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Investigation of Multilevel Injector for Ramp-up Process in Vertical Well using Steam Assisted Gravity Drainage Method

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Abstract

Steam assisted gravity drainage (SAGD) method for heavy oil exploitation using horizontal wells has been done and successful in the field. In the similar concept with SAGD using horizontal wells, vertical well SAGD has been developed as alternative method. This well consists of two strings where one is as a producer on the bottom and the other one is as an injector on the top. This investigation makes different distance between injector and producer perforations gradually. The aim of this research is to make optimization strategy on the vertical well SAGD. The sensitivities tested consist of injection rate and distance between producer and injector perforations. Analysis result reveals that the impact of multilevel injector will decrease cSOR and improve the production rate on the same injection rate. If the process is combined with multilevel injection rate, the result would offer the most favourable option. Furthermore, the longer distance between producer and injector perforations will cause longer restrained heat in reservoir so that the volume steam chamber will be bigger and drainage radius will be wider.

Keyword : SAGD; multilevel injector; cumulative steam oil ratio; steam chamber; drainage radius.

Nomenclature
SAGD = steam assisted gravity drainage
CSS = cyclic steam stimulation
cSOR = cumulative steam oil ratio
BHP = bottom hole pressure

1. Introduction

The energy from crude oil is still needed for daily live, such as for the transportations, cooking, light etc. Substituting energy from other sources is still limited, so improving exploitation of crude oil is required. Heavy oil is an alternative crude oil source which its existence is actually larger than those of conventional crude oil (Butler, 2004). In the heavy oil cases, several methods have been successful to be applied such as SAGD, steam flooding, cyclic steam stimulation (CSS) etc. for producing those resources.

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SAGD is one of alternative methods to produce heavy oil. This method was introduced firstly by Butler in 1981. After that, several researchers made optimization of SAGD and its improvement with experiment and numeric model (Nars, 1997; Barillas, 2006; Li, 2009; Tamer, 2012; Suranto, 2015; 2016a). Generally, performance of SAGD method uses a horizontal well pair. One well is as an injection well on the top side and the other one is as a production well on the lower side.

In the further development, vertical well SAGD has been developed as alternative method. This well consists of two perforations which one is on the top and the other one is on the bottom. Steam is injected to the top side and oil is produced from the bottom side (Duerksen, 1990). Proportional with the CSS method, the separation of perforations to be a top injection and a bottom production will improve approximately 30% compared with conventional CSS (Suranto, 2016b). Here, steam is injected into the top perforation, therefore the steam would condense because of heat loss to the reservoir, and finally, it would flow to the lower part because of gravity force. Hereafter, the oil is produced through the bottom perforation.

The mathematical of radial flow equation of vertical well SAGD has been developed by Reis in 1993. The model is based on the experimental observation that the steam zone can be modelled as an inverted cone around a vertical injection well. The result of this study indicates that SAGD in radial geometry is a promising recovery process for Tar Sand. Field trial of vertical well SAGD has been done in well 4C11-1, Husky Energy's Pikes Peak. The well consists of two strings and a downhole packer is isolated by two interval perforation. The first string is an injector in upside and the second string is a producer at bottom side (Miller, 2010). Further, because of geological variability within the pay zone (e.g. permeable lean zone, shale barrier, and low vertical permeability), Hocking (2013) proposed to use an installing single vertical well which was completed with an injector and a producer perforations for operating SAGD method.

Actually, vertical well SAGD still has chance to be developed but until now, it is not much study about vertical well SAGD. Even though the simulation study and field trial have been done but they remained unclear in how to manage steam distribution in the well become optimum. Too small distance between injector and producer perforations will cause faster preheating but the steam will be easy to move from the injector to the producer. While, if the perforation of injector-producer is further, preheating time will be longer, but the steam chamber will be good to propagate.

This study is focused on managing the steam injection in ramp-up process for improving SAGD performance. Here, the steam chamber will be developed with multilevel propagate. To make this process, the distance between injector and producer perforations will be changed gradually. The first process uses 5 meters of distance and the next process is set longer.

