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# Evaluation of the First Cyclic Steam Pilot in Offshore Oilfield of China

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## Abstract

As a viscous offshore oilfield (600~2300 mPa·s at reservoir conditions), LD oilfield was developed by natural drive in early time. One well of the field initially produced around 20 $m^3$/d with early water breakthrough until today. However, the production rate decline rapidly when the water production rate increased.

In order to improve the development effect, the cyclic steam pilot was founded. 12 horizontal wells were designed, two of which had been implemented. Through the comprehensive study, the injection parameters were optimized as follows: bottom hole temperature > 340°C, steam quality >0.4, injection rate equals 300 $m^3$/d. The predicted oil recovery increases from 5% for cold production to 18% for cyclic steam injection.

In this paper we present the application and evaluation of the cyclic steam injection, which is a high quality steam injection with the miniaturization steam generator. For the evaluation of this thermal process for the first test well, an available history matched full field thermal model of the LD reservoir (Local refinement in space around the wells) was established.

Meanwhile, heat loss study of wellbore, decline rate analysis as well as suggestions about next well of this pilot project will be presented. The production effect of cyclic steam injection was compared with that of the cold production: peak oil production rate is 5.3 times and cycle oil productivity is 2.1 times of that for cold production; monthly decline rate is 23%;the valid time of first cycle is 200 days or more. The success of this pilot will provide technology and confidence for the better development of heavy oil in offshore oilfield of china.

## Introduction

LD oil field is a typical unconventional I heavy oil which formation viscosity is 2300 mPa.s, and buried depth of 1300 meters, average porosity is 34.4%,average permeability mainly concentrated in 330.0 ~ 11116.9mDarcies, average 3786.5 mDarcies(**Fig. 1**). There are several pattern reservoirs, such as edge water, bottom water and without water drive(**Fig. 2**), most of which are too complex to develop economically.

There are 2 cold production wells designed for experimental development in the ODP(Overall Development Plan). Its limits were exposed such as low productivity, high water-cut rise and low cumulative oil production (**Fig. 3**). The cumulative oil production of A14H is $2\times10^4 m^3$ and A15H is

$3.4\times10^4 m^3$. The predicted recovery rate is only 5%. It is obviously that conventional development of these reservoirs cannot meet the economic demand of offshore oilfield.

| | |
|---|---|
| Start Up the Production | 2009 |
| Oil zone | Nm |
| Depth(m) | 1272～1526 |
| Depositional Facies | shcal water |
| Initial reservoir pressure(MPa) | 12.6 |
| Initial reservoir temperature(℃) | 52 |
| Net pay(m) | 6～18 |
| Porosity（%） | 31 |
| Permeability（mD） | 1000～4000 |
| Initial oil saturation(%) | 64 |
| Dead oil viscosity 50℃ (cp) | 2678 |
| Oil viscosity in reservoir condition (cp) | 400～2400 |
| Gas/oil ratio | 3 |

