IIOAB JOURNAL
ISSN: 0976-3104

ARTICLE

STEAM ASSISTED GRAVITY DRAINAGE IN HEAVY OIL RESERVOIR (SAGD)

Mehdi Foroozanfar

School of Petroleum Engineering, University of Tehran, Kish International Campus, IRAN

ABSTRACT

Heavy oil and tar sands are important energy sources, currently making a significant contribution to the overall energy of the United States and Canada. It is evident that the resource base is much larger than the in-place "conventional" oil which is about 2 trillion barrels worldwide, with about a third recoverable. In the case of heavy oil and tar sand, the recovery factor varies greatly from area to area, depending on the oil and the reservoir characteristics, as well as the process to be used. In this article investigated effect of some parameters such as initial reservoir pressure, initial reservoir temperature, molecular weight of components, energy in rock , water and oil on single horizontal well SAGD process.

KEY WORDS
Heavy oil, Steam injection, Gravity drainage

Published: 10 October 2016

***Corresponding Author**
Email:
m.foroozanfar@ut.ac.ir

INTRODUCTION

Heavy oil and tar sands are petroleum or petroleum-like or semi-solids occurring in porous formations, mainly sands, but also consisting of carbonates. Most of heavy oil deposits occur in shallow (3000 ft or less), high permeability (one to several darcies), high porosity (around 30%) poorly consolidated sand formations. The oil saturations tend to be high (50-80% pore volume) , and formation thicknesses are 50 to several hundred feet . All of these characteristics are desirable for the applications of oil recovery methods.

Geology is in the single most important factor determining the success of a heavy oil recovery project. Geology is important in conventional methods such as water flooding also, but in heavy oil recovery it is more so because the injected fluids (steam, air, oxygen , hot water) are costly and it is crucial that they flow in the desired directions .

Thermal techniques aim at reducing oil viscosity in order to increase its mobility, through the application of heat. A 400°F temperature increase reduces the viscosity of most heavy oils to about 1cp. This is accomplished either by hot fluid injection or by underground combustion.

The thermal process currently in use is

Cyclic Steam Stimulation is basically a Single Well Operation

Communication between the wells are developed and the process becomes very complex. Steam is injected into a well at a high rate for a short time (10 days to one month), following which the well may be shut in for a few days for heat distribution. After that, the well is allowed to flow or pumped. The oil rate increases rapidly to a high value, and stays at a economic level for months. When the rates become uneconomic, the whole process is repeated.

Steam flooding

Much like water flooding, is a pattern drive with array of injection and production wells. In this case, the performance is strongly dependent on the pattern size, since heat loss to the surrounding rocks can consume a large proportion of the injected heat. Steam is continuously injected into the injector, resulting in the formation of a steam zone, which advances at an ever-decreasing rate. Steam overrides due to gravity. Steam reduces the oil saturation within the steam zone to very low values, of the order of 10%.

In-Situ Combustion

Is a unique process because a portion (about 10%) of the in-place oil is oxidized to generate heat. The process has a high thermal efficiency. Air must be injected to oxidize the oil. Heat is generated within a very narrow combustion zone at a high temperature (around 1100 °C). Directly ahead of the combustion zone, cracking of the oil occurs, leading to deposition of a heavy fraction (coke), which burns to support combustion.

Hot water flooding

Is seldom employed because heat losses in surface lines, wellbore and formation , cause a large drop in temperature and reduce its effectiveness in decreasing the oil viscosity.

Effect of temperature

A temperature increase leads to a drastic reduction in oil viscosity, much greater than that for water . The relative permeability are also affected by an increase in temperature. This is attributed to the presence of clays and minerals in the rock, as well as the wettability and contact angle changes with an increase in temperature. In most instances, the residual oil saturation decreases and the irreducible water saturation increases with an increase in temperature. Additionally, the water relative permeability appears to decrease, while the oil relative permeability increases. On the whole, the oil tends to become more mobile as a result of temperature increase, not even considering the viscosity decrease. The oil-water interfacial tension would decrease and capillary number increases considerably.