2. Background Theory

SAGD is a thermal oil recovery process, originally conceived by Roger Butler (1981), for recovering viscous heavy oil. Figure 1 shows the schematics of SAGD process mechanism. To achieve continuous injection and production at the same time, a pair of parallel wells is used. Steam is injected into the upper part of formation through an injection well leads to form a steam saturated zone which is usually called the steam chamber. The steam flows toward the edge of the steam chamber and releases its latent heat to the formation causing it is condensed. The viscous heavy oil is mobilized and drained by gravity toward to the production well. Hereinafter, the steam chamber grows vertically and spreads laterally in the formation.

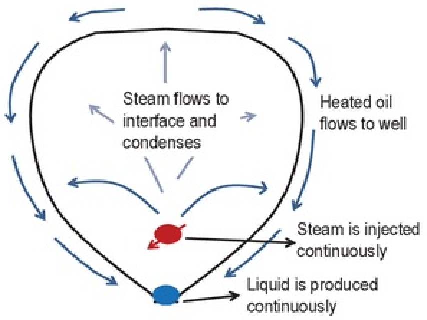

Fig. 1. The SAGD schematic mechanism (Butler, 1981)

3. Reservoir Simulation Model

The thermal reservoir simulator, STARS Version 2015, by Computer Modeling Group, was applied to construct reservoir model. The reservoir model which representing a generic in Athabasca oil sand was selected for this research as described in Table 1. The model was built with radial-dimensional numerical simulations and one well is in the center of the model. The production perforation is 1 meter above bottom reservoir and the injection perforation is 5 meters above production well. The grid numbers are 29 x 4 x 30 (r,theta,k) and the grid size is gradually between 0.35 until 8 meters in r, 90^0 in theta direction, and 1 meter in k direction. The initial pressure is 2000 kPa and determined from normal gradient hydrostatic pressure in the depth of 212 meters. The steam injection uses constant rate in sand face with a steam quality of 0.9.

The initialization step of the model was the OOIP (original oil in place) of Athabasca Oil Sand model had oil approximately 282 M m^3, water 71 M m^3 and the model was without gas. There are two steps on initiating the SAGD method, i.e. preheating and ramp-up process. Preheating is to build a connection between the injector and the producer using steam circulation in the wellbore. Preheating period is about 6 months and the temperature is set at 230 °C. During the preheating process, the heat will be transferred by conduction to the surrounding wells, and then, both of perforations will be connected hydrodinamically. After preheating, it starts to inject the steam and produce the oil continuously through the both perforation. Usually, this step is called ramp-up process.

Afterward, the sensitivity parameters are tested for steam injection rate and the length of injector and producer perforation. The string production is constrained with bottom hole pressure (BHP) about 500 kPa and the production rate maximum is no limit. The injection pressure is constrained at 3000 kPa and the minimum oil rate of all scenarios is constrained about 2 m^3/day.

Table 1.Average Reservoir Rock and Fluid Properties Data (Tavallali, 2011)

Parameter	**Value**
Depth, m	200
Net Pay, m	30
Horizontal Permeability, mD	5,000
Kv/Kh, fraction	0.5
Porosity, fraction	0.35
Initial Pressure , kPa	2,000
Oil Viscosity @ Tr = 12 °C, cp	2,000,000
Oil Saturation, S_o	0.8
Oil gravity, °API	10
Oil viscosity correlation (CMG manual,2015)	A = 1.91785E-7; B = 8543.031
Formation compressibility, 1/kPa	9.60E-06
Rock heat capacity, kJ/m^3°C	2,010
Rock thermal conductivity, kJ/m day °C	660
Oil thermal conductivity, kJ/m day °C	11.5
Water thermal conductivity, kJ/m day °C	53.5
Gas thermal conductivity, kJ/m day °C	0.14
Residual oil saturation (S_{or}), fraction	0.15
Irreducible water saturation (S_{wir}), fraction	0.15
Water relative permeability @S_{or}, fraction	0.1
Oil relative permeability @ S_{wir} , fraction	0.992