**Figure 1—Reservoir data**

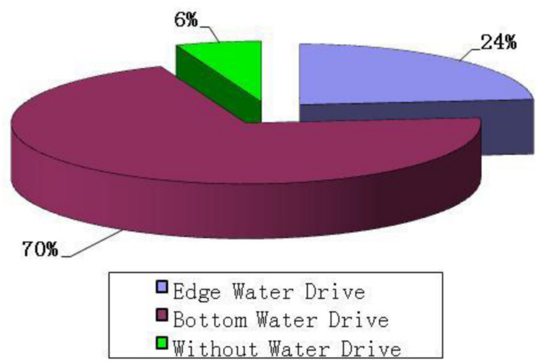



**Figure 2—Heavy oil volume percentage of different pattern reservoir for LD oilfield**

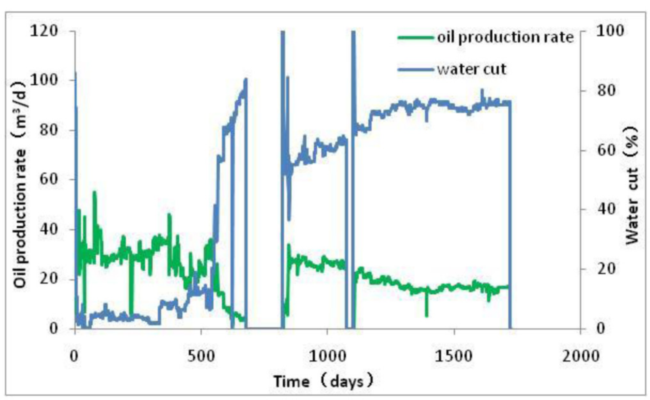



**Figure 3—Performance curve of cold production well**

Thermal recovery may be a good method to develop these reservoirs efficiently, but normal steam generator can not meet the demand of platform space and economic benefit. For the cyclic steam pilot, miniaturization offshore steam generator has been developed to as shown in **Fig.4**. Compared with conventional steam generator, the Miniaturization offshore steam generator has 68% smaller volume and 58% less weight, which can generate steam with 340°C and 80% dryness. Meanwhile, high vacuum heat insulation oil pipe with E level and annulus nitrogen injection technique are used to reduce the heat loss in the wellbore and then enhance the quality of steam at the bottom hole, which can improve the effect of thermal recovery greatly.

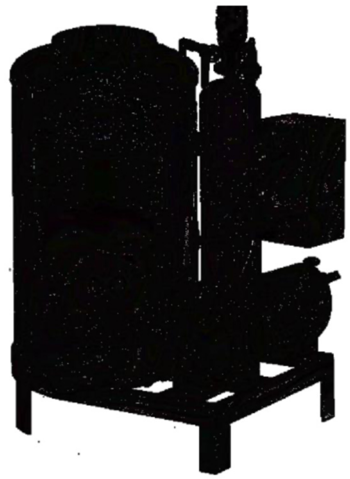


Figure 4—Miniaturization steam generator used in offshore oilfield

## Selection of the Pilot Area and Optimization of the Steam Injection Parameters

In order to select the pilot area exactly and quickly, the producing principle of these reserves is studied, which shows that the edge water reservoir with 6 meters thickness or more and the distance of oil within boundary more than 100 m can be priority developed, the bottom water reservoir with more than 15 meters oil column can be developed tentatively. Based on this principle, the cyclic steam pilot area is confirmed. Three reservoirs with 12 wells have been selected as cyclic steam pilot area, two of which are edge water reservoirs and one of which is bottom water reservoir(**Fig. 5**).

