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Steamflood Injection Performance on 2 Types of Sand Heterogeneity in XYZ Field

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ABSTRACT

Steamflood is one of the best thermal enhanced oil recovery methods to improve heavy oil production. This project focuses on the benchmarks of steamflood performance in two types of sand: homogenous and heterogeneous formations in the XYZ field. The co-kriging technique was implemented to generate the porosity and net to gross distribution. Afterward, twelve designs of experiments were run to obtain the oil production information and analyze the affecting factors of steamflood performance on each sand. The findings showed that clean sand provided higher oil production compared to the fining sand. Additionally, the well spacing had a higher contribution compared to the steam quality in applying steamflood injection. This study could serve as a guideline for engineers for planning the well spacing and steam quality utilization in steamflood injection in these two types of sand formation that contain heavy oil reserves.

1. Introduction

The fast-growing demand for energy pushes for implementation of effective engineering strategies to increase the energy supply. Petroleum and other liquids are predicted to contribute at least 50% and will become the most consumed energy source required in the future [1]. Therefore, it is essential to investigate methods that can effectively produce fossil energy, especially crude oil and natural gas.

Heavy oil production poses considerable challenges due to very high oil viscosity in reservoir conditions that range from 100 to 10,000 centipoise (cP) with API gravity between 10-22.3 degrees [2]. In fact, the primary recovery techniques could only provide of no more than 10% to 15% of the original oil in place (OOIP) [3,4]. Steam injection is the most widely used method to increase heavy oil recovery. It was first applied by Shell in Venezuela in 1959 based on the report by Schenk [5] and since then steam injection projects have been developed in several countries such as the United

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States, Canada, Indonesia, and other countries [6]. Steam injection utilizes heat injection into the reservoir to reduce the viscosity of crude oil, consequently increasing the oil recovery factor. There are three types of steam injection which include steamflooding, cyclic steam stimulation (CCS or usually called steam huff and puff). And steam assisted gravity drainage (SAGD) [7,8].

Comprehensive steamflood monitoring is the most important activity to be conducted for the success of thermal EOR implementation. Therefore, it is crucial to identify the issue during the steamflood process and evaluate the sweep efficiency, pattern spacing, area connectivity between producer and injector, payout zone permeability, steam quality, and heat management. This information could be obtained from the observation well and the interference tests [9].

Margarita *et al.,* [10] and Jones and Dwivedi [11] found that a high steam rate would also have an impact on the steam oil ratio (SOR). The higher the steam rate, the higher the SOR, leading to an impact on oil production. Al-Hinai *et al.,* [12] indicated that the infill wells would reduce the well spacing and affect the oil recovery factor (RF) on steamflood performance. Zhao and Sarma [13] found that the well spacing also had an impact on peak oil production, where the smaller well spacing would provide a higher peak oil production rate and oil recovery. Dinata *et al.,* [14] claimed that the inverted 5-spot pattern had the highest oil production on the steamflood project. Kusumastuti *et al.,* [15] mentioned that the higher steam quality would provide a higher oil recovery factor for the steamflood project. Liu *et al.,* [16] studied the steamflood injection in extra heavy oil using vertical injection and horizontal producer. The results showed that the oil viscosity was the dominant factor affecting the oil production where the oil production could obtain a 13.3% oil RF of OOIP. Afterward, Pang *et al.,* [17] conducted an experiment and simulation study in the quartz sand for steamflood injection, the result found that four factors affect the oil production performance namely effective displacement, stable displacement, steam channeling, and complete water invading. The oil RF was 36 after these for processes of steamflooding.

The aforementioned studies were conducted on the experiment, simple cylindrical, cartesian static model, complex static model, pilot project, and field application on the homogenous and heterogeneous sandstone reservoirs. However, to the authors' knowledge, there are no comprehensive projects that discussed the comparison of steamflood performance on Clean (homogenous) and Fining (Heterogenous) sand formations. Therefore, this project conducted a benchmark study of the steamflood performance of each sand type in a heavy oil reservoir. This EOR project is considered essential for assisting to fulfill the energy demand. Additionally, the findings of this project could help in faster decision-making on steamflood implementation for each type of sand formation.

2. Simulation and Methodology

This research was conducted by collecting sandstone reservoir data of XYZ field from the Central Sumatra basin, Indonesia as the primary data for rock properties and secondary data for the fluid properties. These data were used to estimate the reserve and oil production. The simulation projects started by utilizing Digitizing the contour map and well log data, Petrel software was used to build a complex reservoir static model, and Computer Modeling Group (CMG) STARS software to set the initial condition, build the dynamic model and design the steamflood scenarios to observe the performance on each sand formation.

2.1 Screening Criteria

Hama *et al.,* [6] and Shafiei *et al.,* [18] mentioned that the screening criteria are essential to optimize the selected EOR project. Table 1 shows the screening criteria for applying steamflood injection.

Table 1
Screening criteria for steamflood [6]

Properties	Preferred condition
Oil gravity (API)	5.8-34
Oil viscosity (cP)	6-5,000,000
Temperature (C)	7.22-82.22
Depth (m)	30.48-1648.96
Porosity (%)	7.5-40.3 (65 is a special case)
Permeability (m^2)	9.8e-16-1.9e-11
Oil saturation (%)	31.8-100

2.2 Data Setup for a Steamflood Injection Project

This project used a black oil model from Argawal and Kovscek [19]. Table 2 shows the fluid properties of this study.

Table 2
Fluid properties [19]

Properties	Water	Heavy oil
Molecular weight (kg/kmol)	234.96	240.40
Critical temperature (C)	373	5,537
Critical pressure (kPa)	2213	68,947
Molar density (g/mol)	28,304	26,539

2.2.1 Rock properties

This project simulated two types of sand formation. Table 3 shows the rock properties from the XYZ field. Afterward, Figure 1 shows the contour map and permeability of the sands.

