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Experimental investigation of cyclic steam stimulation using dual perforation

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Abstract

Cyclic steam stimulation has been widely used to recover heavy oil reservoirs. The process is done by injecting steam into the well, then it is soaked in the reservoir for several days, and after that, the well is produced. This process can be repeated so that the oil saturation around the well is no longer economical to produce. The more cycles, the steam oil ratio increases. Therefore, the process needs a lot of steam to recover heavy oil reservoirs. To maximize the steam effectiveness, the injected steam is to be evenly distributed in the reservoir. To support a wider distribution of steam, two perforations are made in the interval of formation. The first perforation is at the top of the formation as an injection perforation, and the second perforation is at the bottom of the interval perforation as a production perforation. To make this phenomenon observable, an artificial reservoir is made on a laboratory scale. Furthermore, the dual perforation was carried out by adding solvent after half the injection time period. The results showed that dual perforation is more efficient compared to single perforation with a cumulative oil production increase of 45.9% by lowering CSOR by 31%.

Keywords: cyclic steam stimulation; heavy oils; solvent; dual perforation; recovery factor

1. Introduction

Oil reserves throughout the world are increasingly depleting because oil is a type of non-renewable reserve. With the current increase in oil prices, as long as it remains cost-effective, heavy oil production is pursued in addition to light oil production. However, heavy oil has a high viscosity so it is difficult for oil to move from the reservoir to the wellbore. To make its movement, the reservoir needs to be heated to reduce the viscosity and facilitate oil flow through the wellbore. One of the heating methods around the wellbore using steam injection techniques is cyclic steam stimulation (CSS). It has been successful in recovering heavy oil reservoirs (**Hong, 1994**).

The CSS method was first developed by Imperial Oil in the late 1950s in Venezuela. After successful field trials, CSS has been applied worldwide to recover heavy oil and bitumen. Since then, this method has been applied in many fields such as Midway-sunset in California (**Jones et al., 1990**), Bolivar Coastal and Santa Barbara in Venezuela (**Valera et al., 1999**), Cold Lake Oil Sands in Canada, Xinjiang and Liaohe in China (**Liguo et al., 2012**), and other heavy oil fields with the oil recovery factor 10% to 40% (**Johannes Alvarez et al, 2013**). In the field experience, this process can achieve a recovery factor of more than 20% of the remaining oil in place (**James G. 2013**).

In the CSS process, steam is injected into the production well so the steam fills the pores of the rock around the wellbore. About seven days of immersion are needed for the heat from the steam to be distributed to the reservoir. During this time, the steam is expected to transfer its heat energy into the rock and fluid in the pores. After the immersion process, the well can be produced for several months. This depends on the amount of steam that can be injected, the thickness of the reservoir, and the characteristics of the oil and reservoir (**Jones et al., 1990**; **James G. 2013; Erhui, 2019**). The CSS method was widely applied in many fields around the world, including the Duri and Batang fields in Pekanbaru City, Riau Province, Indonesia. The cyclic steam stimulation process is illustrated in Figure 1.

