Effects of Various Steam Flooding Injection Patterns and Steam Quality on Oil Recovery Factor

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Abstract

The main principle of steam flooding is to reduce the oil viscosity using hot steam that is injected into the reservoir. In the field implementation there are several injection patterns that can be applied for steam flooding. This research aims to determine the effect of several injection patterns and steam quality on oil recovery factor. Therefore, it can be known the injection pattern and steam quality are right to obtain the best recovery factor. Analysis was carried out on injection patterns including five-spots, inverted five-spots, seven-spots, inverted seven-spots, nine-spots, and inverted nine-spots. The variations in the steam quality used are 50%, 70% and 90%. The simulation model a 3-dimensional cartesian with grid block size 5x5x5 on CMG STARS. The temperature of steam flooding process for all of the scenario was set at 450 ºF, with the injection pressure of 500 psi, and 1,000 bbl/day of injection rate. Of all the scenarios tested the best results were in the inverted seven spot pattern with steam quality 0.9, where recovery factor was 35,1% and total cumulative production was 269,397 bbl.

Keywords: Steam flooding, pattern, steam quality, recovery factor

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INTRODUCTION

Heavy oil are oil that have a high viscosity value with a low API degree making it difficult to produce in the conventional way. Some new eor methods continue to be developed to increase production in the field having heavy oil or also high paraffin content including low salinity water (Fiki Hidayat, Erfando, & Maulana, 2018), electromagnetic heating, etc. One of the best methods that has been proven to overcome this problem is using steam injection (F Hidayat & Abdurrahman, 2018). The biggest steam flooding project in the world is located in Indonesia, precisely in Riau Province which is the largest oil producer in the country (Erfando & Herawati, 2017). Selection of an injection pattern is essential so that the injected fluid is not lost on the proper target of production aging, and get the sweeping pattern as efficiently as possible. Injection well patterns should also be considered in considering the use of steam types. The injection well pattern can maximize the efficiency of the ignition with uniform heat transfer resulting in a good injection response of the reservoir (Arisyi, Irham, & Prakoso, 2015).

In this study, it will examine the effect of the injection pattern and combine with some steam quality to see which injection patterns and steam quality percentages produce the best recovery factor and cummulative production. In this study used to compare six injection well pattern that is five-spot, inverted five-spot, seven-spot, inverted seven-spot, nine-spot, and inverted nine-spot in increasing of recovery factor and oil production cumulative. The injection pattern to be used is a five-spot, inverted five-spot, seven-spot, inverted seven-spot, nine-spot, and inverted nine-spot, while for steam quality it consists of 0.5 (50% steam and 50% water), 0.7 (70% steam and 30% water), 0.9 (90% steam and 10% water).

METHODOLOGY

This research use CMG STAR to simulate the steam flooding process into the reservoir model. Table 1 fluid and rock properties are taken from Ferizal et al. (2013). The reservoir model in this simulation is a cartesian grid with dimensions of 5 x 5 x 5 where permeability is 300 mD, 300 mD, and 150 mD respectively (Fig. 1). The uniform viscosity value on each grid layer is 500 cp. A total of 18 scenarios that will be applied to the reservoir model, the result of a combination of injection patterns and steam quality. Each scenario is injected for 1095 days. The temperature of steam flooding process for all of the scenario was set at 450 ºF, with the injection pressure of 500 psi, and 1,000 bbl/day of injection rate.
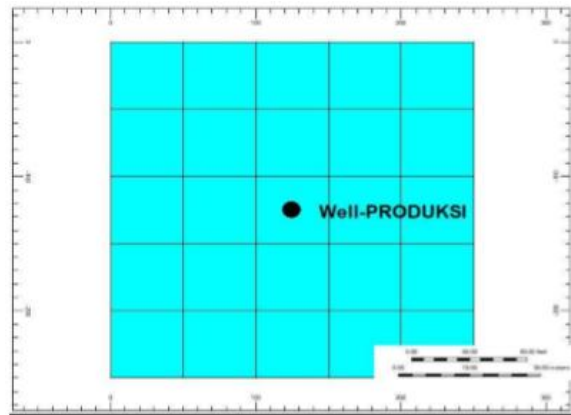
Fig. 1. Cartesian Model 2 D