4. Result and Discussions

4.1. Effect of Multilevel Injector

The main object of this investigation is to know the effect of multilevel injector in ramp-up process. The injection rate was set at constant rate i.e. 30 m^3/day. In the case_1, the distance of injector and producer perforations are 5 meters, the case_2 was set for 10 meters, and the case_3 was set for 15 meters. Based on Figure 2, in the first period, if the spacing of injector and producer perforations is small (case_1), the steam chamber will be easy to grow up then heating around of injector perforation. However, in the middle period until the end of production life, a part of the steam will move directly to the production perforation which will cause decreasing of steam effectiveness as reservoir heater. Here, the heat will be moved to surface through the production perforation and consequently, the heating of reservoir is not optimal leads to increase cSOR until the end of production life. The condition will be different if the injection perforation is enhanced to the top side. In the case_2, the distance between the injection and production perforations is larger. Firstly, the steam chamber will slowly grow up because steam is very difficult to penetrate in the reservoir due to high viscosity. But after the steam can grow up faster (approximately 2 years), the production rate rapidly rises which is higher than in the case_1. It reveals that the steam efficiency increases (Figure 3). This phenomenon is comparable with Nasr (1997). He suggested that if the steam chamber increases, the production rate is going to increase. Eventually, the recovery factor will also increase.

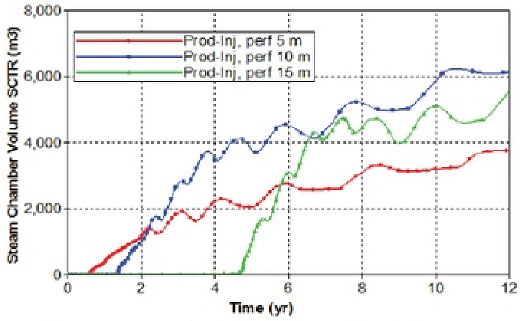

Fig.2. steam-chamber volume in difference distance of injector-producer perforation

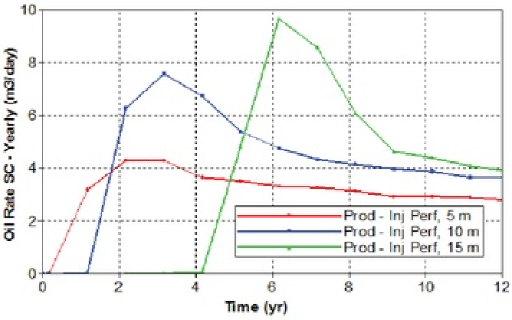

Fig. 3. Production rate in difference distance of injector-producer perforation

As can be seen on Figure 4, the distance of injector and producer perforations has relationship with cSOR. If the distance of injector-producer perforations is small (case_1), the cSOR rapidly increases and decreases alternately in the first production period. Then it will gradually increase until the end of production life. For the case_2 and case_3, both cSOR rise higher than the case_1's cSOR in the first period production. It indicates that the case_1 is more effective compared to the other cases for the first period. Further, after 5 years, if the distance of injector and producer perforations is larger (case_3), cSOR of the case_3 deeply falls so its position will be lower than the case_1 until the end of production life. It exhibits that the case_3 is more effective after 5 years until the end of production life.

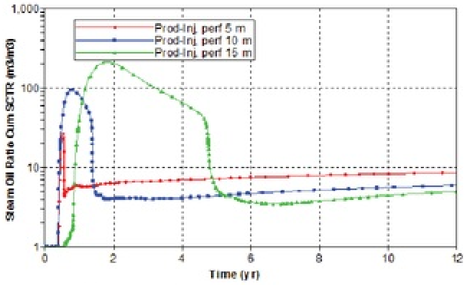

Fig. 4. The CSOR with difference distance of producer- injector perforation

4.2. Optimization of operating condition

There is an advantage from each level injector as described above. To make optimization of the model, each advantage can be combined with multilevel injection rate. The first year is operated using distance between injector and producer perforations of 5 meters and the second year is changed to the 10 meters, then third years is changed to the 15 meters using the same rate (30 m^3/day).