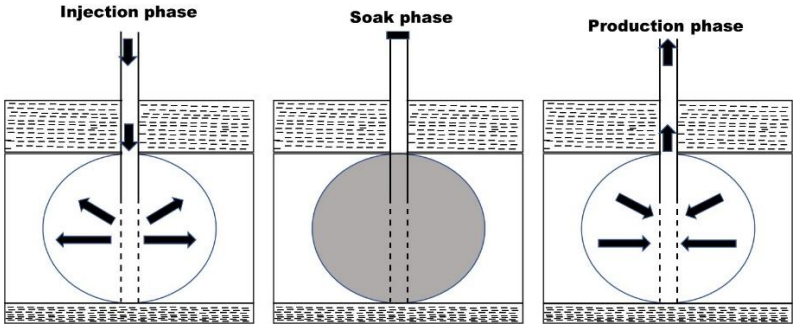


Figure 1. Cyclic Steam Stimulation Process

To improve the disability of the conventional CSS process, various techniques have been applied and successful. A study on integrating solvent injection in cyclic steam stimulation in Venezuela found that the addition of solvent injection could reduce the viscosity of heavy oil with a solvent concentration of 10% in some cases which succeeded in increasing the oil production significantly (**Castro et al., 2010**). The use of solvents with CSS using vertical wells has been demonstrated (**Ivory, 1985**) to result in increased oil recovery as a result primarily of the synergistic effects of steam and solvent in reducing oil viscosity. The hybrid steam solvent injection is a technique that is useful for increasing oil production, especially heavy oil, where injection can be carried out continuously or in the form of a well cycle (**Jiang et al, 2013**). In the hybrid vapor solvent process, a small amount of solvent is mixed with steam and injected into the reservoir. As a result, solvent and steam evaporate at the same time. The solvent will be distilled and dissolved into the bitumen near the edge of the steam chamber. Due to the dissolved solvent and heat from steam, bitumen viscosity will decrease significantly (**Suranto et al, 2015**).

When it is first produced, the oil production rate is generally high because the reservoir pressure increases due to the response from the steam injection. The viscosity decreases due to heating from the steam and the oil saturation which is still high (**Sheng, 2013**). With increasing cycles, the production rate will gradually decrease with the decrease in oil saturation around the wellbore. The more cycles that are carried out, the farther the target oil is from the well. Hence, the more cycles, the more steam is needed. Over time, the ratio of steam to oil obtained becomes higher so that one day the CSS is no longer effective for application in the well. To make the production decrease not too fast and the injected steam is as optimal as possible, the reservoir simulation model research has been carried out. **Suranto (2016)** suggested that the CSS method proposed in this study is based on the modification of the perforation interval. The perforation that penetrates the reservoir formation consists of two hollow parts, where the first part is at the top and the second part is at the bottom of the reservoir interval. In this process, after steam is injected into the upper perforation, the steam will condense due to heat loss to the reservoir, and will then flow downwards due to gravity. Furthermore, oil is produced through the production section at the bottom of perforation. The injection and production cycles are regulated by the interval control valve (ICV). With this CSS model, steam effectiveness is increased by about 30% when compared to using a single perforation. Based on the simulation design of this process, the steam injection and oil production are carried out in different ways so the steam will last longer in the reservoir and the reservoir pressure can be maintained properly. The function of the solvent reduce the oil viscosity and increase the mobility of the oil. As a result, the effectiveness of steam and cumulative oil production in the CSS using dual perforation will be better than that in the CSS using single perforation.

The use of reservoir simulation models is generally very ideal and is still a concept. The simulation model combines mass balance equations, equations of state, and flow equations. It is generally assumed that no heat is lost, the system is closed, and the process is solely at the center of the topic being analyzed. To prove this concept, a laboratory scale model is made so that it can represent the concept that has been proven by reservoir simulation. It is hoped that this laboratory model will strengthen the process that has previously been studied through a reservoir simulation model.

2. Experiment Apparatus and Sample

Laboratory equipment is arranged to analyze the performance of the single perforation and the dual perforation. **Figure 2** shows a schematic of the equipment used in this study. The injection section consists of a reserve of water which is then fed into a steam generator using a pump. The water flow rate entering the steam generation can be adjusted according to the injection rate. In this experiment, the injection rate is adjusted to 6 mL/minute. Furthermore, steam generation functiones to convert water into steam. Therefore, a pipe whose output goes upwards is created, so that only steam can escape through this process, while the liquid water will remain at

the bottom. The steam from the steam generation enters the reservoir. The reservoir is a sand pack with a dimension of length, width, and height of 50 cm, 5 cm, and 20 cm. Inside the sand pack is a mixture of water having a salinity of 15,000 ppm, heavy oil, and cleaned Ottawa sand.

The contents of the sand pack are made by first determining the mixing ratio of oil, water, and sand. It is calculated based on the comparison of porosity calculation data and the size of the available physical reservoir model. The authors choose the type of porosity of 38.4%, So value of 80%, and Sw value of 20%. The ratio of the sand pack material mixture is shown in Table 1.

