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# Feasibility Research of Steam-Assisted-Gravity-Drainage Process in Bohai Offshore Heavy Oil Reservoirs

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**Abstract:** The LD5-2N block is a typical heavy oil reservoir in Bohai offshore oilfield, and the viscosity of crude oil for this block at reservoir condition is about 10000mPa.s. Therefore, the conventional exploitation method of water flooding or chemical flooding will be not suitable for this block, and the thermal recovery should be considered. Using the method of numerical simulation, the steam assisted gravity drainage (SAGD) process for this block is investigated in this paper. Firstly, a sensitivity analysis process of reservoir properties and fluid parameters is conducted, e.g., reservoir thickness, oil viscosity, permeability, the vertical-horizontal permeability ratio etc. Then, on account of the shale cases in this block, an orthogonal test is carried out to study the influences of shale barriers on SAGD process. Results indicate that the parameters of reservoir thickness, reservoir permeability have a significantly influence on the recovery rate of SAGD process. For a SAGD process, the reservoir thickness should be greater than 20m. With the increase of vertical permeability, the expanding rate of steam chamber is on a rise, and thus the recovery rate of SAGD process is increased. The bottom water will reduce the oil recovery by about 10∼20%. Furthermore, the existence of shale barrier also has a tremendously influence on the drainage process, especially for the recovery rate. This investigation could be used for the application of SAGD technique in the similar heavy oil reservoirs.

## 1 Introduction

Currently, the main exploitation method of offshore heavy oil reservoir was cold production, including water flooding, polymer flooding and weak gel flooding etc [Zhang (1999); Zhou (2007)]. For thermal production technology, it was not the common exploitation method for offshore heavy oil reservoir. The earliest pilot test of thermal production in offshore heavy oil reservoir was the steam stimulation process in Bachaquero-01 oilfield, Lake Maracaibo, Venezuela since 1971 [Escobar

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and Valera (1997)] . This oilfield included a bank part and a lake part. For the lake part, the water depth was about 50m. This Lake area was about 79km$^2$, and the oil reserve was 10$^8$t. The reservoir depth was 910m. The oil viscosity was 635mPa.s. Until to 1997, about 285 wells were opened to operate in this oilfield. The daily oil production was 6360t/d, and the oil increment was $1248\times10^4$t. In 1995, two sidetrack horizontal wells were completed to inject steam. Compared with cold production, the oil production of thermal process for these two horizontal wells was about three times high. Then, in 2010, a pilot test of multiple thermal fluid huff and puff was conducted in the NB35-2 block of Bohai oilfield. And it also makes a huge success [Gu, Sun and Guo (2012); Liu, Yang and Zhao (2010)]. Thus, the success of these two tests laid a solid foundation for the large-scale application of thermal production in offshore heavy oil reservoirs.

The common used methods of onshore thermal recovery include steam stimulation, steam flooding and in-situ combustion etc [Zhang (1999); Liu(1998)]. Steam-Assisted-Gravity-Drainage (SAGD) process is a cutting-edge technology for the development of heavy crude oil reservoirs. This technology is proposed by R.M. Butler in 1978. For thick heavy oil reservoir, this technology has tremendous advantage. For SAGD process, gravity is the main driving force of heavy crude oil. The latent heat of vaporization is used to heat reservoir in the drainage process. Compared with steam stimulation process and steam flooding process, this process also has high recovery and high oil steam ratio (OSR). Furthermore, except the large-scale shale barriers, this drainage process is not sensitive for the reservoir heterogeneity [Shin and Choe (2009); Ipek, Frauenfeld and Yuan (2008); Ito, Hirata and Ichikawa (2004)]. It is a potential technology for the development of thick heavy oil reservoir.

The LD5-2N block is a typical offshore heavy oil reservoir in Bohai oilfield. The oil viscosity of this reservoir reaches about 10000mPa.s, and it is the extra heavy oil type. Besides, the oillayer thickness of this reservoir is also high, about 50m. Therefore, during the screening process of development method, SAGD is a potential technology.

Using the method of numerical simulation, in this paper we established several reservoir geological models to study the influence of reservoir and fluid physical parameters on SAGD process. All of these models are based on the physical feature of LD5-2N. In addition, the issues of shale barriers and bottom water in SAGD process are also discussed.