Table 1. Fluid dan Rock Properties

Paremeter	Value	Parameter	Value
Viscosity	500 cp	Bubble Point Pressure	161 psig
Oil Density	0.99 lb/cuft	Porosity	0.25
Water Density	62.4 lb/cuft	Vertical Permeability	300 mD
API Gravity	11^0 API	Horizontal Permeability	300 mD
Formation Volume Factor	1.021 bbl/STB	Compressibility	5E-6 psi-1
Type of Oil	Heavy Oil	Wettability	Oil Wet

RESULTS AND DISCUSSION

Figure 2a shows the show from the recovery factor for five-spot meanwhile figure 2b shows the oil cumulative production.
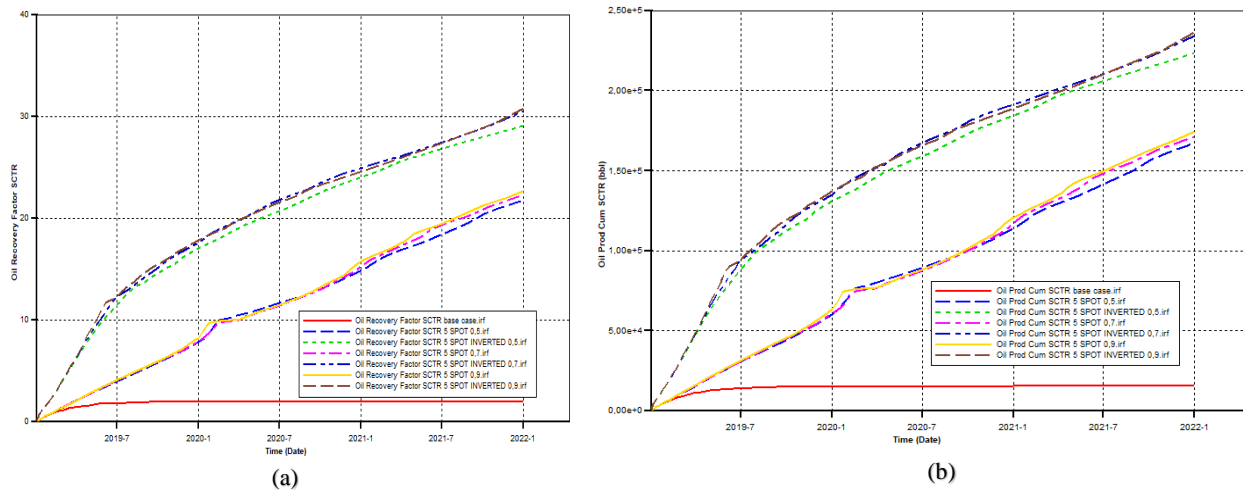

Fig. 2. Recovery factor (a) and cumulative production (b) for five-spot and inverted five-spot pattern

From the figure 2 it can be stated the cumulative production and recovery factor in the steam flooding injection pattern of five-spot inverted are higher than the five-spot pattern in all steam qualities. This result is also similar to the research conducted by Srochviksit & Maneeintr (2016). The quality steam of 0,9 gives the highest recovery

factor of 30.8 %. To compare the incremental recovery oil values between the three scenarios of quality steam can show in Table 2. The higher the steam quality will produce higher cumulative production, therefore the recovery factor obtained is also higher (Erfando, Rita, & Marliaty, 2017).

Table 2. Comparing oil recovery factor cumulative production in five-spot pattern and inverted five-spot pattern

Injection Well Pattern	Quality Steam	Recovery Factor	Cumulative Production
Five-Spot	0.5	21.8 %	167180 bbl
	0.7	22.1 %	171385 bbl
	0.9	22.7 %	174336 bbl
Inverted Five-Spot	0.5	29.1 %	223452 bbl
	0.7	30.5 %	234130 bbl
	0.9	30.8 %	236300 bbl