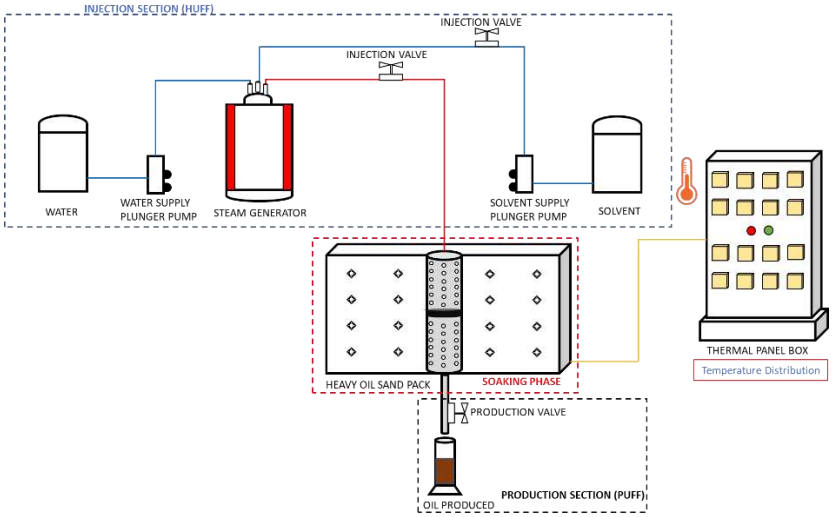


Figure 2. Schematic of reservoir physical model of cyclic steam stimulation

Table 1. Characteristics and volume of each sample

Material	Density, g/mL	Value, mL
Crude oil	0.9118	2462.56
Water salinity, 15.000ppm	1.004	615.64
Ottawa Sand	2,504	5000

The formation water sample is a sample obtained from the manufacture of artificial reservoir water by adding solid NaCl so it resembles the physical properties of formation water in an oil reservoir. This sample is used for fluid mixtures that will mix with quartz sand to make a sand pack. Characteristics of artificial formation water samples are listed in **Table 2**.

Table 2. Characteristics of formation water sample

Characteristic	**Value**
Salinity (ppm)	15000
Density (g/mL)	1.004
pH	7

There are temperature indicators that are spread out inside the sand pack. These indicators will measure the temperature that occurs at each indicator point when steam injection is carried out. There are 17 temperature indicators. One indicator is placed in the steam generator to monitor the steam temperature and 16 indicators are scattered in the sand pack. The arrangement of indicators in the sand pack can be seen in Figure 2. After the injection and soaking process, oil can be produced by opening the faucet under the sand pack. The resulting oil is then stored in the measuring cup.

3. Working Procedure

This experiment consists of four scenarios, namely CSS using single perforation, CSS using dual perforation, CSS using dual perforation combined with solvent, and CSS using dual perforation with continuous steam injection. The detailed workflow for this research is presented in Figure 3.