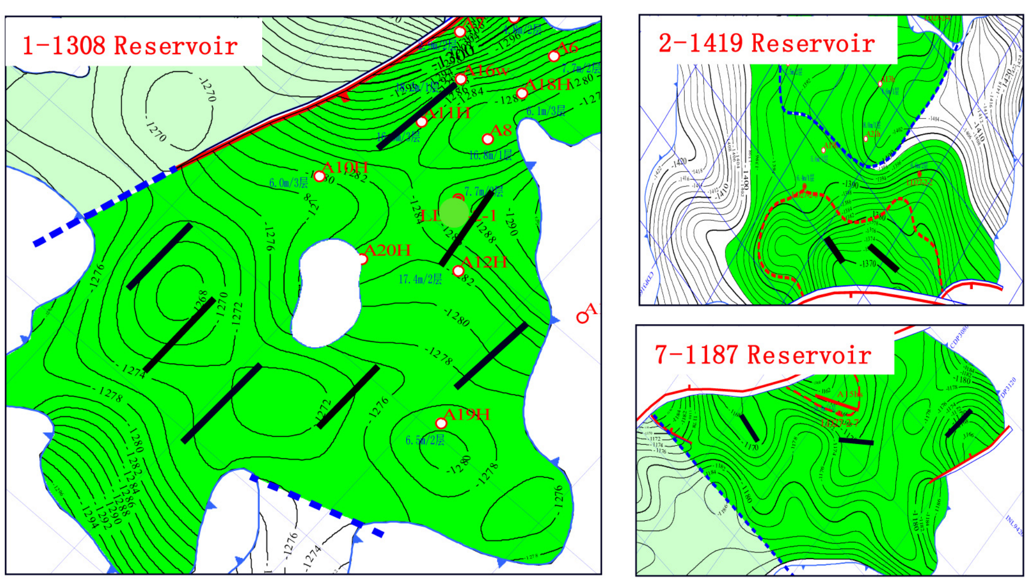



Figure 5—The selected cyclic steam pilot area of LD oilfield

The thermal and component modules are adopted to simulate in STARS of CMG numerical simulation software. The reservoir model is set up with the fluid parameters of LD oil field. The injection steam parameters are optimized as follows: steam injection temperature, steam dryness, the cyclic steam injection volume, the soak time and so on. The process of steam injection parameters optimization is shown in **Fig. 6**.

