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An Investigation of Novel Technique Cyclic Steam-Solvent Stimulation Using Horizontal well to Escalate Heavy Oil Production

A M Suranto[1,*], Ristiyan Ragil Putradianto[1], M. Rizqi Al Asy'ari[1], Allen H. Lukmana[1]

[1]Department of Petroleum Engineering, Universitas Pembangunan Nasional "Veteran" Yogyakarta
Jalan Ringroad Utara, Condongcatur, Yogyakarta, Indonesia, 55283

*Corresponding Author: su_ranto@upnyk.ac.id

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Abstract

The oil reserve nowadays is dominated by the unconventional reservoir, heavy oil, extra heavy oil, and bitumen. The current commercial method that has been implemented widely is using thermal injection. Other challenges worldwide are the need for the efficiency of well to reduce the cost of gaining extra oil production in lenses typical reservoir. Cyclic steam stimulation is one of the EOR Processes that numerous oil and gas operators commercially develop to exploit oil reserves. It has heavy characteristics with a high viscosity that can be applied in a vertical and horizontal well. The current limitation of cyclic steam stimulation in the horizontal well is the low drainage of oil in the reservoir. In this study, solvent addition in cyclic steam stimulation will be investigated with reservoir simulation by generating a hypothetic reservoir model to prove the efficiency of this combination as the objective of this research. As a result, the oil production increased 3.5 times higher, lowering 57% CSOR and 16% CEOR more efficiently than horizontal CSS only. In this case, the range of temperature distribution and steam durability are more comprehensive and displace more oil. Briefly, this research will be beneficial as one of the notable references for the industry to implement the combination of cyclic steam stimulation with solvent injection.

INTRODUCTION

The profitable extraction of viscous heavy oil is crucial in the petroleum industry. Steam flooding, cyclic steam stimulation, and steam-assisted gravity drainage are three of the most widely used and commercially viable steam injection techniques. In recent years, the global utilization of these techniques has increased significantly (Boone et al., 2014).

Cyclic steam stimulation is generally carried out periodically. The process can also be called the steam soak process, cyclic steam stimulation, or the huff and puff process. In the soaking process, there is a change in the oil viscosity and oil mobility due to the injected heat. After going through these stages, the well can be reproduced, and steam stimulation is repeated periodically when the oil production rate decreases, as illustrated in Figure 1.

The purpose of cyclic steam stimulation is the same as a thermal injection in general: to increase the productivity of production wells by reducing the oil's viscosity. If the oil's viscosity decreases, the oil's mobility will increase (Hong, 1994; Sheng, 2013). The increased mobility of oil will undoubtedly enhance the productivity of wells. CSS is a reliable, well-proven method that can adapt to thinner inter-bedded reservoirs and only requires one wellbore, resulting in lower capital investment (Canadian Natural, 2021). A horizontal well is selected due to the reservoir drainage effectiveness in lens-heavy oil reservoirs. Applying CSS in the horizontal well will greatly support heavy oil production with low mobility.

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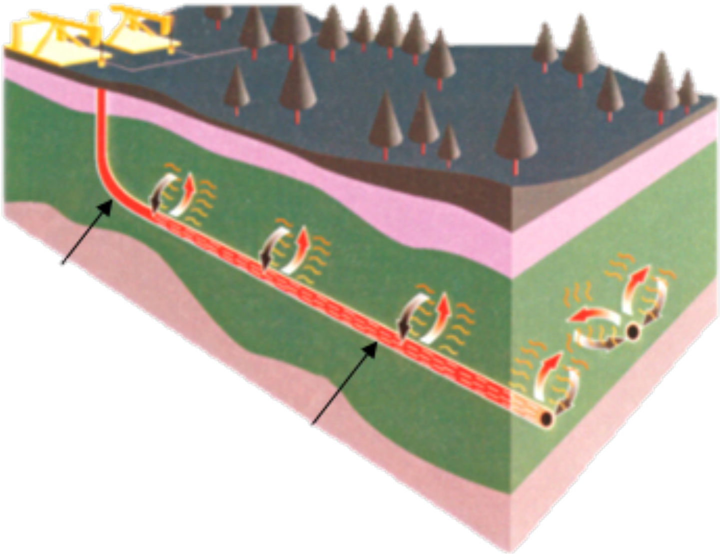

