Enhanced oil recovery: Potential for oil production development in Fang oilfield, Thailand

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Abstract. Fang oilfield is a small onshore reservoir in Thailand containing oil with gravity ranging from 20-40 °API and viscosity of approximately 10-120 cp. The depth of this field is from 300-1,200 meters and the sand thickness is varied from 1 to 7 meters. For over 60 years of natural production, the field has low oil recovery. The difficulty has been attributed to the unfavorable production. Waterflooding, a secondary recovery, has been studied and the results show that the recovery can increase 4-6%. However, the production can be enhanced more with the tertiary recovery methods or enhanced oil recovery (EOR) which are recommended to increase oil production in this challenging field. However, the proper technologies have not been studied for commercial production yet. These technologies can be thermal recovery, gas injection, microbial enhanced oil recovery and chemical methods. Therefore, it will be the objective of this work to review and screen the EOR method to fit well with oil production in Fang oilfield in order to increase oil production. From this EOR screening, the main results from this study reveal that chemical injection is more appropriate for this field than other techniques because of reservoir characteristics and reservoir fluids. Based on the types of oil and composition in the oil, adding alkaline solution and surfactant can improve oil recovery because they can reduce interfacial tension of oil and to make the mobility higher. On the other hand, for other techniques, thermal recovery can increase mobility because of wax formation but it has higher cost. CO₂ injection can increase more oil production. Nevertheless, the sources of CO₂ has less supply and is expensive. Now, microbial enhanced oil recovery is on the beginning state and can provide the good potential. Consequently, based on the revision and screening method, the chemical method provide the higher commercial potential and feasibility to enhance oil production in Fang oilfield and the result of this study can be applied to design the plan of oil production operation in the oilfield in the future.

Keywords: Chemical enhanced oil recovery, interfacial tension, alkaline flooding, microbial enhanced oil recovery, carbon dioxide flooding

1. Introduction
Fang oilfield is a small onshore oilfield in the north of Thailand. It has been produced oil for more than 60 years [1] containing oil with gravity ranging from 20-40 °API and viscosity of approximately 10-120 cp [2]. The detail of geological data and subsurface structure are presented in the literature [1,2]. The

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depth of the oilfield is from 300-1,200 meters and the sand thickness is varied from 1 to 7 meters. For over 60 years of production, the technology used in this field is primary recovery and now the rate of oil production has been decreased. The difficulty has been attributed to the unfavorable production. The technology to increase oil production are the secondary recovery such as water injection and the results show that the oil recovery can enhance 4-6% [2,3]. However, to increase the rate of oil production at the higher level, the tertiary recovery or enhanced oil recovery (EOR) is introduced to apply in this field [4] because this technology is getting more interest due to the less effective primary and secondary recoveries. This technology can be thermal process, gas injection, microbial recovery as well as chemical flooding. The review of these technologies to this field has not been thoroughly studies yet. This will be the gap of this research to study the practical and suitable technologies to apply in this field. Therefore, the objective of this work is to review the advantages and disadvantages of each technique and to select the practical method to increase oil production in this field. Based on oil and produced water properties in this field, the EOR method that is favorable to this oil production will be chemical injection [4,5].

2. Enhanced oil recovery methods

2.1 Thermal recoveries

Thermal recovery is classified into steam processes and in-situ combustion. The main mechanism is to apply heat to oil reservoir to reduce oil viscosity. Steam is used in different ways such as steam-flooding, steam assisted gravity drainage (SAGD) and in-situ combustion [5,6]. For cyclic steam stimulation, steam is fed into the formation and the well is shut for 6 days to allow the steam to soak. The steam can mobilize the oil, build up the reservoir pressure and oil is produced from the same well after 6 days. This can produce oil with the starting state and steam flooding can be applied later. Steam flooding is applied with steam injected into the reservoir through the injection well to supply heat to decrease oil viscosity, making oil easy to flow into the production well. This method is effective in heavy oil reservoirs.

Another more advanced technique is steam assisted gravity drainage or SAGD [6]. It utilizes steam as a media to transfer heat to oil as well as through a gravity drainage. There are 2 horizontal wells with one on top of the other as an injector and a producer. This method is more economical than the other two because gas oil ratio and oil production rates can be enhanced production.

In-situ combustion is another thermal method in which thermal energy is produced in the reservoir by burning. In the combustion that occurs at high temperature from 1000 to 1200 °C [8], the light components of the oil are vaporized and move forward. Based on the high temperature obtained, thermal decomposition may happen and the light components from this combustion move ahead as well. Some parts of the oil is deposited as a coke in the formation and it is used as the sources of energy for burning. While oxygen is fed continuously, a front of combustion moves ahead, the vapor and liquid petroleum materials will move to the production wells.

