

IN-SITU COMBUSTION - A THERMAL METHOD IN ENHANCED OIL RECOVERY

by

Dr. Mohd Nawi Derahman
(Petroleum Engineering Department)

Abstract

Enhanced Oil Recovery, EOR, is the future for oil industry. Any technique of EOR that could increase the total recovery factor by 10% would increase the amount of recoverable oil reserve by 50%. In-situ combustion is one such technique that is applicable to both heavy and light oil reservoirs. The recovery factor by this method is high. This paper explains the benefits of thermal recovery and describes the types of in-situ combustion process.

Introduction

Enhanced oil recovery (EOR) can be defined as any additional production resulting from the introduction of artificial energy into the reservoir¹. The most common EOR techniques in use today are thermal processes, which account for approximately 70% of EOR production².

Figure 1.1 shows the comparison between thermal and other recovery mechanisms for a reservoir at 450 psi pressure, saturated by 15 degree API crude oil. By solution gas drive depletion mechanism, 9% recovery would be obtained at 50 psi abandonment pressure. An additional 9% might be produced if additionally waterflooded. It is estimated that by using thermal recovery method the reservoir could yield 32% to 64% of stock tank oil initially in place (STOIP); corresponding to 50% and 100% vertical sweep efficiency, respectively³.

The following estimate⁴ of the total oil recoverable reserve will help to explain the important role to be played by EOR processes:-

The present recoverable oil reserve is estimated at 96×10^9 tonnes (700×10^9 barrels). Adding it to the 70×10^9 tonnes produced since the beginning of the oil industry, one obtains an ultimate recoverable oil reserve of 170×10^9 tonnes. Assuming that the estimated recoverable oil reserves are presently one third of the original oil in-place (OOIP). Then the oil in place, regardless of recoverability, is assessed at $170 \times 10^9 \times 3 = 500 \times 10^9$ tonnes (3.65×10^{17} bbls). Now, every 1% increase in oil recovery will add 5 billion tonnes to the total oil production which is equal to 1.7 times the present annual world consumption of oil.

Any technique of EOR that could increase the total recovery factor by 10% would bring an increase of 50×10^9 tonnes of oil. This corresponds to a 50% increase in the present amount of recoverable oil reserve.

Thermal Recovery Processes

Thermal recovery processes are characterized by the input of energy into the reservoir, either by injecting hot fluid or through in-situ chemical reaction between crude oil and oxygen. The three basic methods known to date are:

- a. Hot Water Injection
- b. Steam Injection
- c. In-situ Combustion

Applied as a secondary recovery process, thermal methods are superior in the fields where crudes are heavy and viscous. Heat applied to the formation reduces the crude oil viscosity, thus making it flow easier through the reservoir rock to the production wells. This method is also effective for tertiary recovery. Both the residual oil (globules trapped inside pore structures) and the by-passed oil (in the unswept pores) left behind by primary and secondary recovery operations, will be recovered. Thermal methods excel in this aspect because heat conduction from the injection to the production wells is not limited by reservoir heterogeneities.

Thermal processes alter the thermal properties of the crude oil. For very viscous crudes, the viscosity ratio (viscosity of oil / viscosity of displacing fluid) can be of the order of thousands, therefore waterdrive cannot be considered feasible⁵. In such cases, the viscosity ratio can be reduced drastically by increasing the temperature of the crude through application of thermal processes (see fig.1.2).

Reduction of the viscosity ratio is the primary aim in applying thermal methods. In addition, other factors are also involved. In most cases distillation of the crude occurs where the lighter fraction of oil is vapourised and this provides a miscible flood in advance of the thermal front. Thermal expansion of the crude oil will also enhance the recovery.

In summary, the following mechanisms play a part in thermal recovery:

- a. Viscosity ratio reduction, hence increasing mobility
- b. Thermal expansion of the crude oil
- c. Distillation or steam stripping
- d. Thermal cracking of the crude oil
- e. Reduction or elimination of interfacial tension between the crude oil and water
- f. Changes in the absolute and relative permeability to favour oil recovery.