Figure 1. Horizontal Cyclic Steam Stimulation Concept (Modified from Canadian Natural, 2021)

A hybrid steam-solvent injection is one of the steam injection techniques that is useful for increasing oil production, especially in heavy oil. Here, the steam-solvent injection can be carried out continuously or in the form of a good cycle (Jiang et al., 2013). Methane and propane are two types of commercial solvents for use where methane is frequently favored because it is more widely available and has a higher foaming capacity. In contrast, propane has a lower foaming capacity but a good mixing capability.

The horizontal CSS and solvent injection combination have already piloted at Cold Lake in 2014. It is a game-changing technology that has the potential to open up access to new resources that would otherwise be inaccessible via thermal processes. It significantly cut GHG emissions and water use (Boone et al., 2014). A schematic illustration of the concept of the combination of horizontal CSS and solvent injection is illustrated in Figure 2.

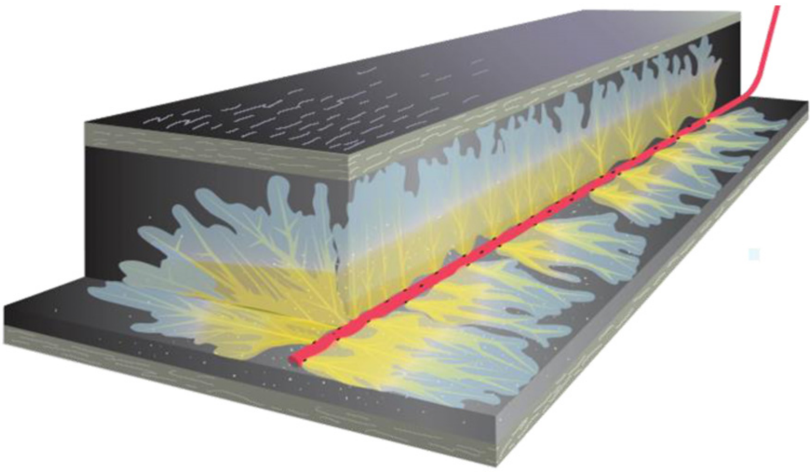

Figure 2. Schematic of combination of CSS and solvent injection where a solvent is injected into a horizontal well (Boone et al., 2014).

A tiny amount of solvent is mixed with the steam and pumped into the reservoir in the steam-solvent combination. As a result, the solvent vaporizes alongside the steam. The solvent will be distilled and dissolved into the bitumen at the steam chamber's boundary. As a result of the combination, the bitumen viscosity will be considerably lowered (i.e., dissolved solvent and the heat from the steam). Condensing a suitable solvent at the same temperature as the water phase is preferable (Suranto et al., 2015).

Based on studies by (Nasr et al., 2003) and Nasr & Ayodele (2006), an excellent typical solvent should be able to condense at the same temperature range as the water phase. The closest one is hexane, a solvent with an evaporation temperature of 215°C at 2200 kPa, which is closest to steam. Shu (1984) stated that the solvent and steam combination much reduced viscosity at low solvent concentrations. Finally, bitumen and heavy oil viscosity significantly decreased as the solvent concentration increased.

The amount of solvent that can penetrate bitumen is determined by the size of the steam chamber. The less solvent penetrates the bitumen, the smaller the steam chamber. At this point, inclining solvent concentration is ineffective since the solvent has restricted mobility to the reservoir's upside and will condense with steam. As a result, it has a positive impact on production. Because the mixture of solvent and bitumen viscosity follows an exponential trend, the effectiveness will be substantially reduced if too much solvent is added (Shu, 1984). On the other hand, horizontal well cyclic stimulation with solvent (HW-CSS-S) has been tested in a Cold Lake-type reservoir. The mixed steam-n hexane as co-injection proses increased oil production and lowered steam-oil rations. Furthermore, the co-injection increases reservoir temperature and reduces solvent solubility (Chang et al., 2009).