Table 3
Rock properties of the XYZ field

Properties	Value
Permeability Clean (m^2)	4.45e-12
Permeability Fining (m^2)	1.38e-12
Porosity (%)	22
Thickness (m)	7.62
Depth (m)	1219.2
Swir (%)	20
Sorw (%)	20
WOC (m)	1150.62

2.2.2 Numerical simulation data

Table 4 presents the reservoir size and other specifications for building the model. Additionally, the construction of steamflood model requires thermal and steamflood data for designing the scenarios as given in Table 5. The pressure, rate and temperature injections were set to constant for analyzing the heat transfer, oil and steam production performance in a continuous injection scheme.

Table 4
Modeling parameters

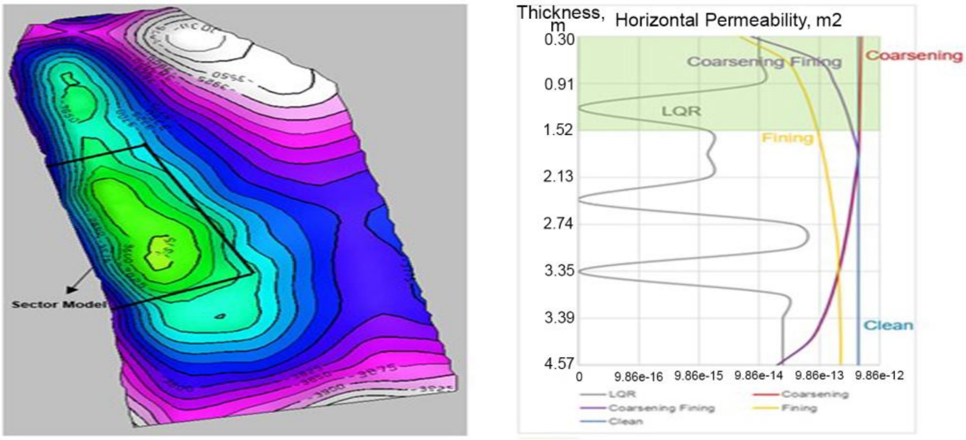
Properties	Value
Number of grid blocks (NxNyNz)	19,753
Grid block size (m)	80.96
Length (m)	3600
Width (m)	6450
Height (m)	129.54
Layer	10

Table 5
Thermal and steamflood data [19]

Properties	Value
Heat capacity (J/gmol-C)	146.51
Thermal conductivity reservoir (J/m-sec-C)	3.17
Thermal conductivity rock for water (J/m-sec-C)	0.149
Thermal conductivity rock for oil (J/m-sec-C)	0.031
Steam rate (m3/day)	238.48
Steam quality (%)	50 and 90
Steam temperature (C)	232.22
Steam pressure (kpa)	20,684.27
Well spacing (m^2)	32,374.9 and 93,077.7

The clean formation is regarded as homogenous formation according to the horizontal permeability in Figure 1(b) since the permeability log profile from the thickness of 0.30 m to 4.57 m is close to vertical which means there is no variance of the permeability values. On the other hand, the fining sand is curving which implies that the permeability values are different in each thickness.

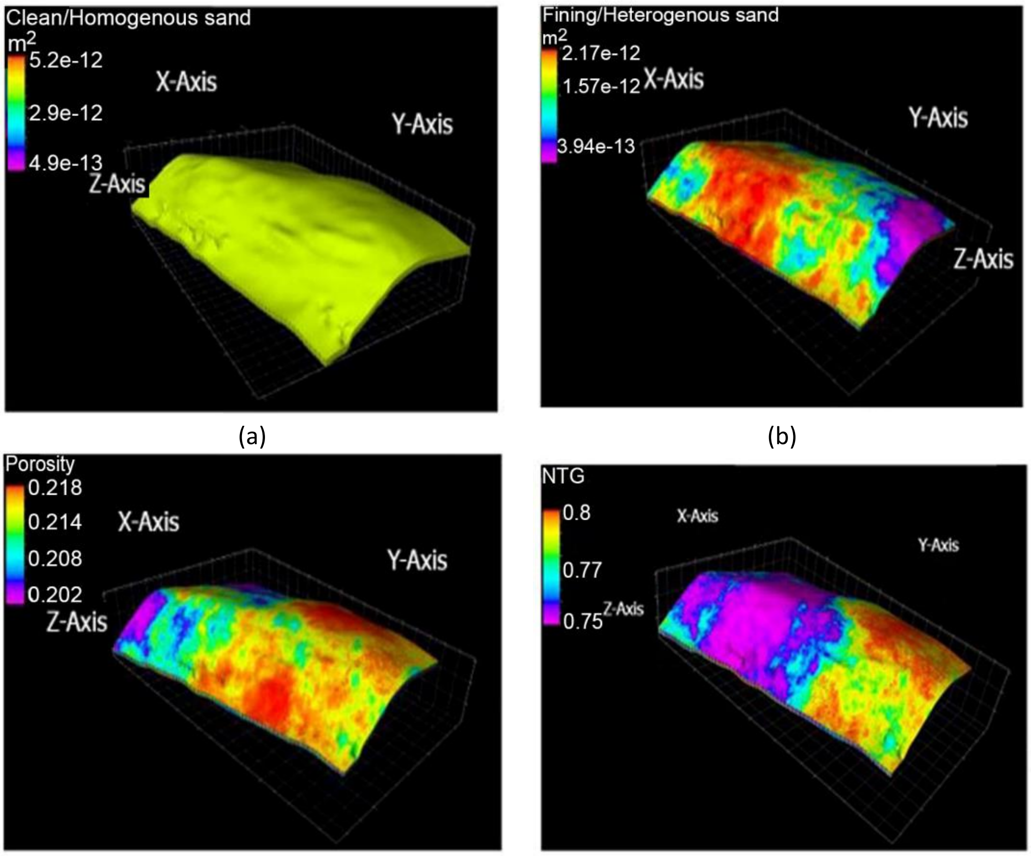
The reservoir simulation was started by digitizing the data from Figure 1. Afterward, the co-kriging technique was implemented to generate the porosity distribution model, where the permeability was treated as a variable that had a statistical relationship with porosity. This technique is typically used for estimating properties at a location that does not have measured data. Therefore, the oil reserve in each sand was different from one to another.