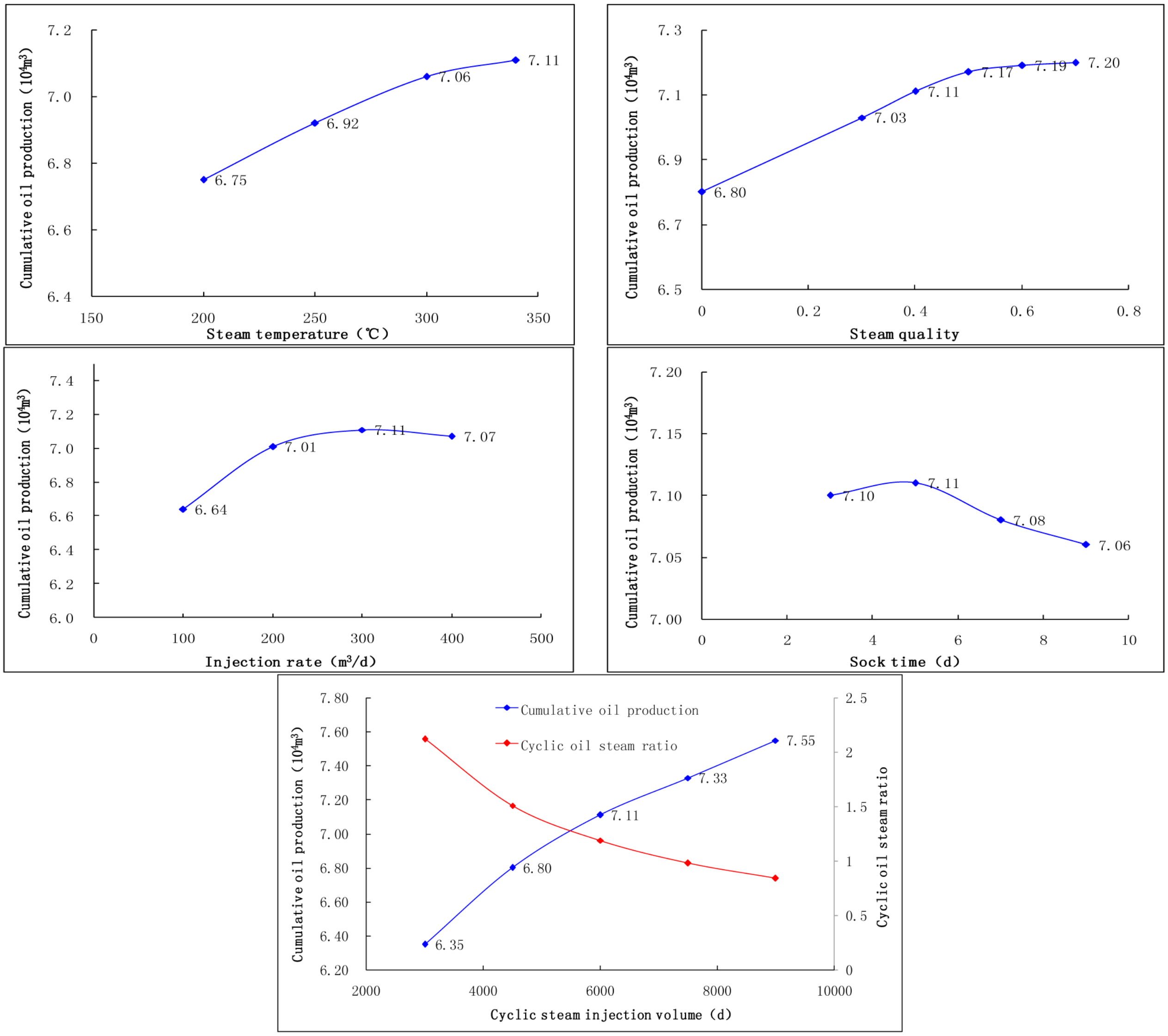



**Figure 6—Optimization of the Steam Injection Parameters**

***The steam injection temperature***:The injection temperature is optimized by the numerical simulation, the results show that the temperature is higher and the result is the better, consider the oil pipe's resistance, the recommended temperature between 300-350 degrees is better.

***Steam quality***:The optimization results show that the dryness of steam injecting is the higher and the result is the better, The cumulative oil is more sensitive to the dryness when dryness is below 0.4, Considering the outlet temperature of the steam generator, the heat loss of steam injection and onshore oil field injection dryness, the recommended dryness is 0.4

***Steam injection rate and sock time***:The optimization result shows that the best steam injection rate is 300 $m^3$/day and the best soak time is 5 day.

***Cycle steam injection volume***:The optimization results of different cycle injection volume show that: although the steam injection volume is greater and the cumulative oil production is higher, but when steam injection volume is more than 6000 $m^3$, the cycle oil steam ratio is reduced, at the same time by using the experience of Liaohe oilfield, the recommended cycle injection volume is 6000 $m^3$.

Combined with numerical simulation, the steam stimulation of heavy oil injection experience onshore oilfield and the ability of small generator, these recommend injection parameters were temperature in bottom hole > 340°C, steam quality >0.4, injection rate is 300 $m^3$/d, soak time is 5 days and cycle steam injection volume is 6000 $m^3$(first cycle is 3000~4500 $m^3$ due to the high initial reservoir pressure).

## Prediction Cases

The prediction cases were designed under different development method which have to be accomplished during the field operation(**Fig. 7**), 1-1308 reservoir as example. In the following, we present the results of the evaluated prediction cases(**Fig. 8**).