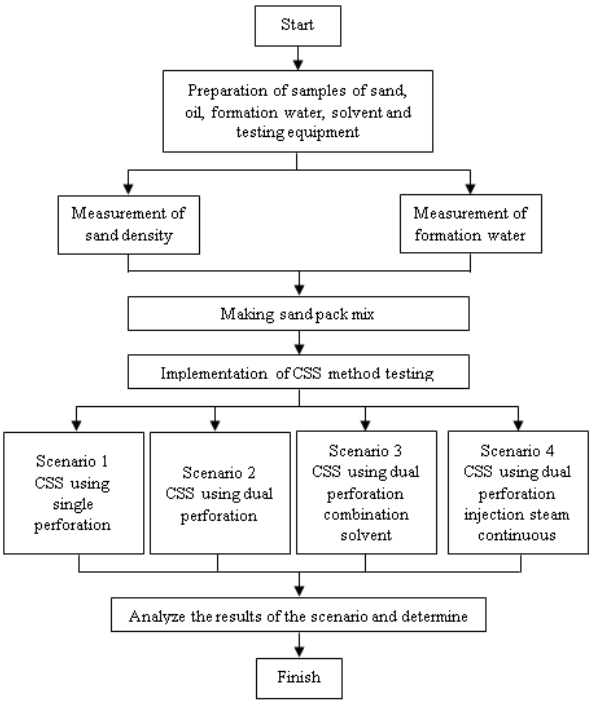


Figure 3. Research Workflow

The working procedure of the installed equipment is as follows. Water from the reservoir is pumped into the steam generation. Two scenarios will be running, namely CSS using single perforation and CSS using dual perforation. The shape of the perforating equipment can be seen in Figure 2. In the single perforation, steam is injected through the perforation at an injection rate of 24 cc/minute for 5 minutes. Then, soak for 5 minutes to give time for the steam to transfer heat to the reservoir. After that, the valve at the bottom of the perforated iron pipe is opened to produce reservoir fluid. The results of this production are accommodated in a measuring cup to analyze the amount of oil and water production.

In dual perforation, steam is injected through the upper perforation section. The upper and lower perforations are insulated so they are not interconnected. The perforation tool used can be seen in Figure 4a and Figure 4b. To prevent the sand from entering the borehole, the cassa is installed to cover the perforation (Figure 5). In this case, the volume and time of injection for a dual perforation are the same as for a single perforation. After immersion, the bottom perforation is opened by flowing a valve on the continuity of the perforated iron, then the resulting fluid is accommodated in a measuring cup. The length of production time is 10 minutes. The injection, soaking, and production processes are referred to as one cycle. Each cycle is run for 6 cycles with the same steam injection rate, settling time, and injection duration.



Figure 4. Perforation tools for (a) Single perforation (b) Dual perforation



Figure 5. Perforation Tool After Screen Installation

4. Result and Discussions

4.1. Comparison between CSS using single perforation and CSS using dual perforation

Figure 6 shows the oil production resulting from scenario 1 and scenario 2, namely CSS using single perforation and dual perforation. The dual perforation results in 45.9% more oil than the single perforation. Based on Figure 7, scenario 2 (dual perforation) has a lower cumulative steam oil ratio (CSOR) compared to scenario 1 (single perforation). Dual perforation results in 32% lower CSOR than single perforation. This shows that the type of perforation (single or dual perforation) affects oil production and CSOR. Based on the perforation scheme, the dual perforation type has a better role because consists of two perforations, the first part is at the top and the second part is at the bottom of the reservoir. In the dual perforation process, after the steam is injected into the upper perforation, the steam will condense due to heat loss into the reservoir and then flow downwards due to the gravity effect. Furthermore, oil is produced through the bottom perforation.

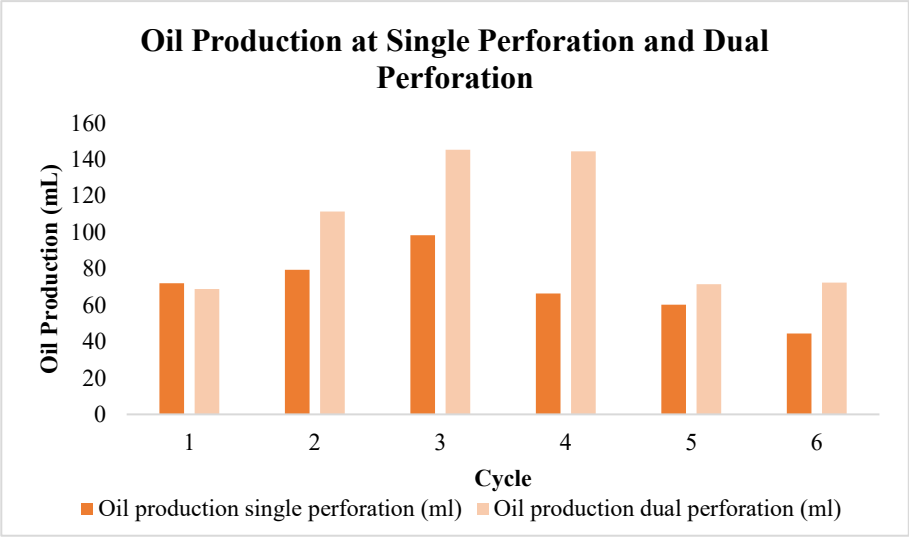


Figure 6. Oil Production at the Single Perforation and Dual Perforation at Cycles 1 to 6