(a) (b)

Fig. 1. (a) Contour map and (b) Horizontal permeability log of the XYZ field

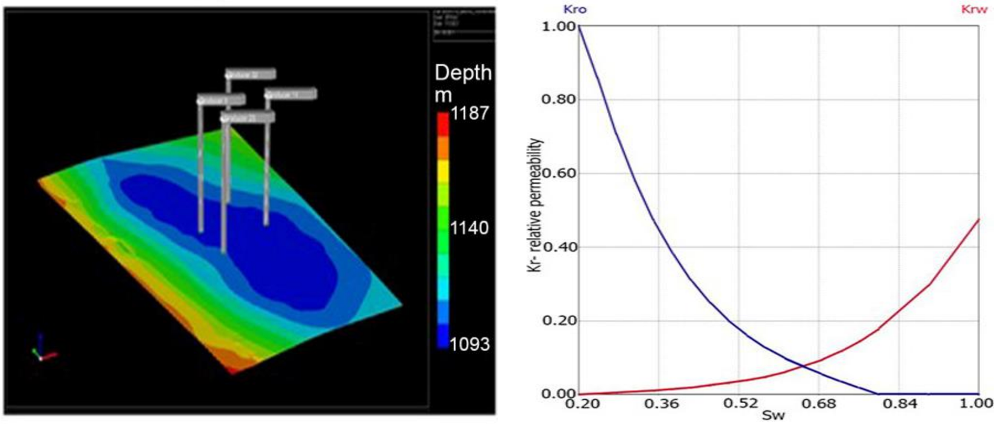
Figure 2 displays the distribution of rock properties from each sand permeability, porosity, and NTG. Afterwards, Figure 3 shows the distribution of wells and relative permeability in the XYZ field.



(a) (b)

(c) (d)

Fig. 2. Distribution of different sand types (a) clean (homogenous), (b) fining (heterogenous) and (c) porosity, and (d) NTG of the reservoir model



(a) (b)

Fig. 3. (a) the distribution of wells, and (b) the relative permeability data in the XYZ field

2.3 Design of Experiment (DOE) of Steamflood Project

The simulation project was run 12 times: 4 times baseline scenarios and 8 times steamflood scenarios. The oil production rate, oil production cumulative (OPC), pressure distribution, steam oil ratio (SOR), and heat transfer performance were analyzed and compared by adjusting the steam quality and well spacing according to Table 5. As previously mentioned, the pressure, rate, and temperature injections remained constant throughout the 10 years of production to analyze the steamflood performance in a continuous injection scheme [16]. Liu *et al.,* [16] implemented a similar approach in that the pressure, rate, and temperature injection scheme were also set constant in studying the heat transfer and oil production performance after steamflood injection. In total, the project had 36 and 16 injectors, with inverted 5-spot well patterns. The simulation project ran for 10 years starting from 0 years until 10 years, and the injection schemes were performed after the third month of production time. The DOE was utilized for a sensitivity analysis study in steamflood injection performance.

3. Results and Discussions

According to the research findings, steamflood injection successfully boosts heavy oil production in the XYZ field. During the 10 years of production, there were fluctuations in the oil production, which were caused by the process of heat transfer from the injector well to other areas in the reservoir, which could reduce the oil's viscosity and make it easier to mobilize into the producer well, resulting in cumulatively higher oil production.

Pang *et al.,* [17] stated that there were four stages of steamflood processes i.e effective displacement, stable displacement, steam channeling, and complete water invading. Figure 4 depicts the outcome of the steamflood injection method with 90% steam quality and 32,374.90 m^2 of well spacing. During the effective displacement stage, the temperature gradually increased from the injection well to production well leading to a sharply increasing oil production rate. At the second stage of steamflood process, the stable displacement occurs due to the gradual advancement of heat transfer into a larger area in the reservoir. When the heat transfer arrived at the production well, the stage of steam channeling began. In this situation, the oil production rate greatly decreased. During this stage, the heated area obviously increased, and steam overlap became more serious and more. Finally, in the last stage, complete water invading occurs. During the fourth stage, this phenomenon would slightly increase the oil production rate since the amount of water (condensed steam) produced was getting higher.

The larger SOR would also suggest a greater need for steam to extract the oil, and normally more water (condensed steam) would be produced into the production well, resulting in a decrease in oil production [20]. Despite this, the oil production rate gradually reduced due to an increase in SOR or the occurrence of steam breakthrough. Similar results were found by Dinata *et al.,* [14] on Clean sand, where the oil production rate was lowered due to greater SOR.