## 2 Design of the model parameters

By the use of the typical parameters of LD5-2N block in Bohai oilfield, CNOOC, we establish the geological reservoir models to study the influences of reservoir and fluid parameters on SAGD process, as shown in Fig. 1. The middle depth of oil-layers is 950m. The porosity and permeability are 35%, $3000\times10^{-3}\mu m^2$ respectively. The original temperature of reservoir (TR) is 47°. The reservoir thickness is 50m, and net gross ratio is 0.8. The oil viscosity under reservoir condition is about 5000mPa.s. The vertical distance between injector and producer is about 6m. The wellbore length of injector and producer is 300m. The startup method of SAGD process we employed in this study is steam stimulation, and it is about 3 cycles. The pressure of steam chamber in SAGD process is 3MPa. The relative permeability curves are listed in Fig. 2.

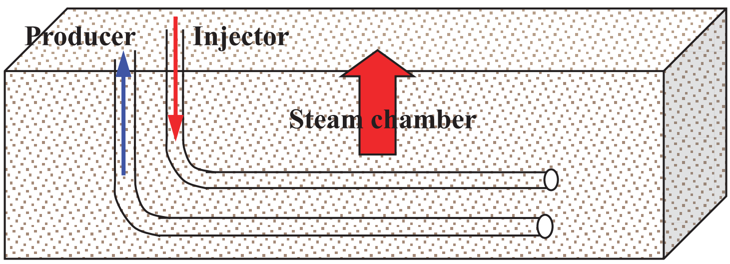


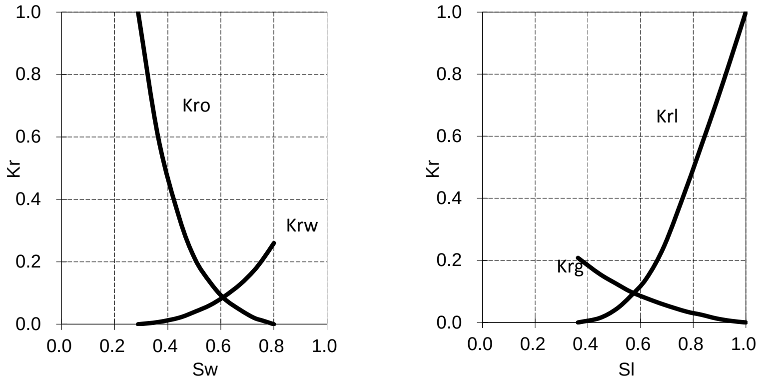

Figure 1: A schematic diagram of the dual-horizontal-well SAGD model.

## 3 Sensitivity analysis process

The factors to influence the exploitation effect of SAGD process include reservoir thickness, oil viscosity, reservoir permeability, shale barriers and bottom water. Furthermore the operating parameters are also tremendously influenced the drainage process, including the steam injection rate, steam chamber pressure, production - injection ratio and the startup method etc [Ito, Hirata and Ichikawa (2004); Collins (2007)]. In this section, a single-factor sensitivity process is conducted to study the influences of these factors on SAGD.

### *3.1 The influence of reservoir thickness*

The fluid gravity is the main driving force of SAGD process. Therefore, the action of gravity will be more obvious in a thick reservoir. Conversely, for a thin reservoir, the gravity is limited, and the heat loss of cap rock is also strengthened. Thus, the




***a.*** Curves for oil & water ***b.*** Curves for gas & liquid

Figure 2: Relative permeability curves.

OSR level in drainage process will be reduced. Generally, for a given well distance, the bitumen production is proportional to the square root of reservoir thickness. In this part, setting different reservoir thickness, we simulate the influence of reservoir thickness on SAGD process. The results are shown in Fig. 3. With the increase of reservoir thickness, the oil recovery of SAGD process is increasing. When the thickness is greater than 20m, the changing tendency is slowed down. The oil recovery for the 10m case is only 21.2%. But when the thickness rises to 20m, the oil recovery increase reaches 59.3%. Therefore, for a SAGD project, the minimum reservoir thickness is 20m.

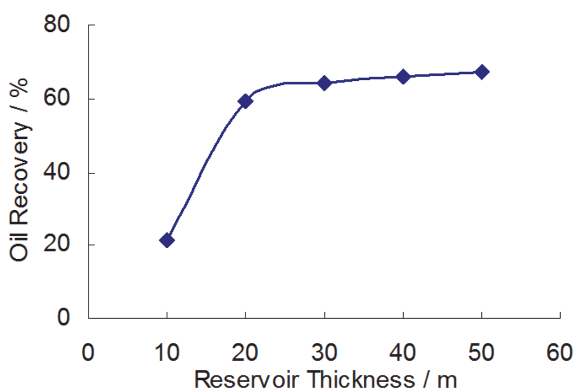



Figure 3: The influence of reservoir thickness on SAGD process.