Steam-solvent stimulation using a horizontal well makes the drainage more comprehensive and more covered reservoir. In this research, hexane added to steam in the CSS process reaches the optimum case if implemented in X field as represents Indonesia oil field. The data is taken from one Indonesian field representing a heavy oil reservoir. The heat efficiencies and the oil production rate will provide analysis to overcome the benefits of the process of steam-solvent injection. This research will focus on the difference in gain production between the CSS process using steam only and hybrid steam solvent injection.

METHODOLOGY

In this research, two scenarios are applied: a horizontal cyclic steam stimulation pure only and a combination of horizontal cyclic steam stimulation with solvent addition. The precise terms and scenarios are shown in Table 1. The solvent type used in this research was hexane since its condensation condition was similar to water used to create steam for CSS processes.

Table 1. Horizontal CSS Experimental Scenario

Scenario	Explanation
Scenario-1	Conventional Horizontal CSS
Scenario-2	Combination of Horizontal CSS + Solvent Injection

In order to prove the efficiency of the heating process during steam injection with solvent addition, the hypothetical reservoir simulation model was created based on X-Field oil samples and subsurface data. Then, after the model was created and each scenario was already prepared, this study will follow the production forecast and solvent concentration sensitivity to evaluate each scenario's production performance. The detailed workflow for this research is shown in Figure 3.

The simulation study used the thermal reservoir simulator, CMG STARS 2015, to create the reservoir model. The effect of incorporating intelligent completion and solvent injection into cyclic steam stimulation procedures will be investigated using this model. Table 2 summarizes the reservoir properties of the B-field for the essential parameters employed. The geomechanics was overlooked in this investigation, and the model was assumed; thus, the model did not have a bottom water drive or a gas cap. Due to a lack of data, it was assumed that the rock and fluid parameters were uniforms across the reservoir. The oil column's thickness was constant throughout all layers.

The grid specification for this experimental simulation is 20 x 10 x 15 (i, j, k), as shown in Figure 4 for the starting model. The grid size was first set at 5 feet near the wellbore, then increased to 75 feet as it approached the reservoir limit. The reservoir in this model was set to be perforated approximately ¾ of the total reservoir area to simulate one long-horizontal well. The steam temperature was 550 °F and the steam quality was 0.9. The authors kept a constant steam injection pressure (450 psi) at the sand-face, with a maximum steam injection rate (equivalent water) of 500 STB/day. Then, for the duration of the production era, the minimum bottom-hole pressure was maintained at 80 psi.

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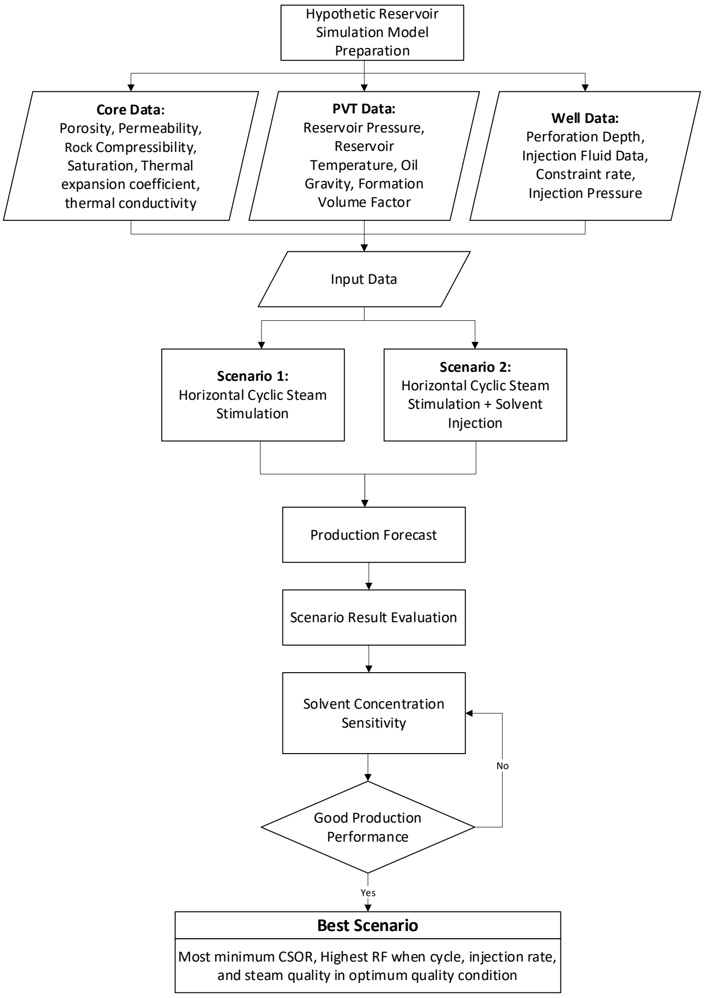