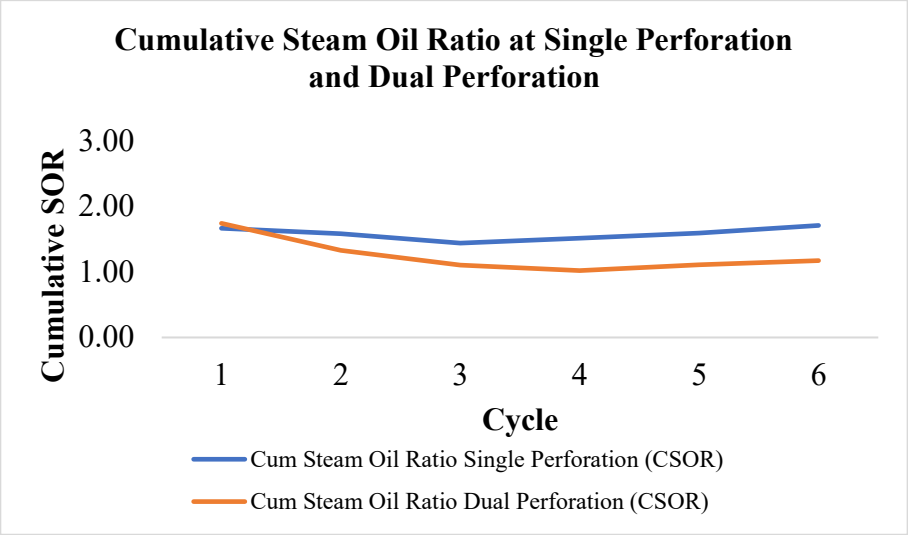


Figure 7. Cumulative Steam Oil Ratio at Single Perforation and Dual Perforation at Cycles 1 to 6

4.2. Comparison between CSS using dual perforation and CSS using dual perforation combined with solvent

Figure 9 shows the oil production resulting from scenario 2 and scenario 3, namely CSS using dual perforation and CSS using dual perforation combined with solvent injection. Scenario 3 results in 21.5% more oil product than scenario 2. Based on Figure 10, scenario 3 has a cumulative SOR 18% lower than scenario 2. The SOR value is proportional to the high volume of oil production. The results obtained are influenced by the type of dual perforation used and proven to be effective. Based on this comparison, it can be seen that the combination of solvent injection in the dual perforated type can increase productivity. The addition of solvent to the steam process aims to improve steam performance by combining two dilution mechanisms (solvent mixing and heavy oil) and heating. Both mechanisms lead to reduced viscosity and faster drain.