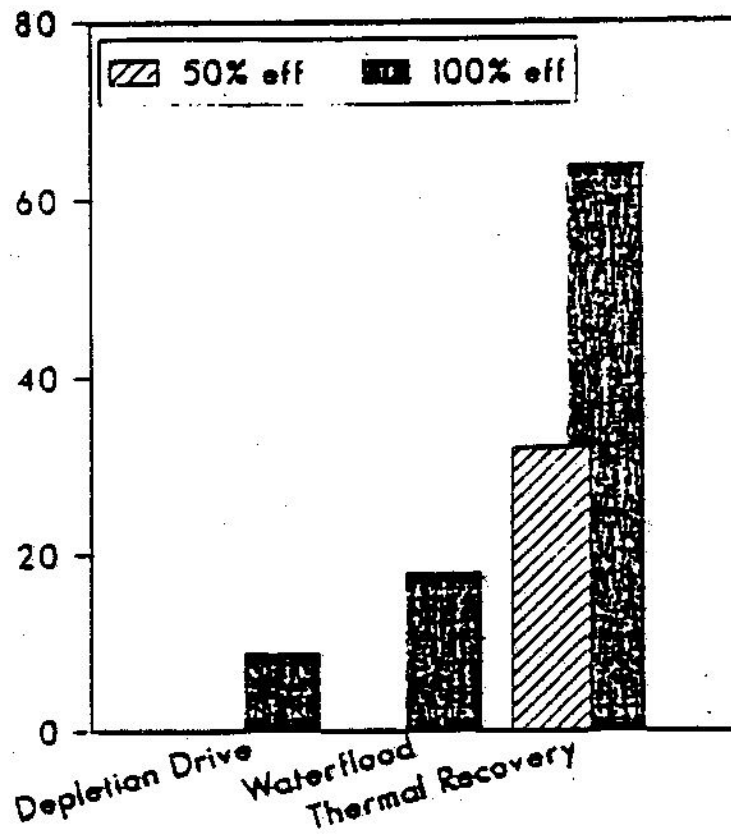


Figure 1.1: Recovery from a 450 psi reservoir saturated by 15°API crude oil

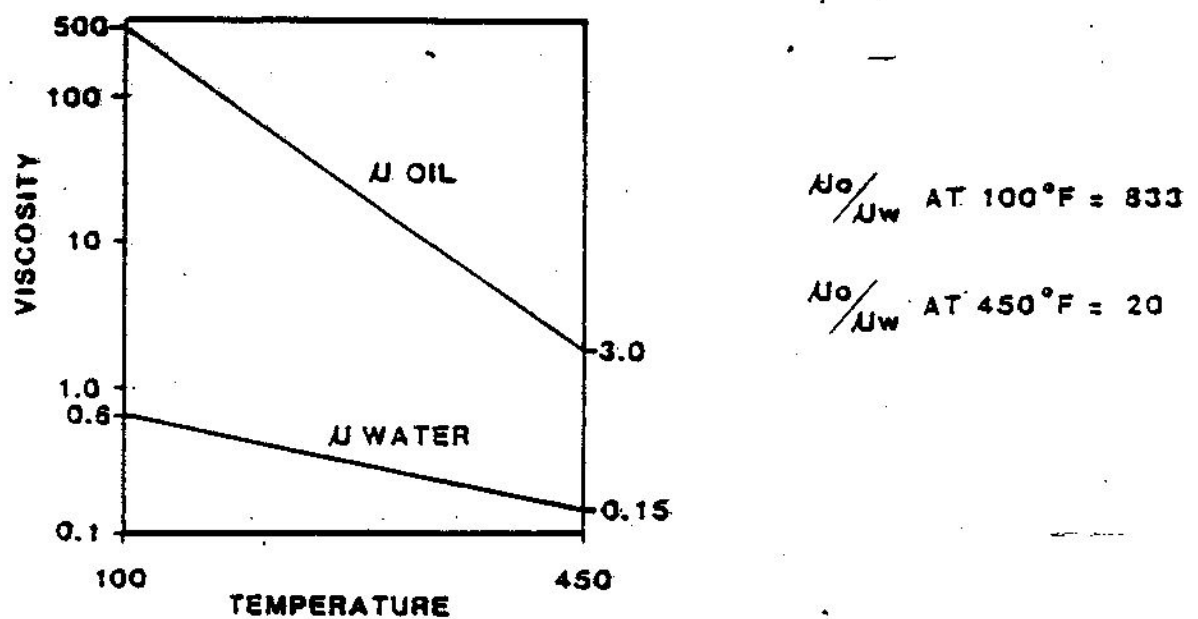


Figure 1.2: Reduction in viscosity and viscosity ratio in thermal processes

In-Situ Combustion

In situ combustion involves burning part of the crude oil in the reservoir to provide the necessary heat. Oxygen-containing gas (usually air) is injected into the reservoir to maintain a combustion zone which is propagated through the reservoir. Ignition of the reservoir crude is spontaneous in some reservoirs; in others it requires preheating of injection air or preceding air injection with an oxidisable chemical such as linseed oil.

There are three common variations of the in-situ combustion process, namely;

- a. Dry Forward Combustion
- b. Wet Forward Combustion
- c. Reverse Combustion

a. Dry Forward Combustion

This process involves injecting air or an oxygen-containing gas into the injection well such that a combustion zone will be propagated within the reservoir rock towards the production wells.