Oil displacement by steam

The displacement mechanism of oil by steam is more complex. In fact, on a microscopic basis, steam tends to behave as a viscous fluid. If a steam finger gets too far ahead of the main front, it would condense, because of the low temperatures there. The process of oil/water displacement by steam involves other important effects as well, arising from the heat transfer to the cold oil ahead of the front and the gravity segregation of steam.

In reality, the oil ahead of the steam is cold. At the same time, steam tends to segregate toward the upper part of the formation due to its low density. As a result, the oil at the top is heated and mobilized, and driven by steam. The movement and void age of oil further promotes steam flow in the upper parts of the formation. Thus steam tends to segregate and spread over the top of formation. Subsequence advance of the steam zone is downwards, which is accelerated if the wells are produced at an appreciable rate.

Steam segregation, and its spreading over the formation is advantageous, also it is leads to a low vertical sweep in thick formations. If steam were of the same density as oil, and there were no gravity segregation of steam, the displacement of oil would be essentially frontal, with a stable steam front. As a result, very high injection pressure would be needed.

Heat transfer mechanism

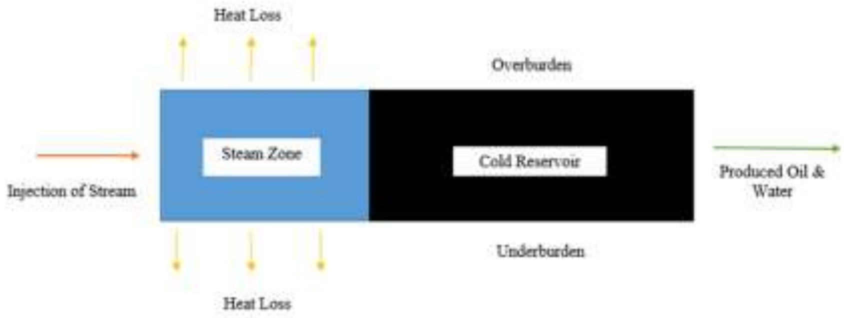
When a hot fluid, gas, liquid or mixture of two is injected into an oil-bearing porous medium, heat is transferred to the rock matrix and the interstitial fluids, as well as to the adjacent nonproductive formations, often referred to as overburden and under burden. Such heat transfer is primarily due to conduction and convection; it is complicated by phase changes and the resulting heat exchange.

In hot fluid injection, heat is transferred to the rock matrix and the fluids by conduction and convection. As the injected fluid partially displaces the oil, water and gas in place, it carries the heat into the pore spaces. The in-place fluids are heated by conduction, and the displaced fluids are heated by conduction and convection, with either predominating, depending on the injected fluid type, and the oil viscosity. The conductive heat transfer to the rock matrix helps to equalize the solid and the fluid temperature, which are usually assumed to be equal in hot fluid injection computations. However, the type of fluid will determine the time to reach such thermal equilibrium. For instance, the heat transfer coefficient in the case of condensing steam is much higher than in the case of hot water. Usually there is a vertical temperature gradient in a formation into which fluid in injected parallel to the bedding plane. In some heat injection calculations, the temperature is assumed to be constant along any vertical plane.

Formation heating by steam injection (marx-langenheim model)

At a given temperature, while hot water carries only sensible heat, steam additionally contains latent heat. This difference in the nature of steam and water is responsible for the contrast in formation heating by either fluid. Hot water must experience a temperature drop in order to transfer heat to the rock and the fluids. Steam on the other hand, can transfer all of its latent heat without any change in temperature.
When steam is injected into an oil-bearing formation at temperature T_R , it displaces a certain fraction of the in-place oil, while condensing and heating the rock and the fluids simultaneously. The condensate formed, still at temperature T_s (saturation temperature) move ahead of the freshly injected steam, preheating the rock farther ahead. Under idealized conditions it could be postulated that the heated zone is at a constant temperature, T_s, extending from the injection end to the point where the temperature abruptly drops from T_s to T_R.