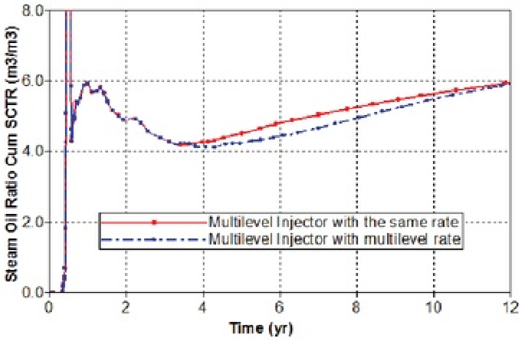

Fig. 5. The cSOR vs time in optimization condition

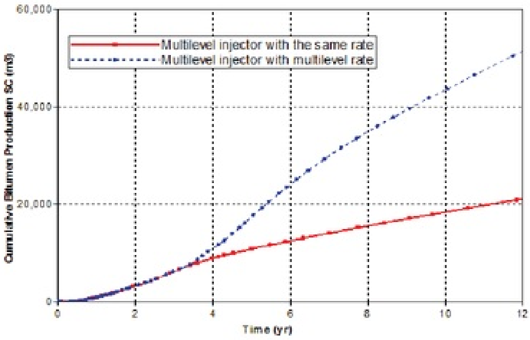

Fig 6. The cumulative oil production vs time in optimization case

The trend of cSOR of the multilevel injection rate is proportional with the constant injection rate but its position is still under the constant injection rate. Furthermore, enhancement of the steam injection rate and the steam effectiveness cause increasing of the production rate. Figure 6 shows that after the multilevel injection rate is set up, the oil production rapidly increases. Figure 7 shows that the vertical well SAGD can improve the drainage radius until 85 meters using both multilevel injector and multilevel injection rate.

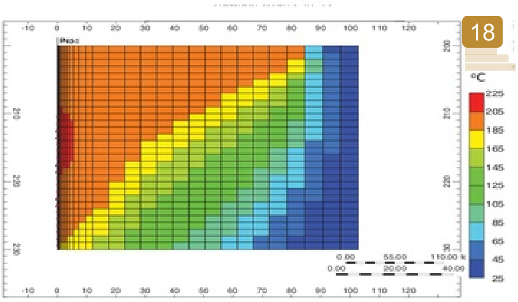

Fig. 7.The temperature distribution on optimization case

In Figure 5, the cSOR falls dramatically after the gap separation is changed to the 10 meters in the second year and continuously changed to the 15 meters in the third years. After third year, there are two scenarios i.e. the first is that the injection rate is constant and the second is that the injection rate increases by time. The multilevel injector with constant injection rate as the first scenario (red line in Figure 5) will cause increasing of cSOR gradually until the end of production life since the steam chamber has already matured. For the second scenario, the production rate in the third year is 60 m3/day and for the fourth year is 75 m3/day. In this scenario, the cSOR is relative stable until the fifth year. After that, the cSOR slowly increases proportional with constant injection rate. Obviously, the multilevel injection rate can maintain stable cSOR in several times because the steam moves laterally in the reservoir. Impact of this phenomenon is that the steam longer stays in reservoir leading to increase the drainage radius and finally, the effectiveness of steam is going to rise.

5. Conclusion

Multilevel injector will be effective for Vertical well SAGD. It can reduce cSOR, increase drainage area, and enhance steam chamber volume. Consequently, it can improve the efficiency of steam injection. However, multilevel injector will have good performance if the injector perforation can be moved gradually. This method can be applied if the reservoir is thick. Otherwise, this method is not recommended. During the ramp-up processes, multilevel perforation injection will be favourable if it is accompanied by multilevel injection rate.

6. Copyright

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Biography

A.M Suranto is a lecturer in the Petroleum Department at the University of Pembangunan Nasional "Veteran" Yogyakarta, Indonesia. He holds a doctor degree from Sejong University, South Korea, in Petroleum Engineering. His primary research interests are enhanced oil recovery (EOR) and reservoir modeling.

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