Simulation Study of Hot Waterflood and WASP Injection Post Mature Steamflood

(Kajian Simulasi Pembanjiran Air Panas dan Injeksi WASP Pasca Pembanjiran Uap Lanjut)

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Abstract

Steamflood is the most successful thermal EOR applied throughout the world and have produced the biggest portion of oil from EOR methods. As high intensity energy and associated cost are put to produce oil, optimization in any level can have tremendous impacts. Optimization in steamflood operation can be achieved by optimizing steam injection (rate, time), especially in mature pattern/ field or nearing the end of field life/ abandonment. This objective can be done thru utilization of retained heat in the reservoir and overburden/ underburden as they are not instantaneously produced with fluids. By using reservoir simulation, it can be shown that injection is not necessary to be continue until abandonment but can be stopped at a much earlier time hence a much profitable steamflood operation can be achieved.

Keywords: WASP, Hot Waterflood, Continuous Steam Injection

Sari

Injeksi uap panas adalah salah satu bentuk peningkatan produksi minyak menggunakan energi termal paling sukses yang sudah digunakan di seluruh dunia, serta telah menghasilkan porsi minyak paling banyak dari semua metode peningkatan produksi minyak (EOR). Karena untuk memproduksi minyak dibutuhkan intensitas energi dan biaya yang tidak sedikit, maka pengoptimalan injeksi uap panas di tingkat manapun dapat memberikan dampak yang luar biasa. Optimasi operasi injeksi uap panas dapat dicapai dengan mengoptimalkan injeksi uap panas (laju, waktu), terutama pada lapangan/bidang matang (mature) atau sudah dekat dengan akhir masa penutupan lapangan. Hal itu dapat dicapai dengan melalui pemanfaatan panas yang tertahan dalam reservoir, serta tekanan overburden/ underburden yang tidak terproduksikan seketika dengan fluida reservoir. Dengan menggunakan simulasi reservoir, dapat ditunjukkan bahwa injeksi tidak perlu diteruskan sampai masa penutupan lapangan, namun dapat dihentikan di waktu yang lebih awal sehingga operasi injeksi uap panas yang lebih menguntungkan dapat dicapai.

Kata-kata kunci: WASP, Injeksi Air Panas, Injeksi Uap Panas Terus-Menerus

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I. INTRODUCTION

Steamflood is one of the most popular Thermal EOR often applied to medium to heavy oil (API gravity < 20). It gains popularity because of the proven technology and economic viability even though requiring high capital and operating cost. Economics viability stems from high output following high energy injected to ensure a quick payout. Oilfield contractors often prefer quick payout scheme to maximize economical profit in an uncertain environment.

However as in immiscible injection, density difference between steam (injecting fluid) often lead to steam fingering that if combined with reservoir heterogeneities often make the reservoir suffers poor vertical and areal conformance. If these heterogeneities include regions of high permeability, injected steam can propagate rapidly towards the producing wells, leading to premature steam breakthrough. High injection will also destabilize injection front, reducing sweep efficiency causing poor oil recovery. Even with relatively homogeneous layer, upper layer will be desaturated earlier and creating flow path for subsequent steam injection, often called thief zone.

As steamflood project (injection pattern) matures, normally oil production rate decreases and the Steam-Oil Ratio (SOR) eventually become uneconomical. Operator will need to decide whether to continue steam injection or conduct other reservoir management practices, such as reducing Steam-Oil Ratio will maintain cost effective operation. According to Hong (1985), the high SOR or SFR generally lead to, (1) a large amount of heat is retained in the rock and fluids in the reservoir near and away from the injection well and, (2) some heat is being cycled through the reservoir without affecting oil recovery [1].

In reservoir heat management practice however, Steam Breakthrough (SBT) indeed marks important phase where injection rate should be reduced to maintain and expanding steam chest rather than achieving areal sweep. Thus, SBT can be considered as an achievement where starting this point forward reservoir will mostly utilize gravity drainage to move fluids toward producing well. Rate reduction will also reduce problem associated with SBT, including handling excessive steam production, necessity to shut in producer (to cover wider areal sweep). Generally, SBT will increase operating costs, waste injected heat, shorten the life of a project and reduce the net present value of the reserves.

Reservoir management approach can be focused on minimizing heat left behind (wasted) in the rock by optimizing amount of steam injected. If steam injection is continued until the project is terminated, the heat contained in the rock and fluids would be left behind (in producing formations and overburden/ underburden) and wasted. Hence, operator must define a strategy for optimization but still maintain environmentally safe operation.

