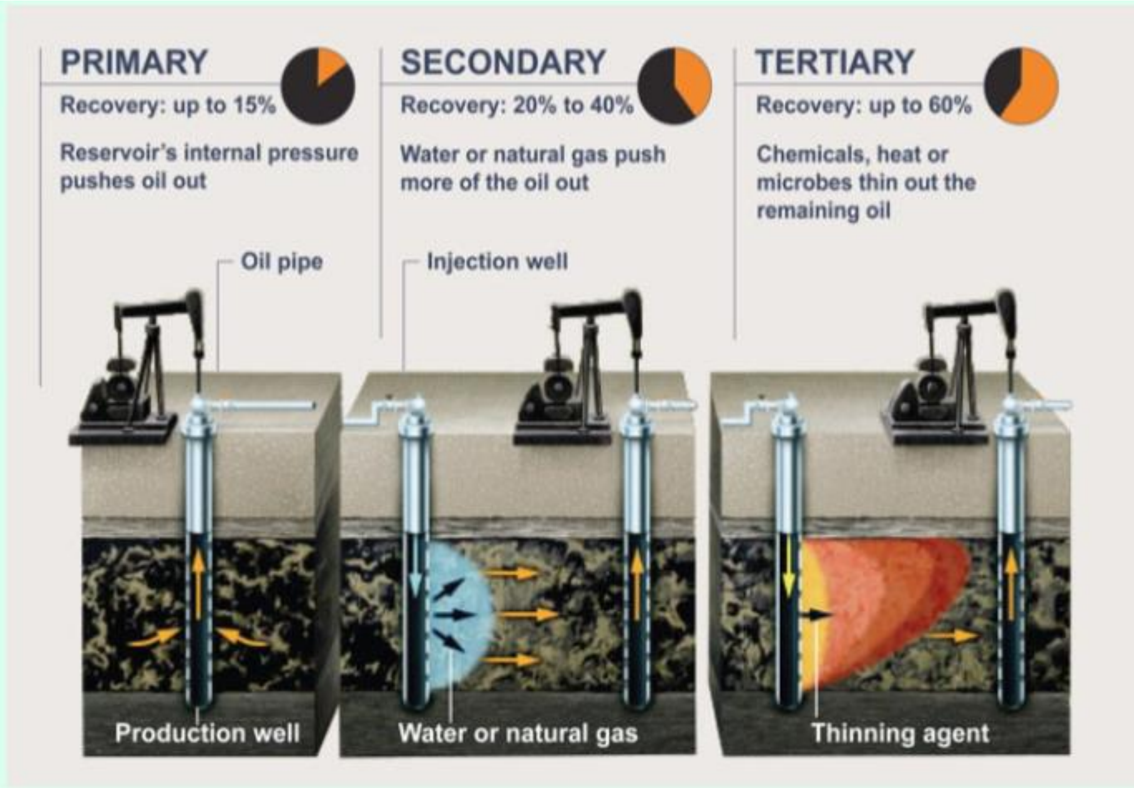

Figure 1.1. Original oil in place recovery percentage during the three recovery phases. Reference: "The Reservoir", 2019

As time goes by, the natural drive force of the reservoir recedes resulting insufficient pressure to draw the oil to the surface naturally. Therefore, for the next (secondary) oil recovery stage, the usage of water and gas injection is utilized in order to maintain the pressure of the reservoir and forcing the oil to move to the wellbore to be extracted. An increase in reserves and production is expected during secondary recovery compared to during primary recovery method. Up to 75% of oil in the well can be driven out by combining the primary recovery with secondary recovery according to the US Department of Energy. The two most common techniques used in the secondary recovery are waterflooding and gas injection. By injecting gas or water into an active well's bottom, these techniques promote in reducing the oil's overall density that exists in the wellbore. Usually, the gas cap is injected with gas and the production zone is injected with water to sweep oil from the reservoir. When the water or gas injected are produced from the production wells in a significant amount, it indicates that the secondary recovery stage has reach its limit and no longer economical for the production. An additional fraction of the original oil in place is retrieved during the secondary recovery phase varying from 20% to 40% ("The Reservoir", 2019). This is also illustrated in Figure 1.1 above.

The final stage of oil recovery is known as tertiary or enhanced oil recovery (EOR). This stage is initiated only when the extracting process is still profitable and when the secondary oil recovery is inadequate to produce enough oil production. Not only this stage aids in preserving the pressure of the reservoir, this stage also helps in intensifying the production of oil by altering the properties of the oil thus boost the mobility of the oil. There are three common groups in enhanced oil recovery technique which are the miscible gas flooding, thermal recovery and chemical flooding. Before deciding which type of EOR is suitable for a reservoir, a thorough evaluation must be made on the reservoir by doing evaluation on reservoir characterization, screening, scoping, and reservoir modeling and simulation. During the tertiary recovery stage, another additional of the reservoir's oil can be recovered up to 60% if the EOR method chosen is suitable with the reservoir type ("The Reservoir", 2019).