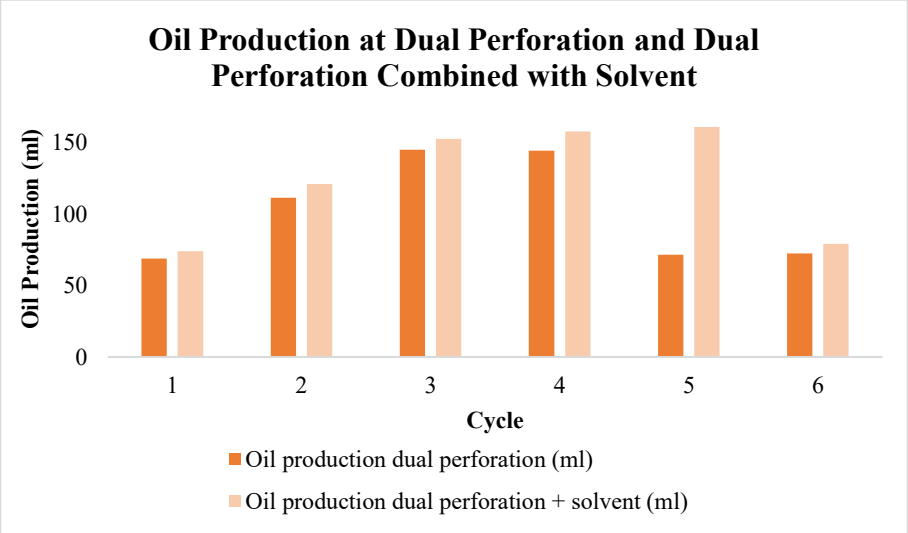


Figure 9. Oil Production at Dual Perforation and Dual Perforation combined with Solvent at Cycles 1 to 6

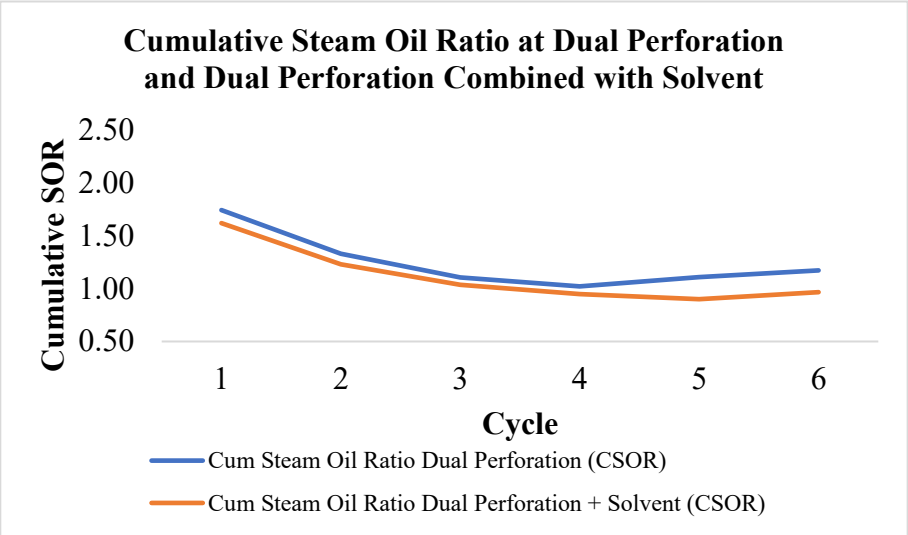


Figure 10. Cumulative Steam Oil Ratio at Dual Perforation and Dual Perforation Combined with Solvent at Cycles 1 to 6

4.3. Comparison between CSS using dual perforation and CSS using dual perforation with continuous steam injection

Figure 11 shows the oil production resulting from scenario 2 and scenario 4, namely CSS using dual perforation and CSS using dual perforation with continuous steam injection. Scenario 2 still results in 25.8% more oil product than scenario 4. Based on Figure 12, scenario 2 has a cumulative SOR 35% lower than scenario 4. The SOR value is proportional to the high volume of oil production. The results obtained are influenced by the scenario mechanism carried out in scenarios 2 and 4. In scenario 4, steam injection is carried out continuously, and at the same time, oil production is also carried out so there is no soaking process in this scenario. As a result, the temperature distribution does not expand optimally throughout the physical model area of the reservoir.