### *3.2 The influence of oil viscosity*

Due to the particularity of mechanisms for SAGD process, the oil viscosity is not a main influencing factor. The first successful SAGD pilot test is the Underground Test Facilities (UTF) in Alberta, Canada. According the experiences of UTF project, even the tar sand with the oil viscosity of $500\times10^3$cp could be economically developed [Collins (2007)]. But the relationship of oil viscosity and temperature influences the drainage rate of bitumen in SAGD process. Therefore the steam frontal movement and oil production rate are affected by the oil viscosity. In this part, we used four viscosity-temperature curves to simulate the influence of crude oil viscosity on SAGD drainage process. The results are shown in Fig. 4. With the increase of oil viscosity, both the oil recovery and oil production rate are reducing. But the reducing trend of oil production rate is more distinct, and the oil recovery has small variation. When the oil viscosity under reservoir temperature condition is higher than 10000cp, the changing tendency of oil production rate and oil recovery is strengthened.

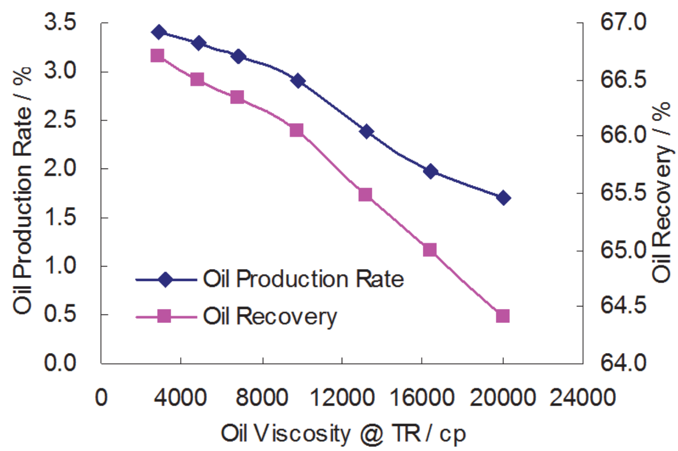



Figure 4: The influence of oil viscosity on SAGD process.

### *3.3 The influence of reservoir permeability*

The influence of reservoir permeability on SAGD process includes plane permeability and vertical permeability. Plane permeability affects the horizontal expansion of steam chamber, and vertical permeability affects the rising rate of steam in reservoir. For the thick reservoir, the value of vertical permeability is more important. Therefore, by the method of numerical simulation, we simulate the influence of reservoir vertical permeability on SAGD process, and the results are shown in Fig. 5. With the increase of vertical permeability, both the oil production rate and oil recovery of SAGD process is increasing. When the vertical to plane permeability ratio is higher than about 0.3, the influencing tendency is slowed down. For the SAGD project in LD5-2N block, the vertical permeability should be higher about 0.3 times than the plane permeability.

### *3.4 The influence of shale barriers*

The shale barriers in thick heavy oil reservoirs have tremendous influence on the expansion of steam chamber of SAGD process. But when the shale layer is thin and small expanded in horizontal plane, it does not exhibit the expansion of steam chamber. Actually, it also plays role of dispersion for the heavy crude oil. And, the contact area of steam and reservoir is increased to make full use of the heat conduction [Shin and Choe (2009); Ipek, Frauenfeld and Yuan (2008)]. In this section, an orthogonal test plan is designed to study the influence of shale barriers on SAGD process, including the shale distribution range, well-pair position and the permeability of shale barriers. The results present the existence of shale barriers has tremendously influence on the oil production rate of SAGD process. But for oil recovery, OSR and cumulative steam injection volume, the influence of shale barriers is small. For the situation of shale barriers above the injector-producer well pair, the closer the distance between shale layer and well pair, the stronger the influence of shale barriers on oil production rate of SAGD process. Furthermore, the principal axis direction of shale layer also has tremendously influence on SAGD process. Therefore, during the design of well-pair position, the horizontal wellbore should be perpendicular to the principal axis direction of shale barriers.