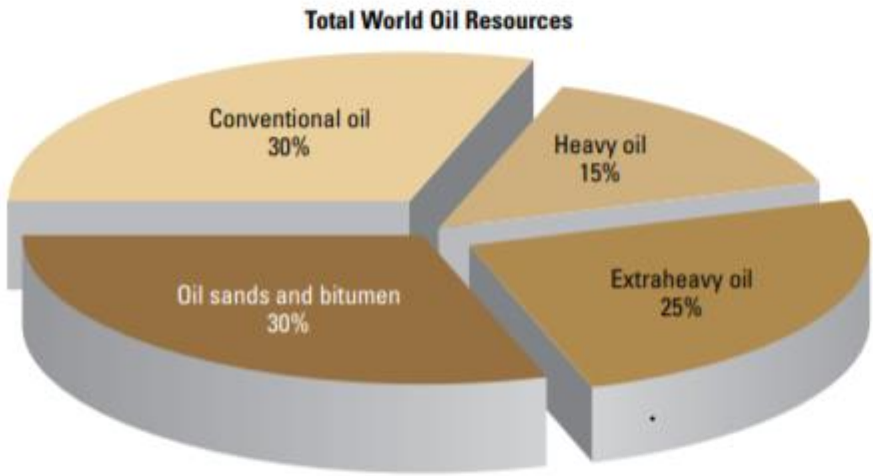

Figure 1.2. Proportion of world oil resources in the world. Reference: Faergested, 2016

According to Irene M. Faergested in her paper 'Heavy Oil', more than 35% of the world's heavy oil resources are located in Venezuela and Canada, followed by the Middle East, US and Russia. Together, heavy oil, extra-heavy oil, oil sands and bitumen account for about 70% of the world's total oil resources; heavy oil alone accounts for 15%. In some California heavy oil fields, EOR has doubled or even tripled the oil reserves and ultimate oil recovery. This can be seen on the largest oilfield in California, the Midway-Sunset Oil Field. There are currently around 89 billion barrels of additional oil trapped in onshore reservoirs estimated by the US Department of Energy. They claim that the pervasive application of enhanced oil recovery technologies on the US reserves could boost the oil recovery of the country from roughly 30% to up to 60% ("What Is EOR, and How Does It Work?", n.d.). As mentioned before, substantial portion of petroleum resources that have been discovered in the world is mainly made up from heavy oil and it is expected in the future that these heavy oils going to be the main source to the world's energy as the conventional oils supplies is progressively decreasing. As heavy oils have high viscosity and high density, their recovery energy is more critical and challenging to deal with when compare with other lighter oils, thus only limited amount of these heavy oil was able to be produced up to now. Not only that, the current costs to generate a barrel of the heavy oil is much greater than the current costs to produce a barrel of oil from conventional resources.

1.1.1 Description of Heavy Oil

According to U.S. Geological Survey (USGS), a crude oil that is distinguished based on its asphaltic, dense, viscous nature, and its asphaltene content is known as a heavy oil. Heavy oils contain waxes, carbon residue and other impurities and these things need to be removed before the heavy oil is refined. For heavy oil, the viscosity is said to be around 100 centipoise and the upper limit is said to be 22° API gravity. Hence, as a consequence of having high density and high viscosity, heavy oils could hardly be recovered in their natural state by traditional production techniques and peculiar methods need to be used to efficiently recover the heavy oils.

1.1.2 Production of Heavy Oil

Even though heavy oil can be recovered through conventional methods – pumps, pressure maintenance, and vertical wells – they are not very efficient for the recovery of the heavy oils. Other than conventional methods to recover the heavy oil, there are other methods that are used to extort the heavy oils and among the methods used to extract heavy oils are include but not limited to cold production, thermal injection, toe-to-heel air injection (THAI), vapor-assisted petroleum extraction (VAPEX), steam-assisted gravity drainage

(SAGD), cold heavy oil production with sand (CHOPS), microbial degradation and in-situ combustion.

One of the promising methods in recovering heavy oil is the CHOPS method that improves the well productivity by allowing sand into the wellbore with the heavy oil. CHOPS is also known as the primary production of heavy oil that involves the meticulous inception of sand influx into a permeated oil well, and the extended production of massive amount of sand along with the oil, perhaps for many years ("Cold Heavy Oil Production with Sand in the Canadian Heavy Oil Industry", n.d.). This method was developed in Canada.