Figure 3. Research Workflow

Table 2. X-Field oilfield reservoir properties

Reservoir Properties	Value
Depth, ft	300-1000
OOIP, MMSTB	144
Initial reservoir temperature, °F	135
Initial reservoir pressure, psi	140
Net thickness, ft	60
Porosity, %	30
Permeability, mD	1500
Rock compressibility, 1/psi	6.62E-05
Oil density, °API	20
Oil viscosity at reservoir condition, cP	1030.6
Oil viscosity at 100 °F, cP	250
Solution gas-oil ratio, SCF/STB	7
Reservoir, underburden/overburden volumetric heat capacity, BTU/ft^3°F	29.9704
Reservoir, underburden/overburden thermal conductivity, BTU/ft-day-°F	105.928
Reservoir Drive	Water Drive
Saturation Pressure, psi	80

During the preheating period, which lasts around 124.7 months, the wellbore temperature is set to 550 °C. The heat will be transported to the near wellbore area by conduction, and the injection and production wells will be connected hydrodynamically during this process. After the preheating process, the wells will be periodically switched from injection to production wells. Steam is injected at constant pressure with a steam quality of 0.9 from the surface.

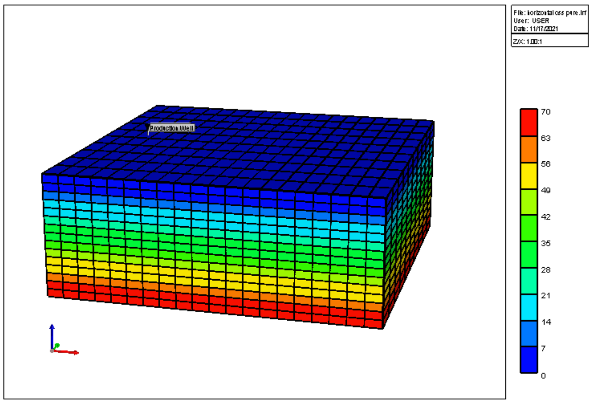


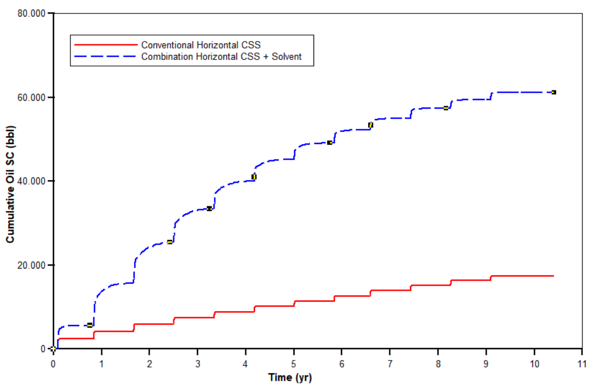
Figure 4. The Idealization of the 3D Model for X-Field