However, based on thermal recovery, these techniques have been found to be not economical and environmentally friendly because steam and oxygen generation requires high energy to produce thus; resulting in an increase in carbon emission into the environment and the cost of operation [7].

2.2 Carbon dioxide injection

Injection of gas is definitely one of the techniques used to increase recovery and its application has enhanced currently especially from CO₂, nitrogen or flue gas. A gas is fed into the formation with high pressure. That pressure will push oil into the well and go up to the surface. Other than the result from of the pressure, oil recovery by gas injection depends on the phase characteristics of the mixtures of the gas and oil which are greatly rely on reservoir temperature, pressure and oil composition [9].

There are 2 mechanisms for gas injection. First, the injected fluid such as liquefied petroleum gas is miscible with the reservoir oil at the pressure and temperature conditions in the reservoir to displace the oil. The other mechanism is that the injected fluid is immiscible with oil in the reservoir on the first contact. However, the process relies on the component change of the gas and oil, by multiple contacts
between oil and gas in the reservoir and the transfer of components between these phases. With the suitable conditions like composition, pressure and temperature, this change will result in miscibility between the gas and oil phases. These mechanisms generate gas miscibility, enhancing volume of oil or oil swelling and the reduction in viscosity and interfacial tension (IFT).

The CO₂ process is one such process. In general, CO₂ is very soluble in oil at reservoir pressure. As a result, the volume of oil will expand and the viscosity will be reduced prior to miscibility is attained. While the miscibility is obtained, oil containing variety of the intermediate components of oil and CO₂ phases can flow along due to the reduced IFT and the enhancement of the total volumes of the mixed CO₂ and liquid petroleum phases. Nevertheless, the miscibility formation of CO₂ and oil is still the significant mechanism and this will result in CO₂-oil interaction while the pressure is maintained at high level [10]. In these applications, however, more than half of the injected CO₂ recovers with the produced oil and is normally re-injected into the formation to save the operating costs. The rest is kept in the formation by many methods. Furthermore, CO₂ injection causes fingering of the CO₂ through the oil zone and get less displacement efficiency [10].

2.3 Microbial enhanced oil recovery (MEOR)
Microbial enhanced oil recovery (MEOR) is hardly applied in recent year because it is expensive. The development in this field is not commercially proven compared to other techniques. The mechanism of this technology is either by partially digesting long hydrocarbon molecules, by generating bio-surfactants, or by emitting carbon dioxide to make oil flow more easily.

MEOR has two distinct benefits: (1) microbes take less amounts of energy, and (2) the use of microbes is independent on the oil price, as compared to other EOR techniques. In some formations, the microbes are indigenous and only require some food to grow or increase population. Owing to the exponential-rate growth, it has possible to increase the huge amounts of products quickly from cheap and replaceable resources. Therefore, MEOR has the feasibility to be more cost-effective than other EOR methods [11]. However, for Fang oilfield, MEOR has been studied and the results for preliminary study is relatively effective by using bacteria to produce bio-surfactant [12].

2.4 Chemical enhanced oil recovery (CEOR)
CEOR is considered as one of the effective chemical flooding agents because it can greatly lower the IFT between oil and water interfaces and increase the values of sweep and displacement efficiencies, as well as reduce residual oil saturation [4,5]. It includes alkaline, surfactant and polymer flooding. All of these methods involve combined chemicals in water prior to injection into the reservoir. Therefore, these methods need conditions that are favorable for water injection. The mechanisms for these processes consist of mobility-control process and decrease IFT between the displacing fluid and oil. The mechanisms are emulsification of oil to help mobility control. An example of the first mechanism is the polymer-augmented waterflooding and the examples of second mechanism are surfactant/polymer and alkaline flooding.

Alkaline injection is a process to inject alkaline chemicals like aqueous solution of sodium hydroxide or sodium carbonate. The alkaline chemicals react with some components in the oil to form an in-situ surfactant to lower the interfacial tension between water and oil. The process has potential but apparently is limited in some application such as high acid number in oil [13].

As mention above, the mechanism for is process is to decrease the interfacial tension between the displacing liquid and oil. The surfactant/ polymer process is shown that it has potential in terms of an increase in oil production for this EOR techniques [3]. In this method, the displacing liquid is a complicated chemical process called a miscellar solution. This solution provides some components like surfactant, co-surfactant, oil, electrolytes and water.

The surfactant methods have significant possibility due to the potential of designing a method with enhanced performance. However, there are some main problems. For instance, it can be justified only when oil prices are comparatively high and when residual oil after water injection is concerned. The chemical solvents, which contain surfactant, co-surfactant and sometimes oil, are costly. Chemical
losses are important and can occur due to adsorption, bypassing, phase partitioning and trapping because of fingering if mobility control is not controlled well enough. In general, the surfactant stability systems is known to be vulnerable to high salinity and high temperature.