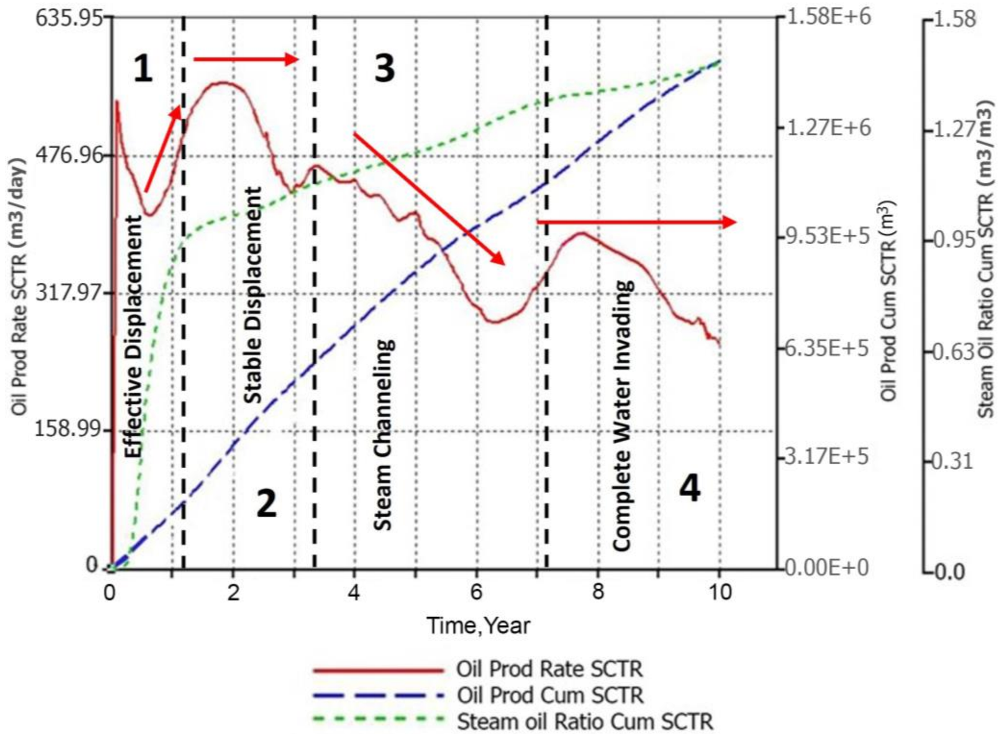


Fig. 4. Clean sand performance with 32,374.90 m^2 of well spacing and 90% steam quality

3.1 Clean Sand Performance

This sand's entire reserve was 280,925,789,481 m^3. Figure 5(a) and Figure 5(b) demonstrate that the base case of 93,077.70 m^2 of well spacing produced higher cumulative oil production than 32,374.90 m^2 of well spacing, with the former reaching 24,460.19 m^3 and later reaching 22,531.96 m^3. This phenomenon was caused by the decreased pressure drawdown seen by the well spacing of 23-acre as shown in Figure 5(c) is slightly lower than the 32,374.90 m^2 well spacing in base case scenarios. Similar results were obtained by Rubin and Izgec [21], indicating that a larger well spacing would reduce well interferences and improve conditions for primary production recovery.

However, Figure 5(a) and Figure 5(b) show that the steamflood scenarios on clean sand demonstrated an inverted occurrence in which 32,374.90 m^2 of well spacing produced more oil than 93,077.7 m^2 of well spacing. In addition, at both well spacings, the 90% steam quality yielded greater oil output than the 50% steam quality. The 32,374.90 m^2 well spacing with a 90% steam quality injection scheme resulted in higher cumulative oil production, with a peak oil production rate of 559.91 m^3 per day and cumulative oil production of 1,465,981.19 m^3. Contradictory, the 93,077.7 m^2 well spacing with 50% steam quality injection scenario contributed the least to total oil output, which totaled 1,044,829.39 m^3. These circumstances were caused by the pressure drawdown and steam oil ratio of the 32,374.90 m^2 well spacing and the 90% steam quality scenario experienced the lowest values and vice versa, as shown in Figure 5(c) and Figure 5(d).