RESULTS AND DISCUSSION

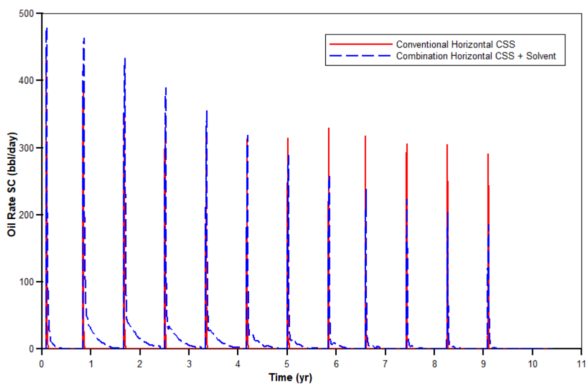
This section discusses the results of the experimental study from various aspects. Those are the cumulative oil production gained, daily oil rate, cumulative steam injection, cumulative steam oil ratio (CSOR), cumulative energy per oil ratio (CEOR), and the solvent sensitivity to make this research more comprehensive and affordable.

As previously stated, the simulation begins with two scenarios and lasts for 124.7 months (equivalent to 10.4 years). Here, the injection phase lasts 24 days, after which the well is soaked for around six days before being put back into production for another nine months. The injection phase, soaking phase, and production phase durations are equal and identical for all scenarios to ensure objectivity and validity.

The results demonstrated that horizontal CSS and solvent injection significantly affect oil production and rate. This remarkable result is represented in Figure 5 as a production performance simulation resulting that the addition of solvent injection can increase 3.5 times incremental heavy oil production compared to the pure conventional horizontal CSS. From this simulation, the combination of horizontal CSS and solvent injection resulting cumulative oil production of 61168.4 bbls, while the conventional one only produces 17459.1 bbls.



(a)



(b)

Figure 5. Production performance of X-Field: Cumulative oil production Vs time (a), and oil rate Vs time (b)

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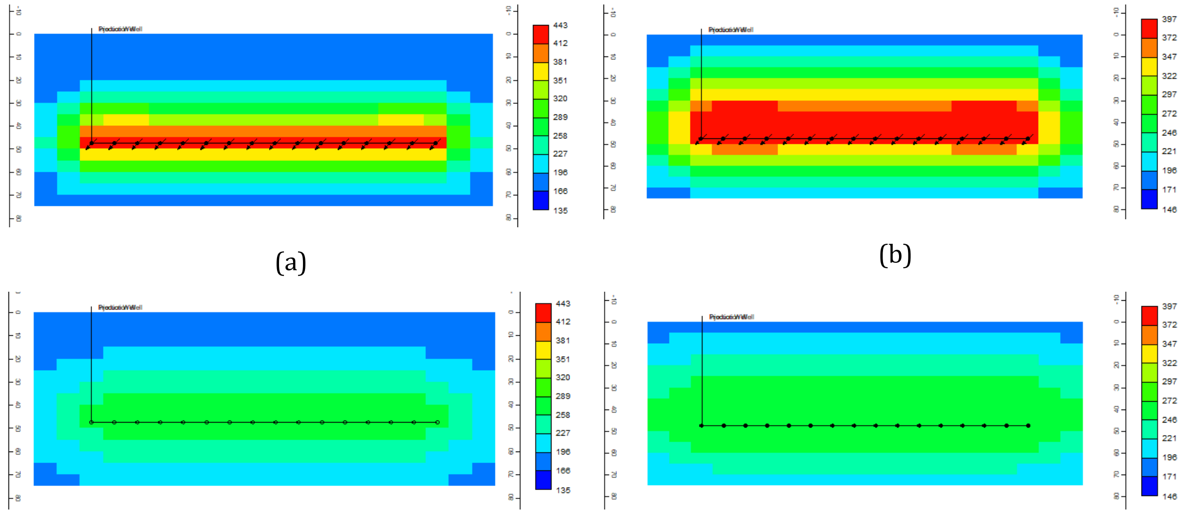
Besides investigating the production performance, this research compares temperature distribution at the end of injection and soaking phases for each scenario. Based on the experimental study, as illustrated in Figure 6, the horizontal cyclic steam stimulation (CSS) and solvent addition combination have better heat distribution than pure horizontal CSS only. Here, the heavy oil viscosity is reduced in two ways, the first is due to steam, and the second is caused by solvent. When the combination of steam and solvent mixes with the heavy oil, it doubly reduces heavy oil viscosity. Therefore, the oil production rate in the steam-solvent injection increases higher than the CSS pore steam.