[Fig. 1] shows the idealized temperature and steam quality distributions for steam injection into a formation under idealized conditions. The heated zone, called “steam zone” encompasses the volume of rock and fluids heated to steam temperature, T_s, regardless of steam quality.



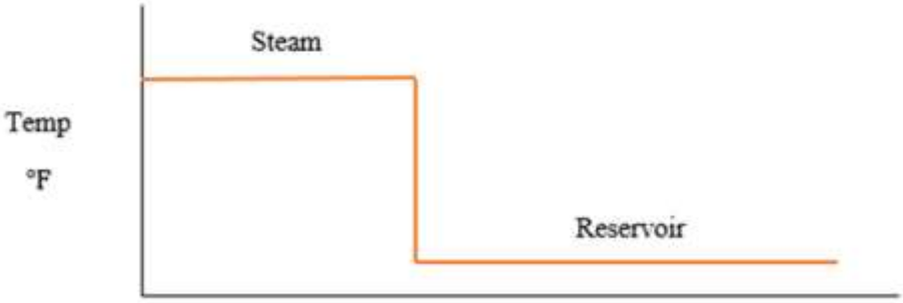


Fig. 1: Schematic Representation of Marx-Langenheim Model for Reservoir Heating By Steam Injection.

Heat Injection Rate = Heat loss rate to the overburden and under burden + Heating rate of the rock and fluids to temperature, T_s

Steam flooding mechanisms

Steam flooding, steam drive or steam displacement is an important heavy oil recovery method. In some instances, it has been shown to be effective in low viscosity oil formations as well. Steam flooding is analogous to water flooding, in that steam is injected on a pattern basis, much like water flooding.

Consider a five-spot pattern, consisting of a center steam injector and four corner producers. As steam is injected into the center well, an expanding steam zone is formed. The hot condensate leaving the steam zone creates a hot water flood effect ahead of the steam zone. Finally, as the condensate cools down to the formation temperature, it gives rise to a cold water flood. Thus, the steam drive process consists of a steam zone, a hot water flood zone, and a cold water flood in the remaining pattern volume. Oil recovery is a result of mechanisms operating in each of these zones.

The most important part of a steam drive is the steam zone, which is approximately at a constant temperature. The oil within this region is highly mobilized, and displaced by the gas drive effect of steam. Many pore volumes of steam reduce the oil saturation in the steam zone from an initial saturation S_{oil}, to a steam flood residual saturation S_{orst}. Thermal expansion of oil further helps increase its mobility; steam distillation of lighter fraction also occurs, further lowering the oil saturation. Other complex effects are also present. For example, the relative permeability to oil increases, and that to water decreases, as a result of temperature increase.

Gravity segregation

It is believed that the gravity segregation is one of the prime factor in overcoming viscous fingering to achieve an efficient displacement process and oil recoveries of 60 to 70%. When we inject steam, it first fingers through a relatively small area of the sand and soon arrives at the producing well. However, due to gravity, with time fingers rise to the top of the sand and spread out a really. In fact, areal coverage is probably close to 100% in many thick, permeable sands. With more time and steam injection steam zone growth downward. Oil at the interface is hot and can thus be stripped off and flows toward the producing well along with hot water falling out the steam zone.

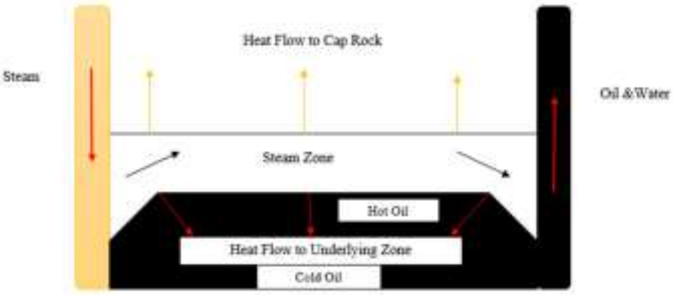


Fig. 2: Recovery Mechanism.