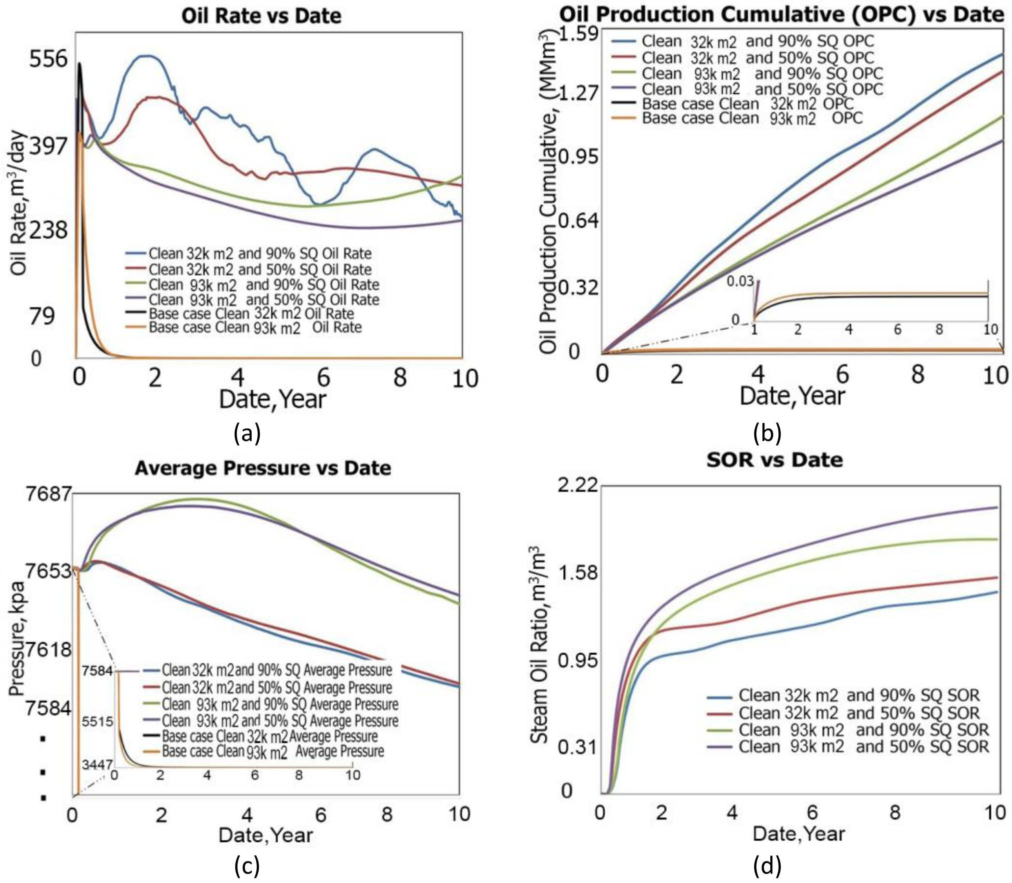


Fig. 5. (a) oil rate, (b) OPC, (c) average pressure, (d) SOR performance in clean (homogenous) sand before and after steamflood

In addition to the causes mentioned earlier, the heat transfer of steamflood injection was also a significant factor; as the temperature increased, the oil viscosity around the heated zone decreased, thereby mobilizing the oil into the production well. According to Figure 6, the smaller well spacing and higher steam quality contributed to a more efficient heat transfer where the heated zone reached the oil production well region, and the maximum temperature increase was 223.88 degrees Celcius. Nonetheless, the larger well spacing and lower steam quality diminished the heat transfer effectiveness because the heated zone was still distant from the production well, causing the oil viscosity around the producer to remain elevated and its highest temperature to reach 276.66 °C in the injection well area. These findings were supported by Rubin and Izgec [21], who asserted that the larger well spacing decreased oil production due to a delay in communication between injectors and producers and a decrease in steam injection unit of area.

The previous steamflood study on clean sand was undertaken by Dinata *et al.,* [14], who asserted that the inverted five spot was the best pattern in terms of peak oil production rate compared to the inverted seven spot and a direct line and that his was due to the improved heat transmission. Therefore, steamflood injection contributed more to oil recovery up to 67% of initially-in-place-stock-tank-oil (STOIIP).

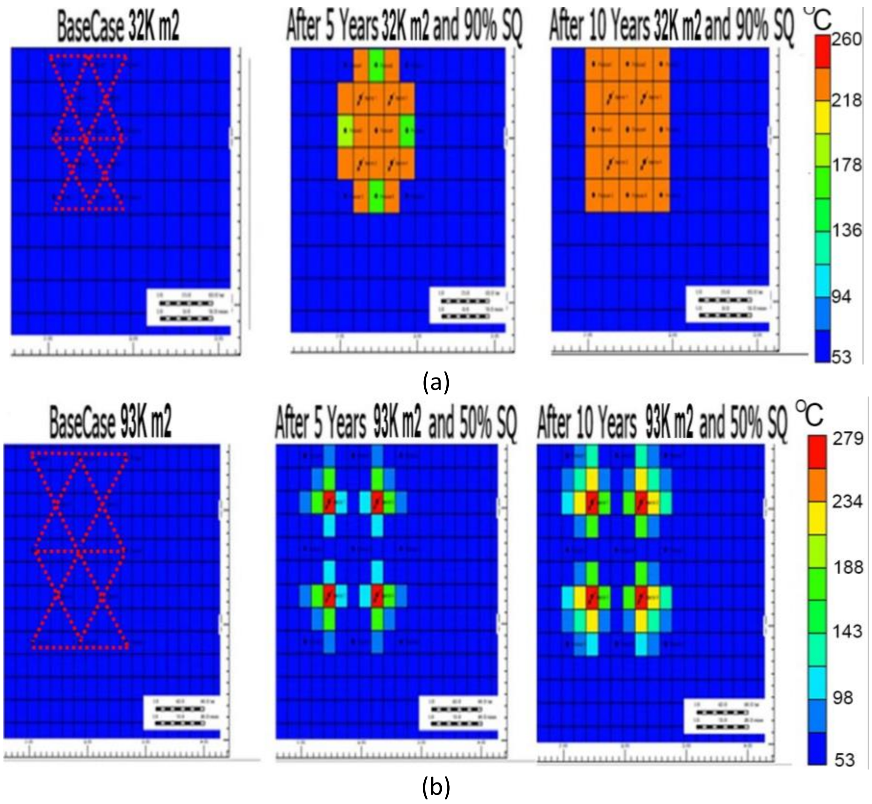


Fig. 6. Heat transfer in clean (homogenous) sand before and after steamflood using (a) 32,374.90 m^2 with 90% steam quality and (b) 93,077.7 m^2 with 50% steam quality

3.2 Fining Sand Performance

The fining sand formation's reserve was 271,453,326.14 m^3, less than the clean sand formation's reserve. Figure 7(b) demonstrates that the larger well spacing distribution yielded 23,564.23 m^3 more than the small well spacing distribution, which produced 20,856.48 m^3 in base case scenarios. Repeatedly, these findings resulted from the larger well spacing's lower pressure drawdown as shown in Figure 7(c) on the base case scenarios. When the pressure drawdown was lower, it produced more oil due to the flow rate being affected by the differences between reservoir pressure and the flowing wellbore pressure. This is the mechanism that mobilizes the oil from the reservoir into the wellbore.