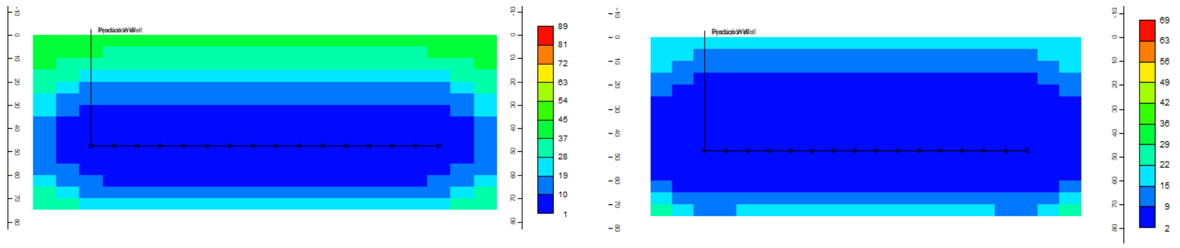


(a) (b)

(a) (b)

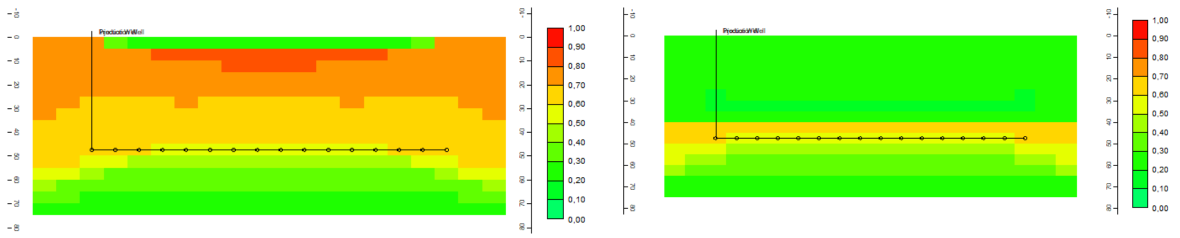
Figure 6. Distribution of temperature during injection period and soaking period: Conventional Horizontal CSS (a) Combination Horizontal CSS + Solvent Injection (b)

On the other hand, the better heat efficiency of a combination of horizontal CSS and solvent addition is also illustrated in Figures 7 and 8. The drainage area on heavy oil in this reservoir has significantly decreased in the steam-solvent injection compared with a conventional horizontal CSS. It is also better for heat distribution compared to the conventional one. Consequently, oil saturation distribution is also reduced in the case of steam-solvent injection because the oil has been displaced by steam.



(a) (b)

Figure 7. Distribution of oil viscosity during injection period: Conventional Horizontal CSS (a) Combination Horizontal CSS + Solvent Injection (b)



(a) (b)

Figure 8. Distribution of oil saturation during injection period: Conventional Horizontal CSS (a) Combination Horizontal CSS + Solvent Injection (b)

Figure 9 shows the result of steam injection of the conventional horizontal CSS and a combination of horizontal CSS and solvent injection. The simulation study shows that the combination of horizontal CSS and solvent injection requires more cumulative injection than the conventional one based on the pressure constraint. This large volume of steam injection was certainly not a significant disadvantage because the implication to heavy oil production was significantly increased.