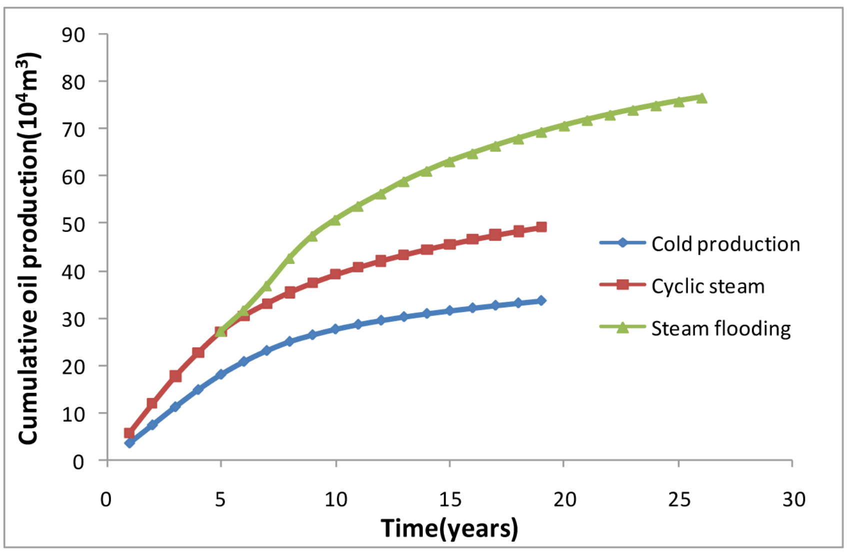



**Figure 7—Cumulative oil prediction of 1-1308 reservoir under different development technique**

| Reservoir | Type | Producing reserves ($10^4m^3$) | Well number | Cumulative oil production of cyclic steam ($10^4m^3$) | Cold recovery (%) | Cyclic steam recovery (%) | Steam flooding recovery (%) |
|---|---|---|---|---|---|---|---|
| 1-1308 | Edge water drive | 269 | 7 | 49.2 | 7.8 | 18.3 | 28.5 |
| 2-1419 | | 80 | 2 | 16.2 | 7.5 | 20.3 | - |
| 7-1187 | Bottom water drive | 150 | 3 | 17.6 | 4.5 | 11.7 | - |

**Figure 8—Production index prediction of pilot area under different development technique**

***Base Case Cold Production***: For this case all existing producers were placed to produce without any additional work over activities for a 19 years prediction period. The cold production recovery of 1-1308 reservoir is 7.8%.

***Cyclic Steam Injection***: For this case some operation restrictions have to be accomplished like: Maximum number of cycles 15, the period of a cycle is 12 month, the prediction period was defined for 19 years. 9 wells are deployed in edge water reservoir, the cyclic steam recovery is 18%, 3 wells are deployed in the bottom water reservoir, the recovery is 12%. Compared with the cold development, the edge water reservoir recovery efficiency can be improved by 13%.

***Steam Flooding***: For the 1-1308 reservoir, 3 oil wells have to be changed to the steam injectors and finely the evolution period was defined for 26 years. After the steam flooding, the thermal recovery of 1-1308 reservoir will be to 28.5%, which can be improved by 10.2%.

## Progression and Evaluation of the Cyclic Steam Pilot

At the moment, two wells located on 1-1308 reservoir have been implemented(**Fig. 9**). A22H well has completed the first cycle steam huff and puff, while A23H well has just started the first cycle.

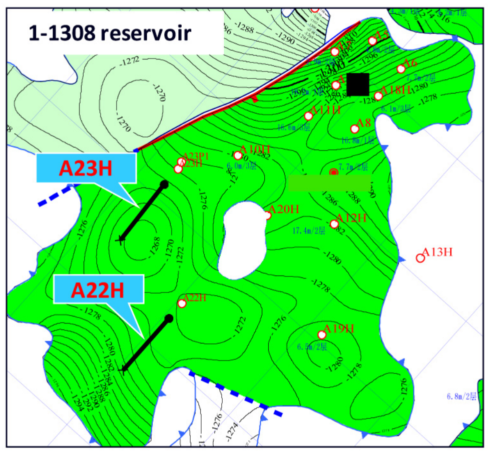



**Figure 9—Implemented cyclic steam well location in the pilot area**

***Injection process***:Well A22H of LD reservoir was carried out the steam huff and puff pilot test from Jan 2014. Consider the 1-1308 reservoir never been developed and the reservoir pressure keep initial state, the cycle injection volume reduced from 6000 $m^3$ designed to 3000$m^3$.During the injection, the steam temperature and dryness generated by minimization steam generator is 340°C and with 80% dryness, Subjected to the limit of well head injection pressure , the daily injected rate was 150$m^3$, and the injection time is longer than designed, So there are some differences between designed and actual which was shown in **Fig. 10**. When the injection was finished, steam of 3000 $m^3$ was injected into the reservoir. The quality and temperature at the bottom hole were obtained through wellbore test and heatloss match(**Fig. 11**).