The steamflood injection scheme showed contradiction on the well spacing aspect as shown in Figure 7(a) and Figure 7(b), The 32,374.90 m^2 well spacing and 90% steam quality contributed the most to oil production with 749,236.14 m^3, and the peak oil production rate was 405.79 m^3 per day. It could be seen that the 32,374.90 m^2 well spacing and 50% steam quality resulted in somewhat reduced cumulative oil production, specifically, 749,003.63 m^3. The scenario with a 93,077.7 m^2 well spacing and a 90% steam quality yielded the smallest increase in oil output, just 591,035.12 m^3, compared to the others. The findings repeatedly showed that the smaller well spacing and higher steam quality could maintain and further reduce the pressure drawdown compared to the higher well spacing and lower steam quality referred to in Figure 7(c). Moreover, this scenario would also reduce the amount of injected water or consumption for steam generation which had a better-heated process compared to hot water injection. It is essential to notice that when the steam quality is zero, it indicates that the injection method is hot water.

The SOR was equally responsible for the oil production rate situations, where the smaller well spacing and higher steam quality produced lower SOR and vice versa. Figure 7(d) shows that the lowest SOR was obtained by utilizing the 32,374.90 m^2 well spacing with 90% steam quality with an amount of 2.79 m^3/m^3, and the highest SOR was contributed by 93,077.7 m^2 of well spacing and 50% steam quality that produced 3.65 m^3/m^3.

In the X field, Rubin and Izgec [21] analyzed the fining sand formation with a permeability distribution between 6.90e-13 m^2 and 1.28e-13 m^2. The results demonstrated that steamflood injection enhanced oil production, with the 32,375 m^2 well spacing producing 16.5 MMm^3 of oil compared to the 97,125 m^2 well spacing's 8.8 MMm3. In addition, the capacity of smaller well spacing to reduce the quantity of SOR by applying a greater steam quality injection than larger well spacing distribution was observed.

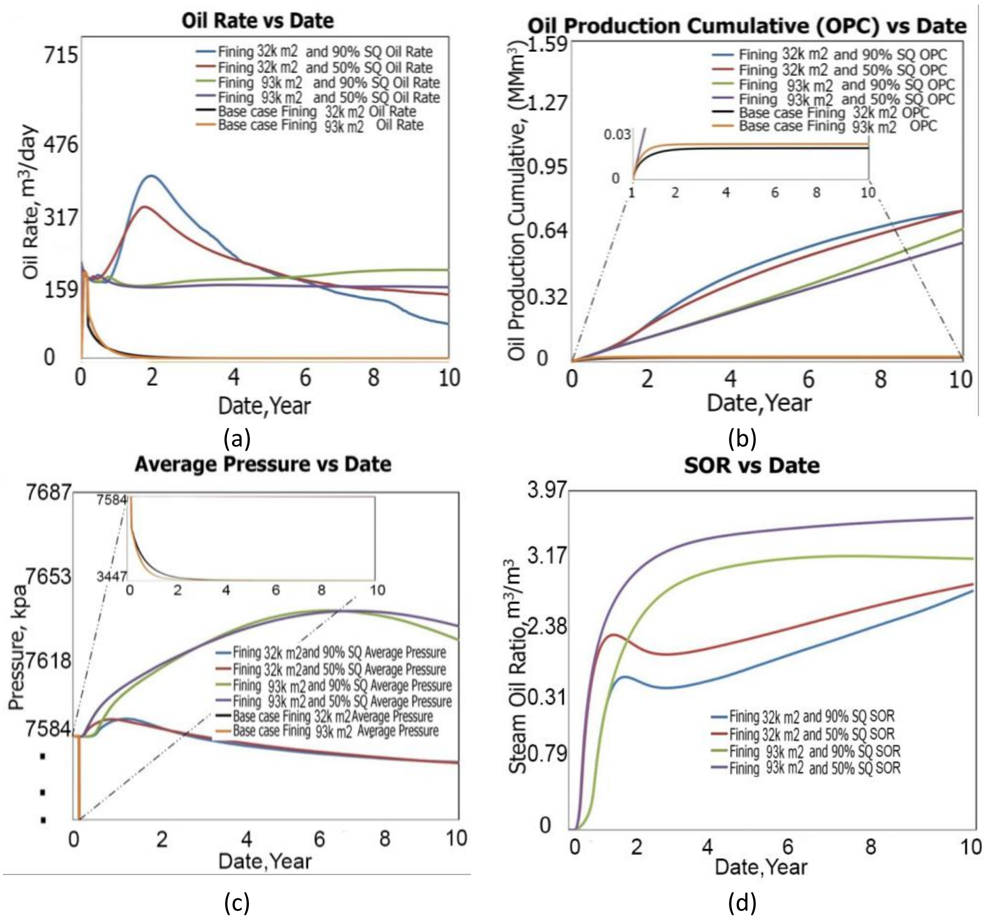


Fig. 7. (a) oil rate, (b) OPC, (c) average pressure, (d) SOR performance in fining sand before and after steamflood

Figure 8 depicts the performance of heat transmission in Fining sand. After ten years of steamflood injection, the results indicated that the 32,374.90 m^2 well spacing with 90% steam quality was still superior to the 93,077.7 m^2 well spacing with 50% steam quality. In the injection well area, the highest temperature for the 32,374.90 m^2 well spacing and 90% steam quality scenario was 276.11 degrees Celcius, whereas the highest temperature for the 93,077.7 m^2 well spacing and 50% steam quality scenario was 322.22 degrees Celcius. These improvements in temperature were greater than the clean sand in the XYZ field.

Similar findings were found by Rubin and Izgec [21] about the distribution of heat, and an increase in temperature was identified as a factor in the expansion of oil output. Compared to the clean sand in the X heavy oil field, the fining sand underperformed for steamflood injection, although cumulative oil output was still somewhat substantial.