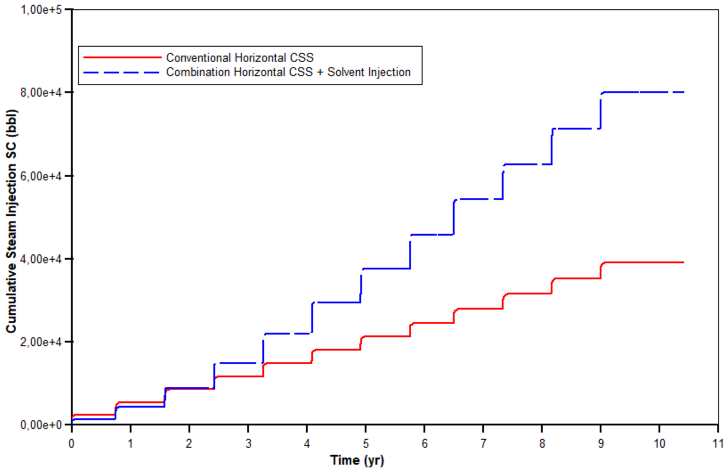
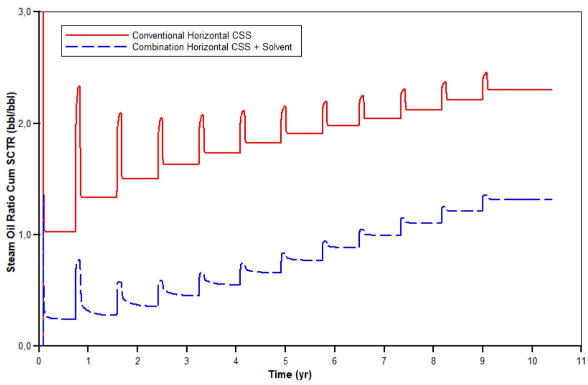


Figure 9. Cumulative steam injection Vs time for each scenario

In the combination of the steam-solvent injection method, there are two terminologies. The first is energy efficiency, defined as the sum of enthalpies from steam injection used to produce bitumen per unit volume (cumulative energy oil ratio [cEOR]). The second factor is solvent efficiency, which is defined as the amount of solvent used to produce bitumen per unit volume (cumulative solvent oil ratio (CSOR)) (Suranto et al., 2015).

This incredible performance from oil production was also validated by a significant reduction in the CSOR when using a combination of traditional CSS and solvent injection over pure cyclic steam stimulation, as seen in Figure 10. The heat efficiency also indicated that the combination with the solvent injection could improve the effectiveness and efficiency of the CSS processes.



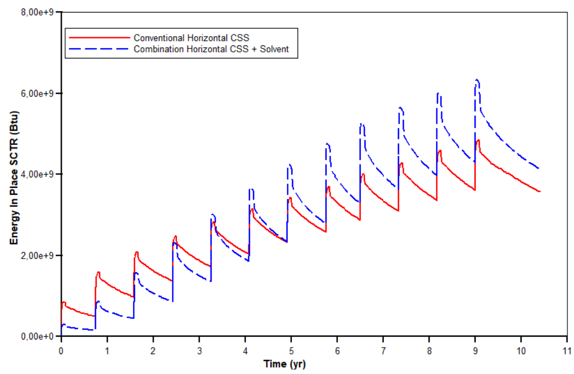


Figure 10. Cumulative Steam Oil Ratio (CSOR) Vs Time (a) and Cumulative Energy per oil Ratio (CEOR) (b)

As stated earlier in the basic theory, the effectiveness will be significantly lowered if too much solvent is added. The phenomenon is caused by the mixture of solvent and bitumen viscosity following an exponential trend. Figure 11 indicates that the effectiveness will be decreased if the solvent is added too much. Generally, more solvent concentration will lead to higher production, but the result shows conversely in this study's case of a horizontal well.