Chu (1993) states that the normal seven-spot has lower recovery factor then inverted seven-spot. The results of seven-spot and inverted seven-spot analysis resulted in the highest incremental recovery factor increase in the seven-spot inverted pattern with quality steam 0,9 of 37.1 % with a cumulative production of 284661 bbl (figure 3 and table 3). Below we will show the analysis of seven-spot and inverted seven-spot pattern. In the inverted seven spot pattern the distribution of steam is more evenly distributed across all production wells and also the temperature in that area is also higher than the other patterns. This explanation is supported by research conducted by Fuaadi, Pearce, & Gael (1991).
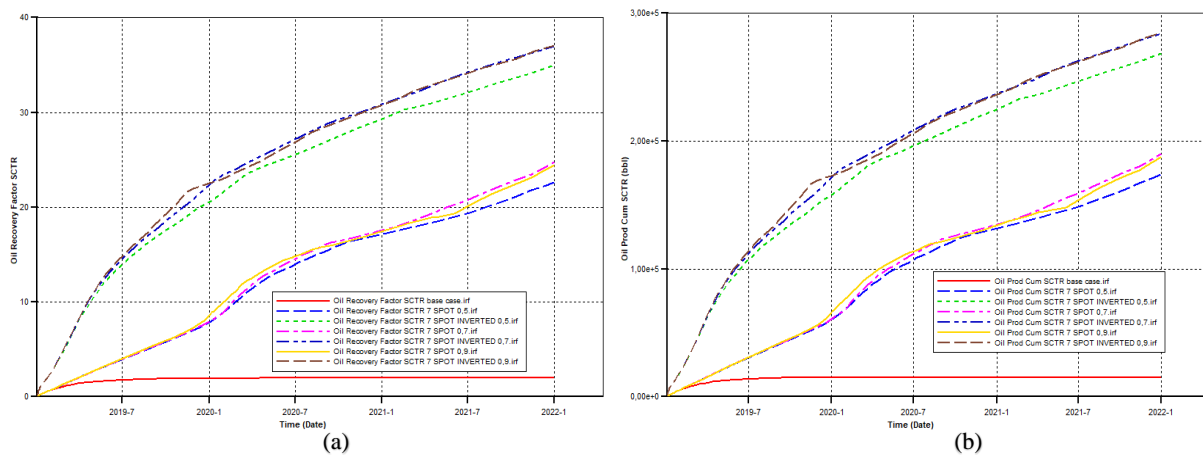

Fig. 3. Recovery factor (a) and cumulative production (b) for seven-spot and inverted seven-spot pattern

Table 3 Comparing oil recovery factor cumulative production in seven-spot pattern and inverted seven-spot pattern

Injection Well Pattern	Quality Steam	Recovery Factor	Cumulative Production
Seven-Spot	0.5	22.6 %	173851 bbl
	0.7	24.8 %	190112 bbl
	0.9	24.5 %	187840 bbl
Inverted Seven-Spot	0.5	35.0 %	268696 bbl
	0.7	37.0 %	284109 bbl
	0.9	37.1 %	284661 bbl

Results of analysis with nine-spot and inverted nine-spot patterns resulted in the highest incremental recovery factor increment in inverted nine-spot pattern with a quality steam of 0,9 of 35.9% with a cumulative production of 276095 bbl (table 4). Below figure 4 we will show the analysis of nine-spot and inverted nine-spot pattern.
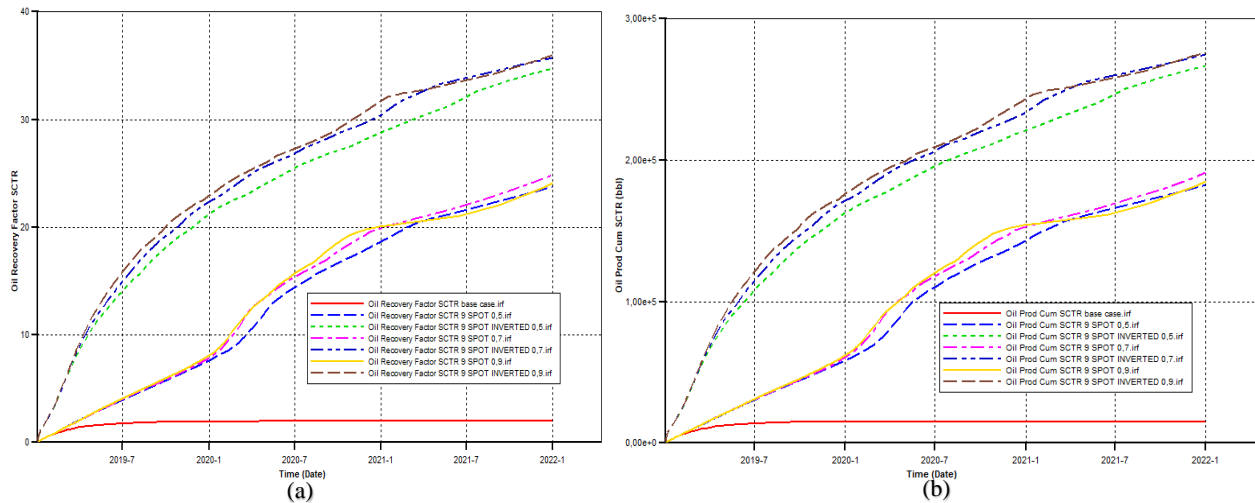