| Parameters | Design | Actual（A22H） | Actual（A23H） |
|---|---|---|---|
| Well head temperature（℃） | 340 | >340 | >340 |
| Well head steam quality（%） | 80 | 80 | 80 |
| Well bottom hole temperature（℃） | 340 | undetective | 360 |
| Well bottom hole steam quality（%） | 40 | | 0 |
| Injection rate（$m^3$/d） | 300 | 150 | 190 |
| Injection time（d） | 10 | 20 | 24 |
| First cycle steam injection volume（$m^3$） | 3000~4500 | 3000 | 4500 |

**Figure 10—Comparision between the design and actual injection parameters**

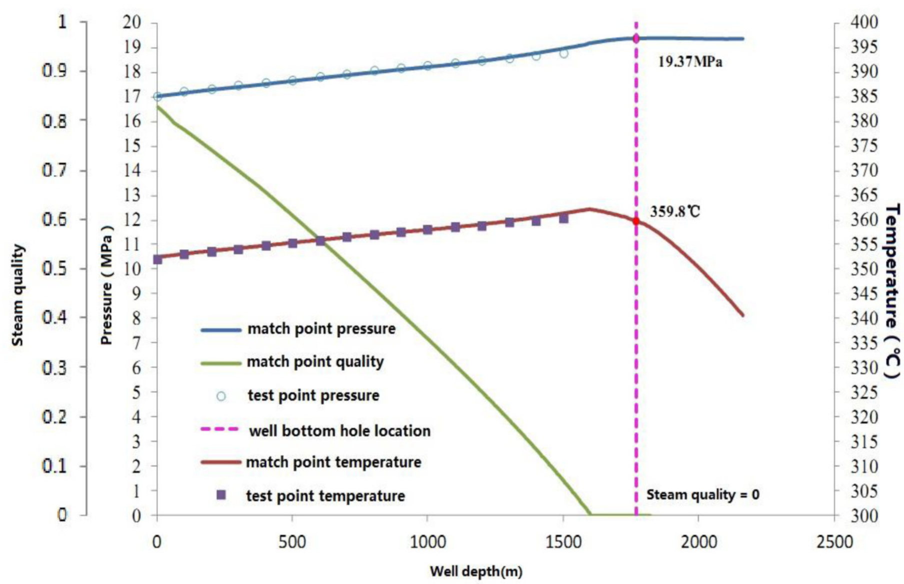
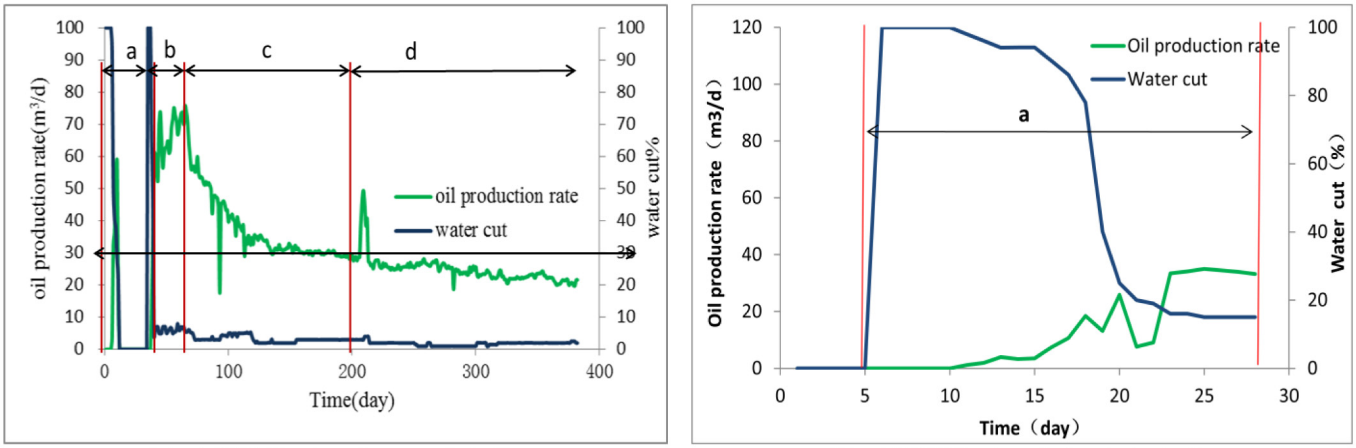