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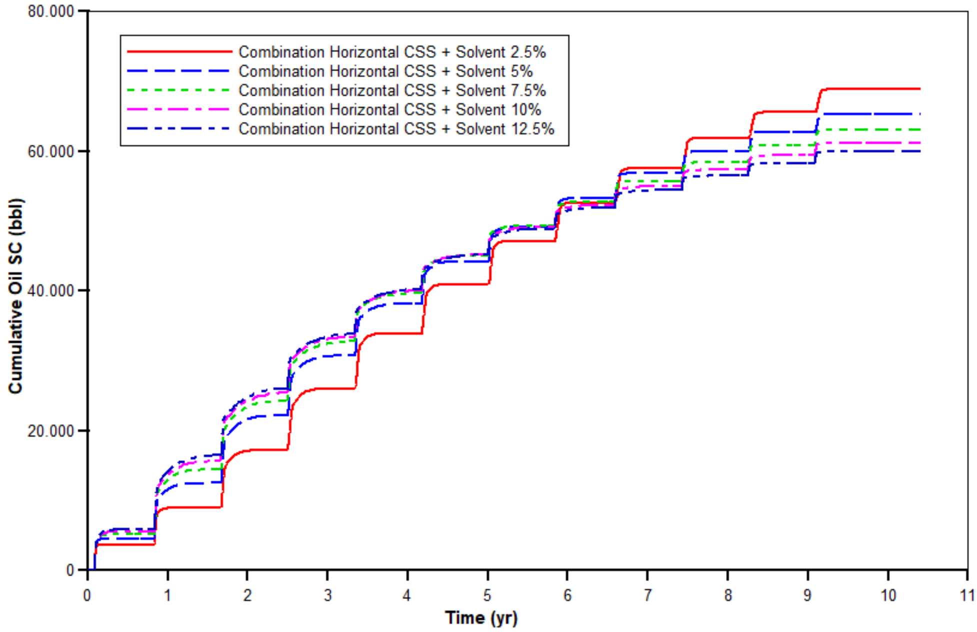
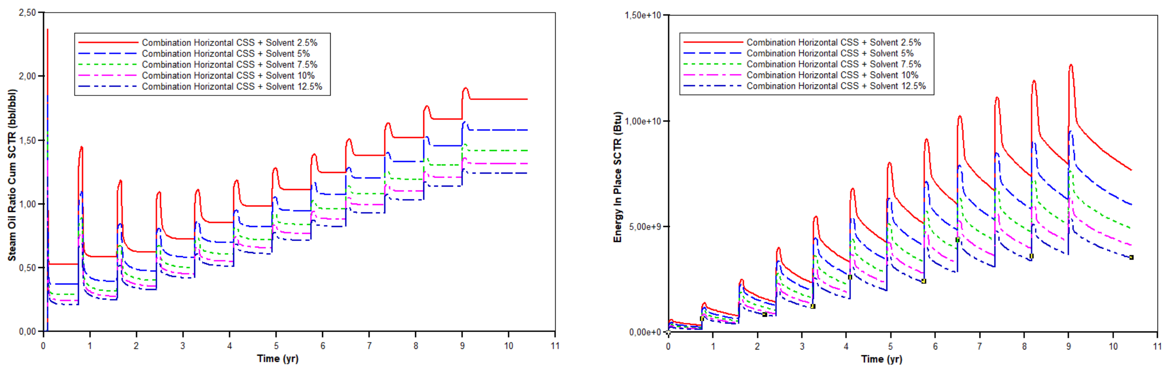


Figure 11. Effect of various range of solvent concentration with cumulative oil production in each scenario

Figure 12 shows that the solvent content decreases the cumulative steam oil ratio (CSOR) and cumulative energy oil ratio (CEOR). The higher the concentration of solvent injection added in CSS processes will lower the CSOR and CEOR. Efficiency and reliability to improve oil production are always the industry's top priority. This experimental study can solve the current challenge of cyclic steam stimulation for steam injection applications more efficiently and significantly increase production. The experimental study of the CSS steam-solvent injection, which has efficient and reliable performance, can be implemented to maximize the value of field assets.



(a) (b)

Figure 12. Effect of various solvent concentration: Cumulative steam oil ratio (CSOR) (a), Cumulative energy per oil ratio (CEOR) (b).

CONCLUSION

This research proves that adding a certain amount of solvent concentration to the horizontal cyclic steam processes has significant advantages. It significantly increases heavy oil production because the solvent multiplies to reduce oil viscosity and make the steam longer and more durable through the reservoir zone for heavy oil horizontal well case. The amount of solvent concentration will become the main reason due to the effectiveness of this combination.

By combining solvent injection with the CSS processes, based on the case study proposed in this research, the result demonstrates significant incremental oil production 3.5 times higher than pure horizontal CSS only. This incremental oil production result also supports CSOR efficiency of 57% with CEOR 16% higher, making this method better results both in efficiency and heavy oil production.

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