### *3.5 The influence of bottom water*

For the development of heavy oil reservoirs with bottom water, bottom water coning is the main problem. For the SAGD process of heavy oil reservoir with bottom water, the existence of bottom water will reduce the oil recovery by about 10%$\sim$20% [Masih, Ma and Sauchez (2012)]. On the whole, SAGD technique is also a potential development method for the heavy oil reservoir with bottom water. During the drainage process, the pressure of steam chamber is stable. The pressure drop between injector and producer is also small. Therefore, the water coning is avoided in SAGD process, and the oil-water interface is also kept stable. In this section, we simulate the influence of bottom water on SAGD process. Results are shown in Fig. 6. With the increase of water-oil volume ratio, the oil production ratio is tremendously reduced. Thus, the producing time is prolonged. Also, when the ratio is higher than about 5, the reducing tendency of oil production ratio is

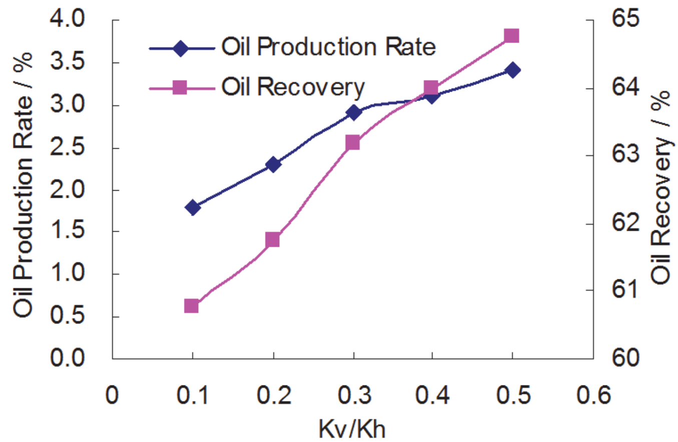



Figure 5: The influence of vertical permeability on SAGD process.

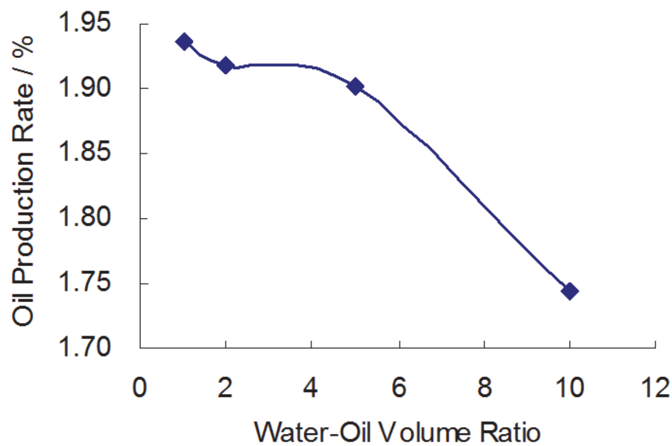



Figure 6: The influence of bottom water on SAGD process.

strengthened. Therefore, for the SAGD process in heavy oil reservoir with bottom water, the water-oil volume ratio should be less than 5.

### *3.6 The influence of operating parameters*

The key problem in SAGD process is the control problem of steam chamber [Qian, Ma and Ren (2011)]. The reasonable expansion of steam chamber directly influences the development effects of SAGD process in heavy oil reservoirs. In this section, we mainly optimized the operating parameters of SAGD process by the method of numerical simulation, including the steam injection rate, the production-injection ratio, the pressure of steam chamber and the distance of well pair. According to the results, the optimal operating parameters of SAGD process in LD5-2N block are listed as follows. The steam injection rate is about 350t/d; the production-injection ratio is 1.2; the pressure of steam chamber is 3MPa; the distance of well pair is 140m.

## 4 Conclusions

(1) LD5-2N block is a typical thick offshore heavy oil reservoir in Bohai oilfield. SAGD process is a potential technique for the development of this block.

(2) Using the method of numerical simulation, the influences of reservoir and fluid physical parameters on SAGD process are studied. From the results, it is found that the minimum reservoir thickness is 20m. The vertical-plane permeability ratio should be higher than 0.3. For the influence of oil viscosity, when the oil viscosity under reservoir temperature condition is higher than 10000cp, the changing tendency of oil production rate and oil recovery is strengthened.

(3) The issues of shale barriers and bottom water in thick heavy oil reservoirs have tremendous influences on the oil production rate SAGD process. For a reasonable SAGD project, the horizontal wellbore should be perpendicular to the principal axis direction of shale barriers. When the problem of bottom water is encountered, the water-oil volume ratio should be less than 5.

(4) The control problem of steam chamber is the key problem in SAGD process. From the results of numerical simulation, the optimal operating parameters of SAGD process in LD5-2N block are: The steam injection rate is 350t/d; the production-injection ratio is 1.2; the pressure of steam chamber is 3MPa; the distance of well pair is 140m.

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