Simulation

Oil component specific heat

Oil component specific heat specifies the first coefficient of the oil component liquid specific heats, for each EOS region. For multicomponent simulations, the oil phase molar enthalpy is the mole fraction weighted sum of the component enthalpies:

$h_o = \sum X_c . h_c . mw_c$ (1)

Where

X_c : is the mole fraction of component C in the oil phase

mw_c : is the component molecular weight

$h_c = C_{P_{1c}} . (T - T_{st}) + \frac{1}{2} C_{P_{2c}} (T - T_{st})^2$ (2)

$C_{P_{1c}}$: is the first coefficient of the component liquid specific heat

$C_{P_{2c}}$: is the second coefficient of the component liquid specific heat

T_{st} : is the standard temperature

Gas component specific heat

Gas component specific heat specifies the first coefficient of the gas component specific heat, for each EOS region. For multi-component simulations, the gas phase molar enthalpy is a mole fraction weighted sum of the component enthalpy values:

$h_g = \sum y_c . h_c . mw_c$ (3)

Where

y_c : is the mole fraction of component C in the gas phase

mw_c : is the component molecular weight

$h_c = h_{c3} + C_{P_{1c}} (T - T_{st}) + \frac{1}{2} C_{P_{2c}} (T - T_{st})^2$ (4)

h_{c3} : is the heat of vaporization at T_st

$C_{P_{1c}}$: is the first coefficient of the component gaseous specific heat

$C_{P_{2c}}$: is the second coefficient of the component gaseous specific heat

Reference pressure

In a live-oil thermal run with N_(C)components , reference pressure specifies the reference pressures at which the hydrocarbon liquid densities are defined.

The expression used to calculate oil component liquid densities is the following:

$$\rho_c = \frac{[illegible]}{[illegible]}$$ (5)

Where

ρ_{ref_c} : is the reference density

C_{P_c} : is the oil component liquid compressibility

P_{ref_c} : is the reference pressure

T_{ref_c} : is the reference temperature

C_{T1_c} : is the thermal expansion coefficient

Introducing the reservoir

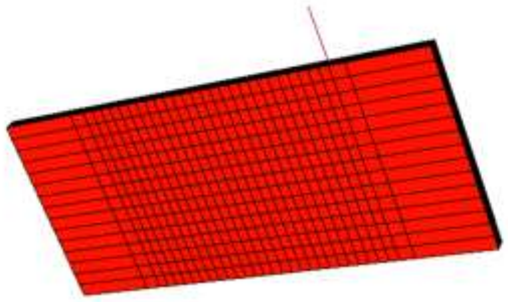


Fig. 3: 3D View of the reservoir.

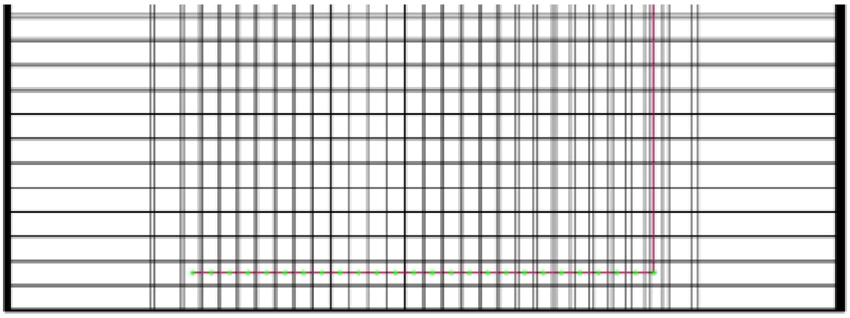


Fig. 4: Well Pattern, Single Horizontal Well SAGD.

Table 1: Reservoir Dimension

X	Y	Z
1400 m	30 m	40 m

In this simulation investigated some parameters such as:

- ☐Initial Reservoir Pressure.
- ☐Initial Reservoir Temperature.
- ☐Molecular Weight of Components.
- ☐ Energy Percentage in Rock.
- ☐ Energy Percentage in Oil.
- ☐ Energy Percentage in Water.