Another promising method is the VAPEX method that is a non-thermal method in extracting heavy oil by injecting the heavy oil with vaporized hydrocarbon solvents (condensable and non-condensable gases) such as CH_4 to C_4H_{10}, CO_2 or N_2. As the vaporized hydrocarbon solvents make a contact with the heavy oil in the reservoir, the vapor will then condense and mix with the heavy oil, where then the liquefied heavy oil and the hydrocarbon solvent mixture will gravitate towards lower well and pumped to the surface (Reinhardt, 2010). VAPEX can be the solution for the environmental issues such as lowering the greenhouse gas emissions and water consumption, however, VAPEX still has not achieved economic viability (Reinhardt, 2010).

Apart from CHOPS and VAPEX, Steam-assisted gravity drainage (SAGD) method is another promising method that involves a thermal in situ recovery method that involves drilling two horizontal, parallel wells. The steam is being injected continuously in the upper well while the oil is being recovered at the same time in the lower well. As the steam heats the heavy oil, the gravity is doing its work by allowing the heavy oil to flow into the lower well (International Energy Agency, 2005). The heavy oil is then pumped from the lower well to the surface for processing. With all these methods mentioned to recover the heavy oils, two main challenges remain in concern during the recovery process are the heavy oil's high viscosity and the gravity (Bjørnseth, 2013).

1.2 Problem Statement

1. Enhanced heavy oil recovery method by injecting only surfactants showed that the method is not economical and has relatively low recovery rates (International Energy Agency, 2005).
2. Although the heavy oil can be recovered through injection, it is still not economically viable as the recovery rates are low.
3. A method or mixture for injection need to be introduced to decrease the heavy oil's viscosity so that the oil can flow more easily, thus increasing the recovery rates of heavy oils.
4. In a present study, by pairing hot water with surfactant, a greater decrease in the viscosity is predicted to be seen with heat from the hot water while the surfactants work in lowering the wettability and interfacial tension of the reservoir rocks and the heavy oil, hence, multiplying the recovery of heavy oil economically and safely.

However, despite the fact that current recovery method, which is the thermal method with injection of surfactants, is showing progress on the outcome, there are still abundant justification and research that showed limitations on the oil fields in performing the injection application.

1.3 Hypothesis

Enhanced Heavy Oil recovery method by purely using surfactant flooding showed that the method is not economically viable and has low recovery rates (International Energy Agency, 2005). In the present study, by pairing hot water with surfactants, a greater decrease in the viscosity is predicted to be seen, thus, increasing the recovery of heavy oil economically and safely. As for now, the fundamental concerns that needed to take into consideration for development and enhancement of these limitations are:

i. A comprehensive understanding on the Pressure Volume Temperature (PVT) Analysis before applying the thermal method with injection of surfactants on-site.
ii. A pervasive knowledge on the heat conduction between injected water, reservoir fluids and the rock/sand of the reservoir as this plays a crucial part in the sweep efficiency.
iii. An extensive insight on the IFT and wettability of the surfactants and the heavy oils in order to enhance the sweep efficiency of the heavy oil.

1.4 Objectives and Scopes of the Study

Keeping in view the facts that have been presented above, the main objective of this research is to boost the enhanced heavy oil recovery by pairing hot water with surfactant. By doing this, it is assumed that the viscosity of the heavy oil to decrease greater than the amount that current methods give right now. The specific objectives for this study are:

- To study on the effect of pairing hot water and three type of surfactants to the viscosity, IFT and wettability (contact angle) by static condition tests.
- To investigate the effect of pairing hot water with the surfactant in enhancing the heavy oil recovery by studying the interfacial tension and the wettability of the reservoir rock thus determine the recovery rates of heavy oil when the interfacial tension and the wettability dropped caused by the increasing temperature of the hot water and the presence of surfactants.

In order to achieve and fulfill all the objectives of this study, the following scope that needed to be done are:

- Conducting static test for heavy oil and three type of surfactants which are Alpha Olefin Sulfonates (AOS) and SDS at various temperature range.
- Determining the effects of temperature and time on IFT, viscosity, wettability various concentration of each surfactant.
- Injecting the best surfactant from static test, pairing with hot water to force the heavy oil out of the core.

1.5 Significance of Study

Present research work is proposed to explore the significance of hot water with surfactant for heavy oil recovery. Results of the current study will be a stepping stone for the economically viable and safer production of good quality heavy oil as it will help in exploring alternative methods in producing heavy oils.

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