**Figure 11—Steam injection parameters match in the well bottom hole based on the wellbore test data**

***Production stage***:**Fig. 12** shows the oil production rate-time diagram of well A22H and A23H of steam huff and puff in the first cycle. The production process of steam huff and puff can be broadly classified four stages, such as water-backflow, high-production, decline and low production. At the beginning of open well, water near the well bore was brought to surface firstly, and the water cut was almost 100%.this period would last for three days. when the water was cleaned up, the oil production rate could reach 82$m^3$/d because heavy oil heated by the steam has lower viscosity. After that, the oil production declined as the bottom flow pressure decreased. when the oil rate declined to a certain value, a pump was needed to help the oil flow to surface. The well can product steadily for a long time with the rate of 30-40$m^3$/d, after that, the oil rate declined to 20$m^3$/d.




**(a) A22H(first cycle completed)** **(b) A23H(first cycle just started)**

**Figure 12—First cycle production performance of implemented cyclic steam wells**

1. Flow production days:Compared with steam stimulation onshore reservoirs, the flowing period of well A22 was recognized to be in the normal category. Compared with the multiple thermal fluid flow of NB reservoir, the flowing period was shorter. It was analyzed that gas injected in the multiple thermal fluid pilot played a great role in keeping pressure and help increase the flow production period.
2. Production capacity multiples: In order to eliminate the influence of different production pressure differential, the specific productivity index is used to describe the production capacity. The peak production capacity of steam huff and puff is 3.28$m^3$/d.m.MPa, and the cycle average capacity is 1.04$m^3$/d.m.MPa, the production capacity multiple is 4.1 and 1.9 which is shown in **Fig. 13**, in the first cycle, production capacity multiples of steam stimulation in LD reservoir was bigger than multiple thermal fluid case. After the third month, production capacity multiples of steam stimulation decreased faster. That is because crude oil viscosity of LD reservoir was more sensitive to the temperature than the multiple thermal fluid case.

| well name | parameter | peak specific productivity index ($m^3$/（d.MPa.m) | cycle specific productivity index ($m^3$/（d.MPa.m) |
|---|---|---|---|
| A22H | thermal | 3.28 | 1.04 |
| | cold | 0.8 | 0.54 |
| | Production capacity multiples | 4.1 | 1.9 |

**Figure 13—Production capacity multiples of well A22H**

3. Decline rate:The oil productivity decline rate of a thermal well might be also characterized by the decline factor. The decline rate curve presented exponential decrease, as shown in **Fig14**. Decline rate in the first five month was 23%, which was in line with that of steam huff and puff well of onshore oil field. The decline rate of NB thermal development is 3.3%, compare with the multiple

thermal fluid flow of NB reservoir, steam huff and puff pilot well of LD reservoir had bigger decline rate.