RESULTS

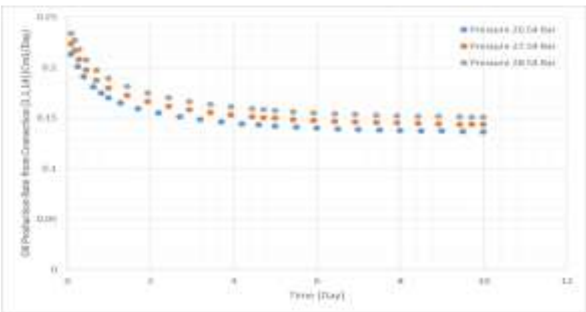


Fig. 5: Effect of Initial Reservoir Pressure on Oil Recovery.

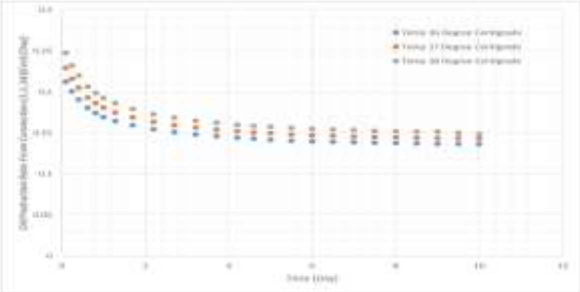


Fig. 6: Effect of Initial Reservoir Temperature on Oil Recovery.

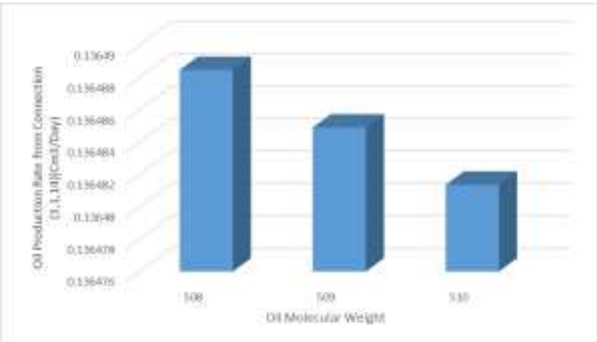


Fig. 7: Effect of Oil Molecular Weight on Oil Recovery.

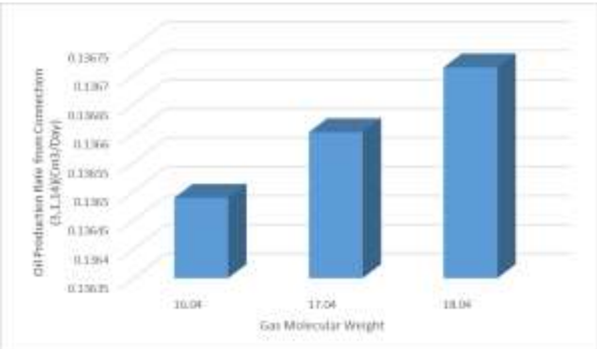


Fig. 8: Effect of Gas Molecular Weight on Oil Recovery.

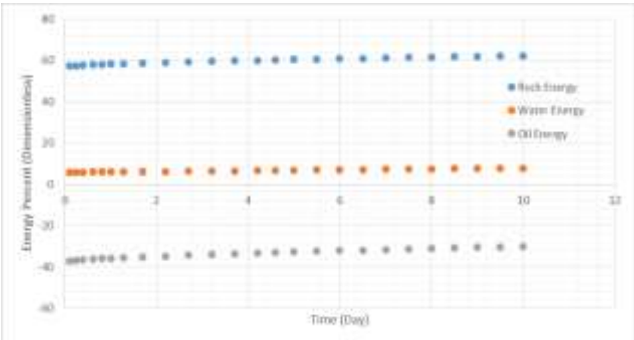


Fig. 9: Energy Percent in Oil, Water and Rock.