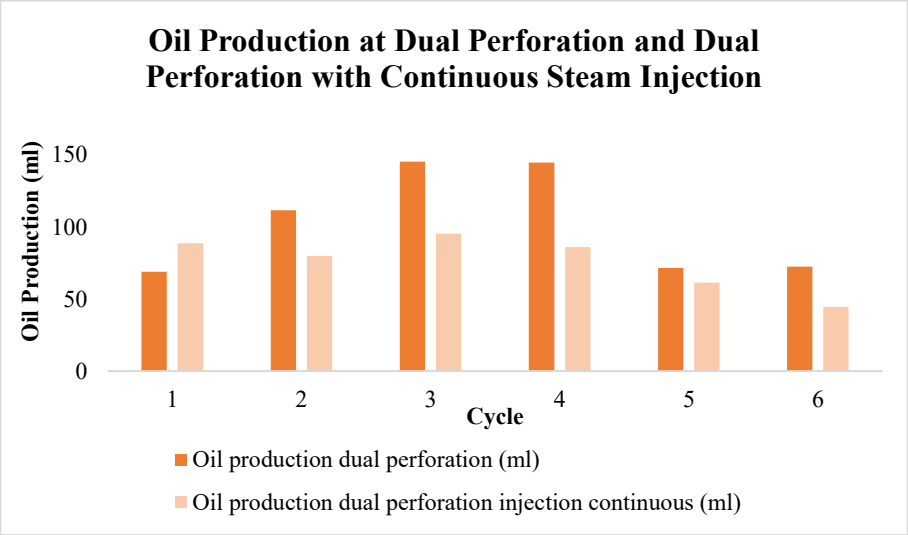


Figure 11. Oil Production at Dual Perforation and Dual Perforation with Continuous Steam Injection at Cycles 1 to 6

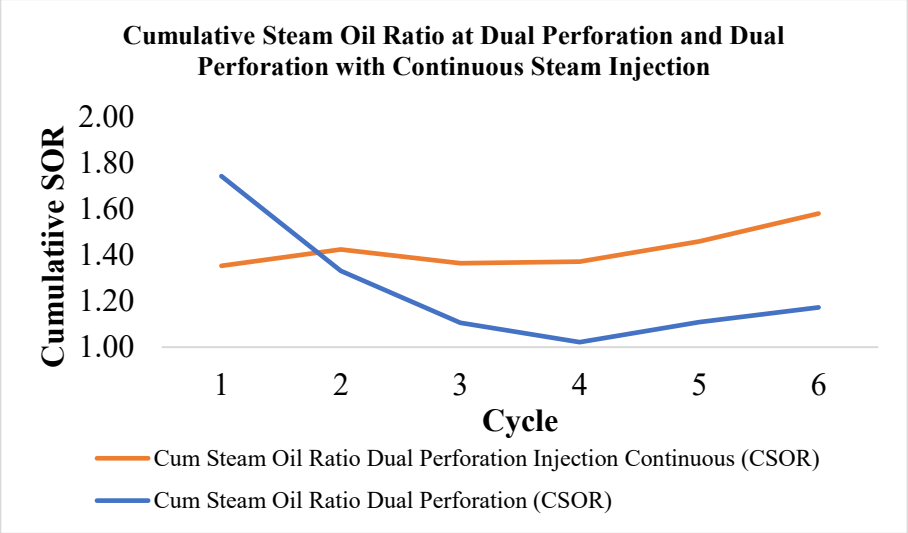


Figure 12. Cumulative Steam Oil Ratio at Dual Perforation and Dual Perforation with Continuous Steam Injection at Cycles 1 to 6

4.4. Temperature distribution in cyclic steam stimulation scenarios

In this study, the temperature distribution on the physical reservoir model will be analyzed based on the results of the thermal sensor panel readings. Temperature recording is carried out at the end of each stage of the CSS process so the temperature at the end of the injection is shown in Figure 13. In scenario 1 (CSS using a single perforation), it can be analyzed that after injection, the temperature in the physical reservoir model increases both vertically and horizontally, with areas having high temperatures at the top to the middle of the model. In scenario 2 (CSS using dual perforation) and scenario 3 (CSS using dual perforation combined with solvent injection), it can be analyzed that these two scenarios have similar temperature distributions. After injection, the temperature in the physical reservoir model increases both vertically and horizontally, with areas having high temperatures only at the top of the model, while the bottom and sides of the model still show low temperatures. In scenario 4 (CSS using dual perforations with continuous steam injection), after injection, there is an increase in the vertically hottest temperature from the top to the bottom but the sides of the model show lower temperatures.