The operations are carried out in the following order⁶:

1. A gas route is established through the oil formation
2. The crude is ignited
3. The supply of oxygen is maintained
4. The air requirement is determined from mass balances

The process is initiated by injecting air into the injection well to establish a continuous gas path between the injection and the producing ends. Ignition may start spontaneously.

Combustion is started in the formation by injecting air that is heated to 400 - 1200°F , depending primarily on the low-temperature oxidation characteristics of the crude oil being ignited. High temperature during burning causes the lighter fractions of oil ahead of the flame to vapourise, leaving a heavy residual coke or carbon deposit as fuel to be burned. The hot produced gases (vapourised light components) and steam formed by combustion and vapourisation of connate water, move forward displacing the oil with it. Upon contacting the cooler portions of the reservoir, the gases and vapours condense. The combustion front moves forward through the reservoir only after burning all deposited fuel. This fuel represents the least desirable portion of the crude under ideal conditions.

Various zones formed in the forward combustion process are depicted schematically in figure 1.3, and a cross-section of the formation is shown in figure 1.4, together with the corresponding temperature profile. Five zones are distinguished in figure 1.3:

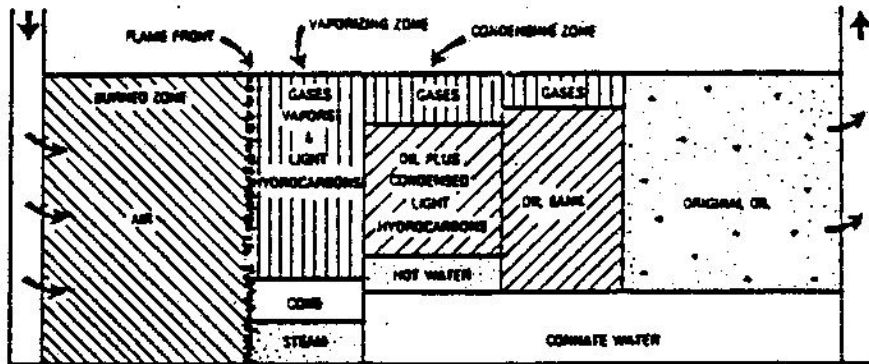


Figure 1.3: Schematic representation of in-situ combustion process

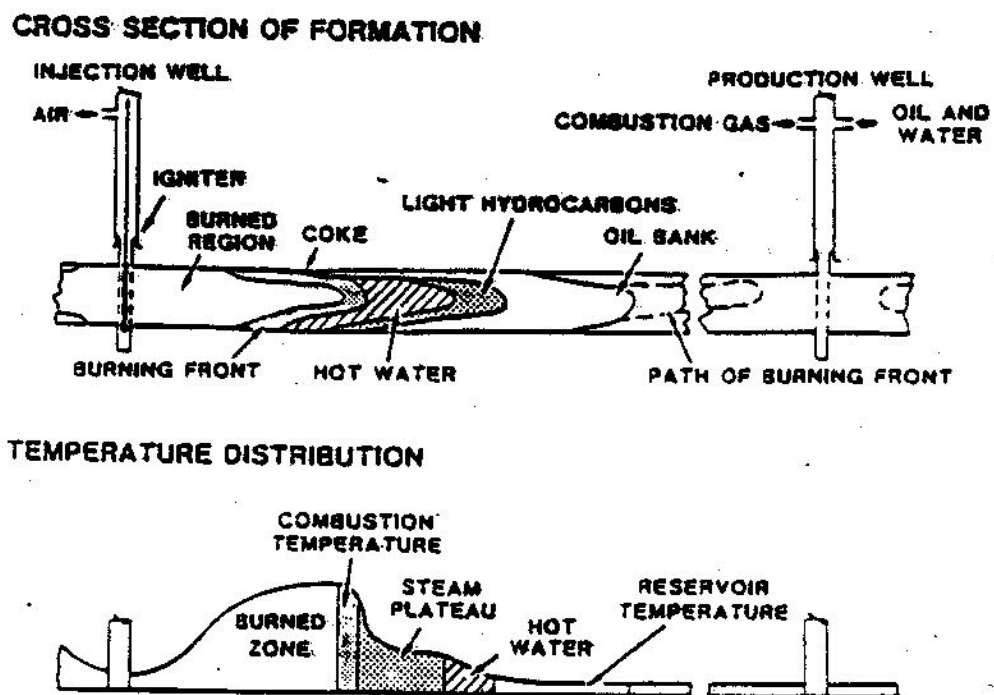


Figure 1.4: Cross section of the formation in in-situ combustion

1. The area nearest to the injector is a burned-out zone which is completely devoid of liquid saturation. Unreacted air passes through this zone. The temperature varies from injection air temperature to a maximum at the burning front. Part of the heat is recovered by air behind the front, but air has poor heat carrying capacity. The remaining heat is lost to the formation and the over- and under-burdens.
2. The Flame Front (Combustion Zone). The high temperature of the burning front from 600 - 1200°F (315 - 650°C) carbonises the crude oil into a coke-like deposit on the sand grains. The coke lay-down from thermal cracking and distillation constitutes the principal fuel that sustains the moving combustion front. The burning front leaves behind a hot clean sand. The size of this zone is negligible in field dimension.
3. Condensing Zone. This is sometimes referred to as steam zone, and is typified by a flat temperature profile. Oil is displaced from this zone by several means:
 - a. Condensed light hydrocarbons become miscible with crude, making the oil more mobile thus improving on the oil displacement
 - b. Condensing steam imparts latent heat to the oil. The resulting hot water then causes a hot waterflood. Mobility is enhanced by the temperature reduction on viscosity
 - c. Combustion gases provide an effective gas drive. Besides physical displacement, the gas also imparts heat and provides carbon dioxide which partially dissolves in the oil, further reducing the viscosity.
4. The Oil Bank, contains higher oil saturation than existed originally. This is formed by the displacement of oil ahead of the water bank. The pore space is occupied by connate water, displaced oil and some combustion gases. Temperature is near initial, hence little improvement in oil viscosity is experienced in this region:
5. The Virgin Zone is essentially at the original conditions, although the exhaust gas drive is imposed upon it.

Energy utilisation in the forward process is very inefficient. Air, being a poor heat carrying agent, will only transfer about 20% of the generated heat, ahead of the combustion front where it is beneficial to the oil recovery. The remaining energy stays in the burned zone and is lost by conduction heat transfer to the surrounding rock.

In order to recover this lost heat, a wet combustion process has been proposed.

b. Wet Forward Combustion

Water is either injected simultaneously or alternately with air to scavenge the heat from the burned sand, thus resulting in a better heat distribution and a reduction in air requirement. Water is flashed to steam, and superheated steam together with heated air transfers heat to the condensation zone ahead of the combustion front. Craig and Parish⁷ have named this alternate air and water injection method the COFCAW process, the Combination Of Forward Combustion And Waterflood.

The amount of water injected will determine whether the process will be normal wet, incomplete wet or superwet as classified by Burger and Sahuquet⁸. The normal wet combustion occurs when all the fuel is burned. At a greater water to air ratio, some of the fuel will be left as residue, and the process is termed incomplete wet. For both normal and incomplete wet processes, water leaves the combustion zone in the form of steam. At some critical level of water to air ratio, liquid water will pass through the combustion zone and the peak temperature disappears. This state is termed a superwet combustion. The movement of flame front leaving behind some residual fuel has an added benefit: less air is required to sweep the reservoir.

c. Reverse Combustion

This method was developed as a technique of improving recovery in reservoirs containing extremely heavy crudes. The combustion front is initiated at the production well and moves backward against the air flow. Crude and high temperature combustion-front come together, severely cracking the crude and forms a relatively large amount of solid fuel. In contrast, the forward combustion drives away the heated crude from the high temperature front, thus only a small amount of fuel is formed.

The greater amount of fuel formed (and consumed) by reverse combustion leads to a lower recovery compared to the recovery by the other methods in in-situ combustion.

Conclusion

In-situ combustion has a future as one of the EOR methods to be applied to the depleting Malaysian fields. The high recovery factor associated with this method, and its suitability to be used in medium and light oil reservoirs will provide the necessary incentives to make this method a viable winner.

Reference

1. Herbeck et al, "Fundamentals of Tertiary Oil Recovery", Petroleum Engineer Jan 1976
2. "Enhanced Oil Recovery - A Technology Primer", Core Lab.
3. Howard, J. , "Thermal Recovery Comes Of Age". World Oil Reprints, 1969.
4. Third meeting on Improved Oil Recovery - An opening speech, Roma, 16-1 April, 1985.
5. Dake, L.P. , "Fundamentals of Reservoir Engineering", Elsevier Scientific Publishing Co., 1988.
6. Wilson, D.C. and Fowler, R.M. , "Location, Size and Characteristics of the Reservoir", Oyez Seminar, London, Mar., 1985.
7. Craig and Parrish. "Laboratory Study of a Combination of Forward Combustion and Waterflooding - COFCAW Processes", SPEJ, Aug., 1982.
8. Burger, J.G. and Sahuquet, B.C. , "Laboratory Research on Wet Combustion". SPE paper 4144, 1972.