CONCLUSION

In steam-assisted gravity drainage, the use of horizontal production wells provide a large contact with the reservoir and this allows provides a large contact with the reservoir and this allows operation at economic rates without bypassing of steam . Reduction in oil prices caused economic issues be more sensible and crucial in compare with last decade , one factor that considered in this simulation is one single horizontal well instead of drilling two horizontal wells , injection through inner tubing and production through outer annulus.

According to the obtained results by increasing the reservoir pressure and temperature the amount of oil recovery increased, one proof for this result is [Fig. 10].

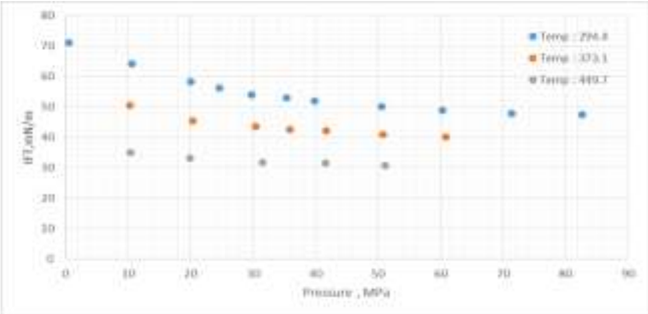


Fig. 10: Effect of Pressure and Temperature on IFT.

……………………………………………………………………………………………………

By increasing the oil molecular weight the amount of oil recovery decreased and this influence is vise versa for gas . One reality that govern in the reservoir is “oil and gas achieve complete miscibility and the vapour-liquid interface vanishes. At the pore level, the miscible displacement is practically 100% efficient, as the lack of interface eliminates the retainment of the oil in pores.” It mean oil and gas should be similar to each other to form one phase to increase oil recovery.

CONFLICT OF INTEREST
No conflicting interests in relation to the work

ACKNOWLEDGEMENTS
To my parents

FINANCIAL DISCLOSURE
No financial in relation to the work

REFERENCES

[1] Butler RM, Mcnab GS, LO HY. [1981] Theoretical Studies on the Gravity Drainage of Heavy Oil During Steam Heating; Canadian Journal of Chemical Engineering. 59:455-460.

[2] Butler RM, Stephens DJ. [1981] The Gravity Drainage of Steam-Heated Heavy Oil to Parallel Horizontal Wells, Journal of Canadian Petroleum Technology. 90-96.

[3] Janisch A. [1981] Oil Sands and Heavy Oil: Can They Ease The Energy Shortage? ; 1st UNITAR Conference, Edmonton, Alberta (June 4-12, 1979), reported in The Future of Heavy Crude Oils and Tar Sands, New York: McGraw-Hill. 33-41.

[4] Berry VJJr, Parrish DR. A Theoretical Analysis of Heat Flow in Reverse Combustion, Trans, AIME 219: 124-131.

[5] Dietz DN, Weijdema J. [1968] Reverse Combustion Seldom Feasible, Producers Monthly. 32(5):10.

[6] Buckles RS. [1979] Steam Stimulation Recovery of Cold Lake, Alberta; SPE 7994.

[7] Shepherd DW. [1981] Steam Stimulation Recovery of Cold Lake Bitumen ; 1st UNITAR Conference , Edmonton , Alberta (June 4-12 , 1979) , reported in “ The Future of Heavy Crude Oils and Tar Sands” , New York : McGraw-Hill. 349-360.

[8] Mainland GG, LO HY. [1983] Technological Basis for Commercial Congress, London, Session RDT3 (1).

[9] Denbina ES, BOBERG TC, Rotter MB. [1987] Evaluation of Key Reservoir Drive Mechanical in the Early Cycle of Steam Stimulation at Cold Lake; SPE 16737, Dallas, TX.

[10] Griffin PJ, Trofimenkoff PN. [1986] Laboratory Studies of the Steam-assisted Gravity Drainage Process; AOSTRA Journal of Research. 2(4):197-203.