3. Technology comparison

3.1 Characteristic of Fang oilfield

The data of Fang oilfield is obtained from Defense Energy Department (DED), Northern Petroleum Development Center [1-2,14]. One of the areas in Fang oilfield is San Sai area and the detail of formation and fluid properties in this area are presented in Table 1.

Table 1. The detail of formation and fluid properties data in Fang oilfield

| Parameter                  | Values       |
|----------------------------|--------------|
| Top depth [m]              | 700-2,500    |
| Thickness [m]              | 2-70         |
| Density of CO₂ [kg/m³]     | 410-450      |
| Reservoir Pressure [MPa]   | 10-28        |
| Reservoir temperature [°C] | 60-77        |
| Porosity [%]               | 15-24        |
| Permeability [md]          | 18-300       |
| Type of rock               | Sandstone    |
| Oil gravity [°API]         | 20-40        |
| Oil viscosity at surface [cp]| 10-120    |
| Total acid number          | 1.2-1.6      |
| Composition                | C1-C35+      |

3.2 Technology selection for Fang oilfield

In some cases, only one type of EOR technique is practical for a certain field condition but in many cases, the effective techniques can be used more than one. The choice of the most effective and suitable techniques is applied by proper selecting the field characteristics and petroleum properties to the necessity for each EOR techniques. A guideline of the technology selection for the EOR methods is provided in the literature [13].

A differentiation is provided for the formation characteristics and petroleum properties that are needed for each technologies. For example, steam-flooding is valid for oil with high viscosity in comparatively shallow formations. In contrast, gas flooding work well for oil with high API gravity and deeper reservoir that are favorable to miscibility to be attained. Chemical flooding technologies such as polymer, alkaline or surfactant work best with low to medium viscous oils.

From Table 1, it can be seen that the depth is not shallow and the thickness is thick enough for gas injection. The formation is sandstone which is favorable for gas and chemical injections. Also, the porosity and permeability is medium to high range. Reservoir pressure and temperature are conducive to gas and chemical injection as well as thermal recovery.

For oil properties, chemical and gas injection can be applicable for this field. However, thermal recovery is possible but the oil reserve is quite low, thus; making the production cost per unit is high and leading to uneconomical for this technique.

For gas injection, depth is one of major factors to consider because at the deeper level gas can be more miscible in oil. However, at great depths in Fang oilfield, some formations can be applied with CO₂ injection [10]. In addition, the higher temperature or deeper reservoir may cause some problems for microbial population to feed the microbes. At present, the preliminary study for MEOR is successful in this field.

Furthermore, criteria for chemical enhanced oil recovery can be evaluated based on the literature [13]. This method is good for sandstone with medium porosity and permeability (more than 20 mD) with depth less than 3 kilometers. Furthermore, oil density and viscosity should be higher than 13 for
density and less than 150 for viscosity. The composition should be light to intermediate and contains some organic acids. This method corresponds to the characteristics of reservoir in Fang oilfield. Therefore, chemical enhanced oil recovery can be applied very well for oil production in this area [4]. However, some problems such as chemical loss from adsorption on rock surface can be challenging resulting in chemical consumption. Also, the effect of temperature can cause the chemical degradation.

4. Conclusions
Fang oilfield is a small reservoir in the north of Thailand. It has been produced oil for more than 60 years with primary recovery. The difficulty has been attributed to the unfavorable production. A secondary recovery with waterflooding has been studied and can increase the oil production for 4-6%. Therefore, to increase production rate, the tertiary recovery methods or enhanced oil recovery (EOR) are recommended to apply in this field. These technologies are thermal recovery, gas injection, microbial enhanced oil recovery and chemical injection. To decide which techniques will fit well this reservoir, the EOR technologies are reviewed and screened based on the reservoir data and fluid properties in this filed to increase oil production. Based on the screening criteria, the results reveal that chemical injection would be more suitable for this field because it has more advantages over other techniques in terms of reservoir characteristics and fluid properties.

Based on the oil properties and composition in oil, mixing alkaline and surfactant can improve oil recovery because they can reduce interfacial tension of oil and to make the mobility higher. Also, CO₂ injection can increase more oil production. Nevertheless, the CO₂ supply has less and the cost will be higher. Currently, microbial enhanced oil recovery is at the starting state and can provide the good potential. Moreover, the chemical method provide the higher efficiency to enhance oil production in Fang oilfield and the result of this study can be applied to design the plan of oil production operation in the oilfield in the future.

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