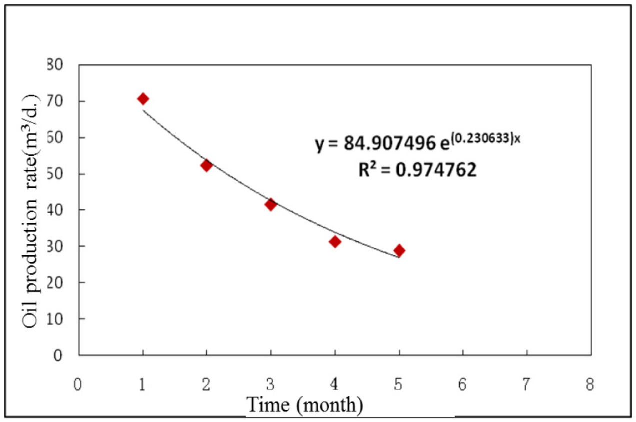



**Figure 14—Decline rate curve of cyclic steam well A22H**

4. Valid period evaluation:The thermal valid period for steam huff and puff well is referred to as the length of days when thermal well can produce more oil than that of depletion development. It is an essential parameter of steam huff and puff for the reason that only in the thermal valid period the thermal well can produce more oil than that of non-thermal recovery. The longer the thermal valid period last, the more increment in cumulative production oil is.
5. The valid period is judged by the specific productivity index. Valid period evaluation of steam stimulation in LD reservoir was shown in **Fig.15**. Based on the analysis of month declining rate, it was predicted that the valid period of the first cycle steam stimulation in LD reservoir was about seven months. Many thermal cases verified valid period of vertical wells was longer than horizon wells. The valid period decreased as the crude oil viscosity increase.

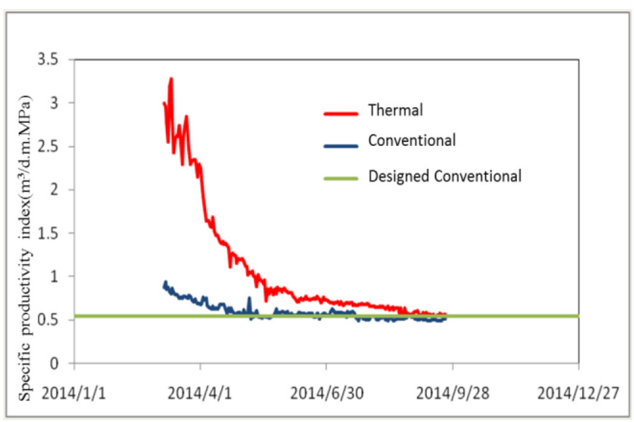



**Figure 15—Valid period evaluation of cyclic steam well A22H**

6. Cycle incremental oil production:Cycle incremental oil production means that the thermal cycle cumulative oil production minus the cumulative oil production of conventional develop. It is an important indication for offshore thermal development. Predicated cumulative oil production of well A22H is $0.42\times10^4 m^3$ if it's conventionally developed. According to the Valid period evaluation and declining rate and the production capacity study , we can get the cycle cumulative

oil production of steam huff and puff is $0.88 \times 10^4 m^3$, so the cycle incremental oil production is $0.46 \times 10^4 m^3$.

Because the fact injection rate($150 m^3/d$) is lower than the designed value($300\ m^3/d$), the fact incremental oil production is lower than designed($0.68 \times 10^4 m^3$). We get the cycle cumulative oil production is $1.36 \times 10^4 m^3$ when the injection rate is $300\ m^3/d$ by the numerical simulation. And then the cycle incremental oil production will be better and reach $0.94 \times 10^4 m^3$(**Fig. 16**).

| parameter | A22H | predicted after improved |
| --- | --- | --- |
| injection rate($m^3/d$) | 150 | 300 |
| conventional develop | 0.42 | 0.42 |
| cycle cumulative oilproduction ($10^4 m^3$) | 0.88 | 1.36 |
| cycle incremental oil production (104m3) | 0.46 | 0.94 |

**Figure 16—Predicted incremental oil production after improved injection rate**

## Conclusions

1. The limits of conventional development way cannot meet the high speed and high efficiency requirement of offshore oilfield unconventional heavy oil development. And Conventional steam generator cannot be used for the thermal development in the offshore heavy oil reservoirs because its large volume and big weight contradict with the narrow space of offshore platform. With the success of Miniaturization steam generator, steam huff and puff can be carried out on offshore oil field.
2. Based on the program research, the pilot area of steam huff and puff was carried out at LD oil field. this is the second thermal development oil field in BoHai oilfield which aimed at improve the development effect of higher viscosity and explore the adaptability of different thermal recovery technology in offshore heavy oil field
3. The performance of A22H shows that steam huff and puff can improve the development of heavy oil. peak oil production rate is 4.1 times and cycle oil productivity is 1.9 times of that for cold production; the valid date is 200 days or more. And the predicted recovery would increase more than 10% on the base of conventional production

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