Fig. 4. Recovery factor (a) and cumulative production (b) for nine-spot and inverted nine-spot pattern

Table 4. Comparing oil recovery factor cumulative production in nine-spot pattern and inverted nine-spot pattern

Injection Well Pattern	Quality Steam	Recovery Factor	Cumulative Production
Nine-Spot	0.5	23.8 %	182563 bbl
	0.7	24.9 %	191060 bbl
	0.9	24.1 %	185181 bbl
Inverted Nine-Spot	0.5	34.7 %	266935 bbl
	0.7	35.8 %	274758 bbl
	0.9	35.9 %	276095 bbl

All of the above results show that the inverted five-spot injection pattern, inverted seven-spot, and inverted nine-spot produce cumulative production and recovery factor which are better than the normal shape of each pattern. This is caused by the inverted heat pattern that is scattered throughout the surrounding production wells. Meanwhile in the normal pattern of injection wells which are only focused on one production well does not provide a significant recovery increase. The difference between inverted and normal patterns ranges 7.3% and 12.4%.

Analysis Effect of Quality Steam in Increasing Reservoir Temperature

Oil recovery will increase with the increase of steam injection quality, but at the temperature sensitivity it is seen that gain increase as the steam temperature rises and falls back aftter temperature exceeds 500^0 F (Salam, 2017). The success of continuous steamflooding injection in inverted seven-spot injection well pattern in addition to the precision of the quality steam is also due to the successful heat transfer from the steam injection in raising the temperature of the reservoir. So as to change the viscosity of heavy oil to a lighter oil viscosity.

Thermal phenomena do not occur evenly throughout the volume of steamflooding reservoirs. Certain regions are affected thermal from other regions. Thus steamflooding process usually produces several different temperature and fluid flow regions. The picture will be show how temperature distribution in injection well pattern inverted five-spot, inverted seven-spot, and inverted nine-spot.

Average temperature of initial reservoir or the base case pattern average temperature value of reservoirs is 110^{0} F. in figure 5a, figure 5b, and figure 5c displays the temperature distribution in reservoir due to influence of distribution from quality steam. Table 5 below will be show the results of temperature distribution from well pattern inverted five-spot, inverted seven-spot, and inverted nine-spot.