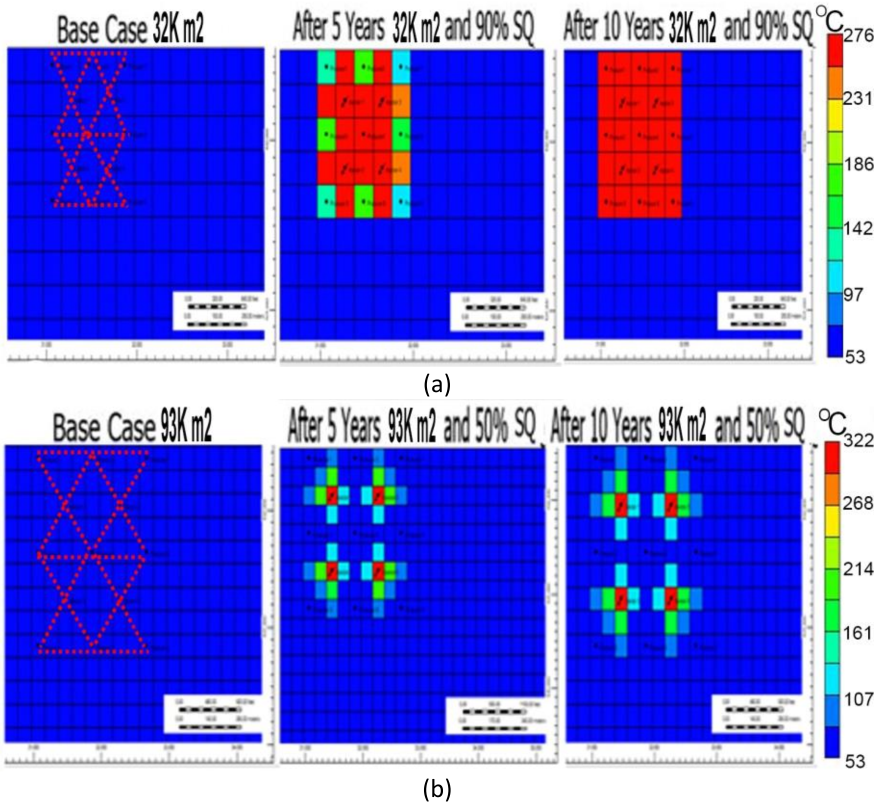


Fig. 8. Heat transfer in fining sand before and after steamflood using (a) 32,374.90 m^2 with 90% steam quality and (b) 93,077.7 m^2 with 50% steam quality

3.3 Sensitivity Analysis of Steamflood Injections in XYZ Field

Steamflood injection scheme showed that the clean sand formation in the XYZ field produced the most cumulative oil compared to the fining sand. Because of the uniform and continuous reservoir of clean sand formation without thief zones, the oil was mobilized into the production well more effectively. Additionally, this could occur due to the fining permeability having a lower-quality reservoir. The findings showed that the well spacing has more contribution compared to the steam quality to oil production performance on each type of sand formation in this field.

The higher oil production cumulative was obtained by using a 32,374.90 m^2 well spacing with 90% steam quality compared to the 93,077.7 m^2 well spacing with the same steam quality. The difference in the oil production cumulative was 302,075.87 m^3 after ten years of production time. Another aspect of using 50% of steam quality with 32,374.90 m^2, well spacing had a lower oil production cumulative, specifically 82,196.43 m^3 lower than the 90% steam quality using the same well spacing in the Clean sand formation.

Comparatively, in the Fining sand formation, the well spacing also had a higher contribution to the oil production cumulative than the steam quality. Utilizing a 32,374.90 m^2 well spacing with 90% steam quality could produce higher oil production cumulative up to 158,192 m^3 compared to the 32,374.90 m^2 well spacing with 90% steam quality. The applicable finding from this study is from the heterogenous (fining) sand formation due to its inhomogeneous conditions which reflects the real conditions of a reservoir. However, for a formation with a homogenous (clean) sand condition, the results from the clean sand could be more relevant.

4. Conclusions

Based on the findings of the two types of sands after steamflood injection the XYZ field. The following can be concluded

i. The highest oil production cumulative contribution in the XYZ field was the clean sand, utilizing 32,374.90 m^2 of well spacing and a 90% steam quality scenario, which could produce 1,465,981.19 m^3. In the second place, the fining sand used the same scenarios as the clean sand, which could produce 749,236.14 m^3 of oil.
ii. The 8-acre well spacing and 90% steam quality dominantly produced the lower SOR compared to the bigger well spacing and lower steam quality. The clean sand produced the lowest SOR with an amount of 1.54 m^3/m^3 followed by fining sand using the same scenarios, it produced 2.79 m^3/m^3.
iii. Excellent heat transfer was obtained using 32,374.90 m^2 and 90% steam quality. It was found that the best heat transfer occurred in the clean sand with the temperature escalation until 223.88 °C, followed by the fining sand escalated until 276.11 °C.
iv. The lower pressure drawdown before and after steamflood injection could lead to higher oil production.
v. The well spacing had a higher impact on the oil production cumulative compared to the steam quality in each type of sand formation.