To accomplish these tasks, several reservoir management practices to transition between steamflood and field abandonment stage have been implemented in oilfield through the world including: reducing steam injection gradually, lowering quality steam/ hot water injection, and Water-Alternating-Steam (WASP). Often combination of these methods is employed sequentially or at different parts of reservoir (such as: flank/ attic) and different maturity stage of the injected patterns.

One important aspect that needs to be considered prior to the implementation is the characteristics of the formation, such as sensitivity to the stress applied as there are possibilities of steam collapse, associated pressure drop and pressure re-bound. Strategies below can be applied:

- 1. Shut down all steam injection. Possible reservoir integrity issues will arise here associated with the collapse of steam chest and following compaction/ subsidence. Existence of aquifer will provide water influx that can support maintaining reservoir integrity.
- 2. Convert some/ all injectors into cold water injection. The benefit is to minimize the time to fill-up and for rapid maintenance of reservoir pressure. However, substantial increase in the reservoir pressure can lead to pressure re-bound after the conversion. Often volumes of water required to accomplish this type of conversion is prohibitive and not cost effective.
- 3. Convert some/ all injectors into hot water injectors to cold water while continuing the pattern steam injection wells. This strategy has

risk of heat losses in the attic area resulting in lower recoveries.

4. Cold water injection into the flank wells only with no pattern injectors. This strategy requires adjustments in the injection volumes (re-allocation) of individual pattern.

WASP and hot waterflood increase efficiency by redistributing thermal so that gravity effect is reduced, altering flow path by sweeping lower part of reservoir and utilize remaining heat. The mechanism involves: (1) a displacement process in which oil is displaced immiscibly by hot water (2) improved oil mobility resulting from a reduction in oil viscosity through an increase in temperature and (3) viscous forces that drag the oil after the initial displacement front.

Conversion to WASP/ hot waterflood can significantly improve project cash flow and increase the value of thermal project. Oil production may not be increased but cost of fuel and associated problem with high temperature well will reduce that will improve sales oil recovery in both breakthrough and non-breakthrough patterns. By reducing temperatures in breakthrough wells, the pump can be lowered, and shut-in wells will return to production.

WASP and hot waterflood have been implemented in heavy oil fields such as Kern River, Cymric and West Coalinga, that has been investigated by Johnson et al. (1989), Dornan (1990), Bautista and Friedmann (1994), De Francisco et al. (1995), where WASP was found effective in controlling steam breakthrough to the downdip producers. Duval et al. (2015) also implemented WASP in a thin reservoir at Pelican Lake, Canada which host immobile oil at reservoir condition not suitable for chemical injection. WASP was found to be effective in maintaining reservoir pressure, sustaining pattern oil production, and improving thermal efficiency [2-6].

Impact of transition to water injection will also by reducing operating cost compared to expensive steam cost (steam generation cost constitutes larger part of total operating cost). Steam injection generally inherits extra risks to safety and environmental which can be drastically reduced by the transition. Steam eruption are often found in steamflood operation where injected steam found its way up to surface through leaked fault or compromised wellbore integrity.

II. SIMULATION MODEL

This study uses a modification of simulation model as in Aziz et al (1987) regarding comparison of performance of six thermal simulators. The study found that the performances and results of those six simulators were fairly comparable [7].

Number of grid is modified from original to 360

(9 x 5 x 8) but top layer is changed to 100 ft cap rock (in order to better capture the temperature change in the cap rock) and remaining layer thickness is increased to a total net pay to 70 ft. Thermal conductivity of reservoir is 24 Btu/ (ft·D·°F), while cap rock is 30 Btu/ (ft·D·°F). Heat capacity of the rock is 35 Btu/ (ft^3 of rock· ^{o}F) and effective rock compressibility is 5 x 10^{-4} psi⁻¹. This simulation uses three components: C1, C2 and Heavy oil components with molecular weight 250, 450 and 600, respectively. Pure water properties are used while oil properties used density at standard condition 60.68 lb_m/ ft³ and compressibility 5 x 10^{-6} psi⁻¹. The coefficient of thermal expansion is 3.8 x 10-4 °R⁻¹ and specific heat (constant) is 0.5 Btu/ $lb_m \cdot {}^{o}R$ and molecular weight is 600. Viscosity was 5780 cP @ 75°F and 2.5 cP @ 500°F.

Porosity was set 30% for all cells. Horizontal permeabilities of sand layers were modified slightly from the original, starting with the top from 2,000 mD, then 500 mD all the way down to the bottom of reservoir. Permeabilities were set exceptionally low (0.1 mD) for cap rock. Vertical permeabilities were modified to reflect more realistic field condition with a ratio of vertical to horizontal permeabilities of 0.1. Initial condition was set as: Oil saturation (55%, with reservoir temperature 125°F and the pressure at the center of the top layer is 75 psia.