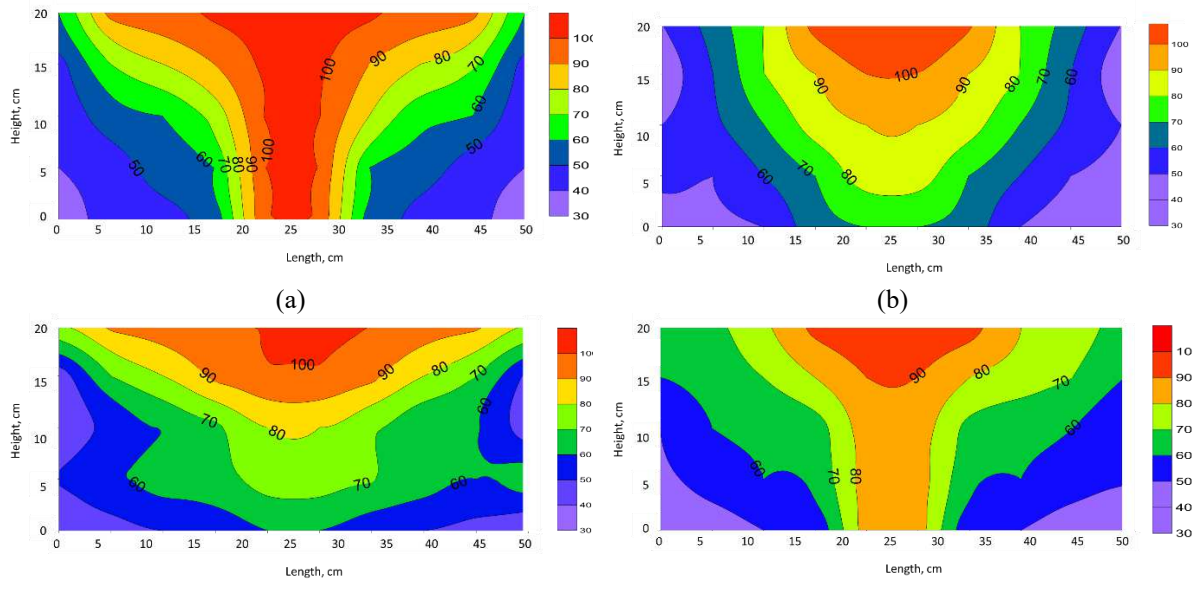


Figure 12. Temperature distribution at the end of Injection Period Cyclic 5 at CSS using (a) Single Perforation with steam only (b) Dual Perforation with steam only (c) Dual Perforation Combined with Solvent (d) Dual Perforation with continoud steam injection

Based on the scenarios that have been carried out using single perforations and dual perforations, the temperature distribution in single perforation spreads more evenly throughout the physical model of the reservoir compared to dual perforations where the temperature spread is slower. This happens because in a single perforation, all parts of the perforation can be flowed by steam so the parts around the perforation hole get heat faster and will be distributed to more distant areas as a whole. However, the dual perforation has two perforation zones, namely the upper perforation which is only flowed by steam during injection, and the bottom perforation is only flowed by oil during production. Therefore, the temperature spread first occurs at the top of the physical reservoir model because in that area the steam is first heated. Along with the work process, the steam will spread to the bottom area along with the flow of oil. Heat carried by the oil or spreading through the pores will evenly distribute heat throughout the area and oil will be produced through the production perforation zone.

5. Conclusions

This research investigates cyclic steam stimulation using single and dual perforations. The dual perforation has several advantages compared to cyclic steam stimulation using single perforation. The CSS using dual perforation can significantly increase oil production by approximately 45.9% and decrease CSOR by approximately 31% compared to CSS using single perforation. Furthermore, the CSS using dual perforation combined with solvent can increase oil production by approximately 21.5% and decrease CSOR by approximately 18%. Therefore, based on the amount of oil produced and also the steam oil ratio, it shows that the modification of the perforation, in the form of dual perforation which is combined with solvent injection, has good effects and results in cyclic steam stimulation.

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