(a)   (b)
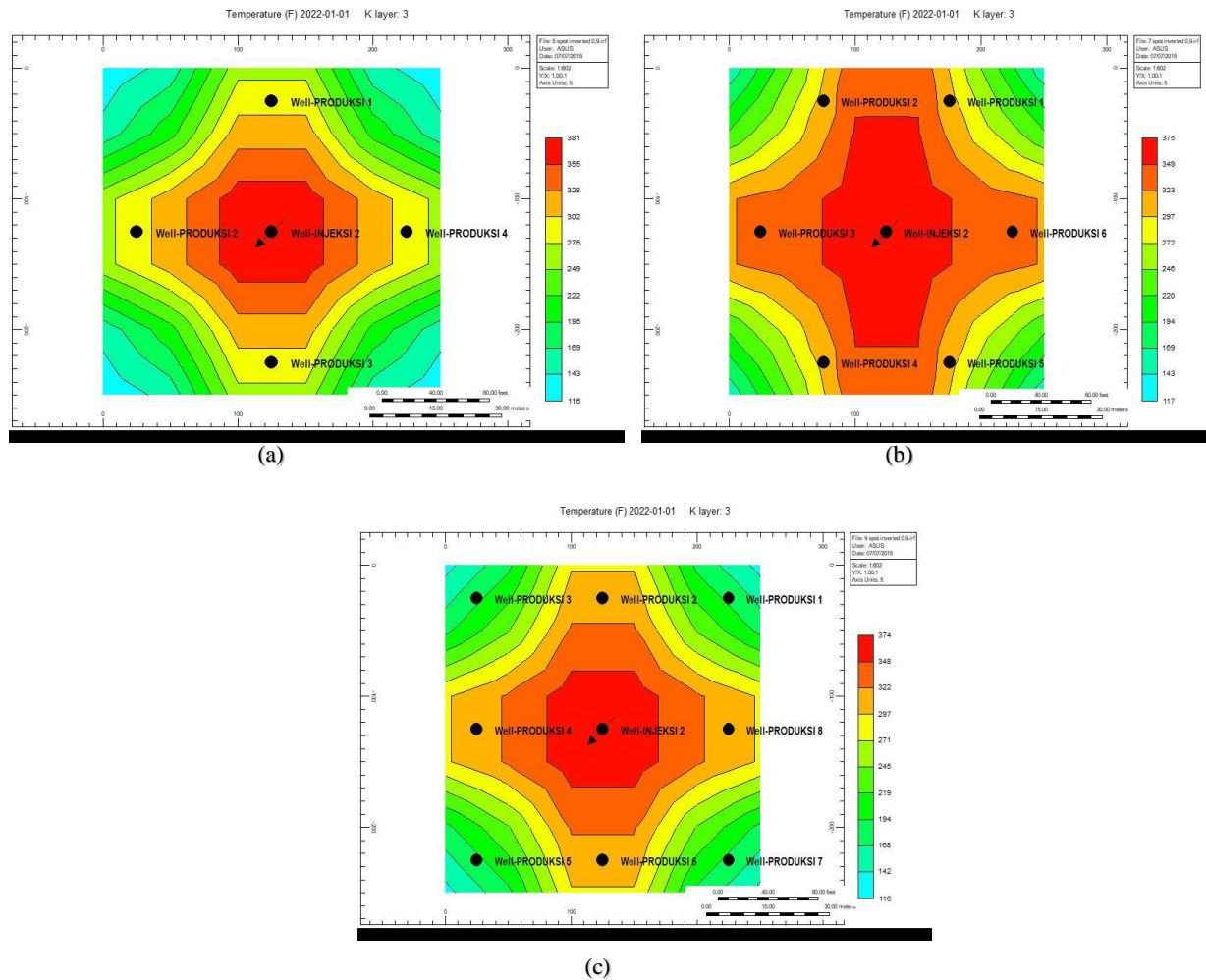

(c)

Figure 5 Effect of quality steam on inverted five-spot (a) inverted nine-seven spot (b) and inverted nine-spot (c) with quality steam 0,9

Table 5 Average Temperature at the end of steamflooding period until 2022

Injection Well Pattern	Average Temperature			
	2019	2020	2021	2022
Inverted Five-Spot (Quality Steam 0,9)	163 F	197 F	237 F	271 F
Inverted Seven-Spot (Quality Steam 0,9)	176 F	216 F	265 F	299 F
Inverted Nine-Spot (Quality Steam 0,9)	178 F	243 F	265 F	286 F

The concept of steam flooding will increase the temperature in the reservoir (Temizel, Purwar, Dursun, & Hancioglu, 2013). In the inverted pattern produces a recovery factor, it will be discussed further changes in temperature in the reservoir in the pattern. Within 3 years the highest injection occurred in the inverted seven-spot

injection pattern. Within 3 years the highest injection occurred in the inverted seven-spot injection pattern. There is an increase of 123^0 F while in the inverted five-spot pattern and inverted nine-spot increase is only 108^0 F. in figure 5b, shows the distribution of temperature is more evenly distributed across all production wells than the other two inverted patterns. This is also the cause of recovery factor and the highest cumulative production in the seven-spot inverted pattern is 37.1% and 276095 bbl.

CONCLUSION

Based on six injection patterns and three variations of quality of steam, the best recovery factor and cumulative production were obtained from the inverted seven-spot injection pattern. Furthermore, when viewed from the change in temperature after injection, this also increased the highest temperature in the inverted seven-spot pattern.

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