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References

[1] U.S. Energy Information Administration. "Annual Energy Outlook 2022." *EIA*, 2022.
[2] Suhag, Anuj, Rahul Ranjith, Karthik Balaji, Zumra Peksaglam, Vidhi Malik, Ming Zhang, Frontida Biopharm et al. "Optimization of steamflooding heavy oil reservoirs." In *SPE Western Regional Meeting*. OnePetro, 2017. https://doi.org/10.2118/185653-MS
[3] Delamaide, Eric. "Comparison of steam and polymer injection for the recovery of heavy oil." In *SPE Western Regional Meeting*. OnePetro, 2017. https://doi.org/10.2118/185728-MS
[4] Rahman, Musfika, and Iskandar Dzulkarnain. "RSM for Modelling the CO_2 Effect in the Interfacial Tension Between Brine and Waxy Dulang Crude Oil During LSW-WAG EOR." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 85, no. 2 (2021): 159-174. https://doi.org/10.37934/arfmts.85.2.159174
[5] Schenk, L. "Steam Drive-Results of Laboratory Experiments and First Field Tests in Mene Grande, Venezuela." In *Symposium on Thermal Recovery Methods, sponsored by Colegio de Irrgenieros Venezolanos, Caracas*, vol. 2, pp. 5-6. 1965.
[6] Hama, Mariwan Qadir, Mingzhen Wei, Laila Dao Saleh, and Baojun Bai. "Updated screening criteria for steam flooding based on oil field projects data." In *SPE Heavy Oil Conference-Canada*. OnePetro, 2014. https://doi.org/10.2118/170031-MS
[7] Merdeka, Mohammad Galang, Syahrir Ridha, Berihun Mamo Negash, and Suhaib Umer Ilyas. "Reservoir performance prediction in steam huff and puff injection using proxy modelling." *Applied Sciences* 12, no. 6 (2022): 3169. https://doi.org/10.3390/app12063169

[8] Pasaribu, Rinaldi, Rony Roma, Yana Wicaksana, Cece Muharam, and Attila Aksehirli. "Maximising Production of Low Injectivity Steam Flood Reservoir through Pressure Balance Approach." In *SPE/IATMI Asia Pacific Oil & Gas Conference and Exhibition*. OnePetro, 2017. https://doi.org/10.2118/186284-MS

[9] Sanyal, T., W. K. Al-Khamees, M. Bagheri, H. Abdulraheem, A. Al-Sane, and Yacob Al-Ali. "A Comprehensive Surveillance Plan for Steamflood Pilots." In *SPE Kuwait Oil and Gas Show and Conference*. OnePetro, 2015. https://doi.org/10.2118/175327-MS

[10] Margarita, Trigos-Becerra Erika, Rueda-Neira Silvis-Fernanda, Rodriguez-Paredes Edwin, Rivera-de-la-Ossa Juan-Eduardo, and Carlos Eduardo Naranjo-Suárez. "Key strategies in the heat management for steamflooding projects, Teca Field Application." In *SPE Enhanced Oil Recovery Conference*. OnePetro, 2013. https://doi.org/10.2118/165223-MS

[11] Jones, J. A., and P. Dwivedi. "An Integrated Workflow Approach to Manage Steamflood Operations." In *SPE Western Regional Meeting*. OnePetro, 2018. https://doi.org/10.2118/190064-MS

[12] Al-Hinai, S. M., J. P. Tromp, M. O. Al Manahali, A. Belghache, M. Koning, A. O. Rabaani, R. S. Al-Adawi et al. "Maximising steam project value in South Oman through flexible development phasing and integrated reservoir surveillance." In *SPE EOR Conference at Oil and Gas West Asia*, pp. SPE-169678. SPE, 2014. https://doi.org/10.2118/169678-MS

[13] Zhao, Yong, and Pallav Sarma. "A benchmarking study of a novel data physics technology for steamflood and SAGD modeling: comparison to conventional reservoir simulation." In *SPE Canada Heavy Oil Technical Conference*. OnePetro, 2018. https://doi.org/10.2118/189772-MS

[14] Dinata, M., M. A. Arham, H. S. Sudono, A. Badar, A. Badr, and M. Mirza. "Thermal Recovery Study for Improving Oil Recovery of Heavy Oil Accumulation with Strong Water Drive Mechanism in Sultanate of Oman." In *SPE EOR Conference at Oil and Gas West Asia*. OnePetro, 2018. https://doi.org/10.2118/190459-MS

[15] Kusumastuti, Indri, Tomi Erfando, and Fiki Hidayat. "Effects of Various Steam Flooding Injection Patterns and Steam Quality to Recovery Factor." *Journal of Earth Energy Engineering* 8, no. 1 (2019): 33-39. https://doi.org/10.25299/jeee.2019.vol8(1).2909

[16] Liu, Peng, Yunjun Zhang, Pengcheng Liu, You Zhou, Zongyao Qi, Lanxiang Shi, Changfeng Xi, Zhongyi Zhang, Chao Wang, and Daode Hua. "Experimental and numerical investigation on extra-heavy oil recovery by steam injection using vertical injector-horizontal producer." *Journal of Petroleum Science and Engineering* 205 (2021): 108945. https://doi.org/10.1016/j.petrol.2021.108945

[17] Pang, Zhanxi, Luting Wang, Fanghao Yin, and Xiaocong Lyu. "Steam chamber expanding processes and bottom water invading characteristics during steam flooding in heavy oil reservoirs." *Energy* 234 (2021): 121214. https://doi.org/10.1016/j.energy.2021.121214

[18] Shafiei, Ali, Maurice B. Dusseault, Sohrab Zendehboudi, and Ioannis Chatzis. "A new screening tool for evaluation of steamflooding performance in Naturally Fractured Carbonate Reservoirs." *Fuel* 108 (2013): 502-514. https://doi.org/10.1016/j.fuel.2013.01.056

[19] Agarwal, Anshul, and Anthony R. Kovscek. "Producer Well Temperature Control and Optimal Oil Production During a Steamflood." In *SPE Western Regional Meeting*. OnePetro, 2017. https://doi.org/10.2118/185685-MS

[20] Lu, Teng, Zhengxiao Xu, Xiaochun Ban, Dongliang Peng, and Zhaomin Li. "Effect of Flue Gas on Steam Chamber Expansion in Steamflooding." *SPE Journal* 27, no. 01 (2022): 399-409. https://doi.org/10.2118/206738-PA

[21] Rubin, Eugene, and Omer Izgec. "Forecasting of steamflood performance in a heavy oil field." In *SPE Annual Technical Conference and Exhibition*. OnePetro, 2015. https://doi.org/10.2118/175127-MS