As in the original model, the wells consist of one injection wells and 2 producers (near and far). Injection well injects 70% steam quality with temperature 450°F and 20% steam with for water injection. Production wells are operated using controlled BHP mode (17 psi). Four simulation cases were created by varying injection modes as below [8-11]:

- 1. CSI: Continuous steam injection for 10 (ten) years.
- 2. WASP: Steam injection phase for 6 (six) months followed by water injection for 6 (six) months for 10 (ten) cycles.
- 3. Case 02: Steam injection for 5 (five) years followed by water injection for 5 (five) years.
- Case 03: Steam injection for 3 (three) years followed by water injection for 7 (seven) years. Interestingly, CSI has the lowest oil recovery compared to other scenario, as can be seen in Fig.1 and Fig. 4 with other scenarios have relatively similar recovery. The most economical scenario, assuming quickest payout is WASP (with each cycle consists of 6 (six) months steam followed by 6 (six) months water injection). CSI scenario also leaves significant heat behind in the cap rock, as shown in Fig.2. At the end of 10 (ten) years injection, temperature of cap rock is still above 260°F. The same goes for upper layer temperature that shown in Fig.3. Other scenarios leave

relatively similar temperature ranging from 180°F to 200°F. While in Fig.4 it shows that CSI has the highest cumulative energy injected but the lowest oil recovery. Thus, it can be concluded that for these simulation cases that CSI is the most uneconomical scenario due to high operating cost and significant heat remaining (wasted) in the reservoir and cap rock at the time of abandonment.

The lower efficiency of CSI is mostly due to development of thief zone following steam breakthrough at the upper part of injection target zone, leaving bottom part of reservoir remain uncontacted. Water is injected in any mode will contact and improve the mobility ratio of the displaced vs. displacing fluids. Hence the displacement of the bottom part of reservoir could actually increase the oil recovery.

III. DISCUSSION

Interestingly, CSI has the lowest oil recovery compared to other scenario, as can be seen in Fig.1 and Fig. 4, with other scenarios have relatively similar recovery. The most economical scenario, assuming quickest payout is WASP (with each cycle consists of 6 (six) months steam followed by 6 (six) months water injection). CSI scenario also leaves significant heat behind in the cap rock, as shown in Fig.2. At the end of 10 (ten) vears injection, temperature of cap rock is still above 260°F. The same goes for upper layer temperature that shown in Fig. 3. Other scenarios leave relatively similar temperature ranging from 180°F to 200°F. While in Fig. 4 it shows that CSI has the highest cumulative energy injected but the lowest oil recovery. Thus, it can be concluded that for these simulation cases that CSI is the most uneconomical scenario due to high operating cost and significant heat remaining (wasted) in the reservoir and cap rock at the time of abandonment.

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IV. CONCLUSIONS

From the results of the analysis from 4 wells to improve performance by strategy from KPI target as the objective to achieve performance.

1. As steamflood project/ pattern matures, optimization can be performed by reducing Steam-Oil ratio by applying injection strategies/ modes such as WASP, hot waterflood/ low quality steamflood to reduce operating costs and increase profitability.

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- 2. WASP/ hot waterflood oil recovery in this simulation model are higher than CSI mode. In a conceptual model with medium thickness (70 ft), homogeneous sand (no layering with vertical permeabilities one tenth of lateral permeabilities), steam broke through after 4 years of injection. Thus, thickness of the reservoir must be taken into consideration, also from the production and reservoir data suggest that improved sweep efficiency in the lower part of the steam driven sands occurred because of water contacting.
- 3. The model shows that 3 (three) years of continuous injection (Case 03) is sufficient to achieve 74% recovery after 10 (ten) years production with heat stored in the cap rock and reservoir layer. At the time of abandonment, cap rock and reservoir are still retaining some of the heat from first 3 (three) years of injection. Consequently due to its retained heat, overheating of the formation rock must be avoided.
- 4. Better project cash flow can be obtained by optimization of heat by considering final condition in the abandonment of oilfield can potentially improve the heat management practice by shutting in injection early or managed earlier with Water-Alternating-Steam injection. The projects' net oil production can increase significantly because of the reduced oil consumption at the steam generators.

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Figure 1. Recovery Factor



Figure 2. Cap Rock Temperature



Figure 3. Upper Layer Temperature



Figure 4. Steam Chest Developed at CSI Scenario (at five years injection)

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