Field application of a modular multiple thermal fluid generator for heavy oil recovery

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Abstract

A modular multiple thermal fluid generator is introduced to enhance heavy oil production, which consists of water treatment system, fuel injection system, air compressor, central burning and heat exchanging system, and measuring and controlling system. All the components are mounted in three separated light shelters, which are easy to be lifted and installed, especially on the offshore production platform. It could be operated under 350 °C and 20 MPa, and the temperature and GWR (ratio of the volume of gas to the equivalent water volume of steam under standard conditions) could be adjusted by the water injection rate under the given heating capability of the central burning chamber. The temperature of the generated fluid is usually 200–300 °C with GWR of 200–300 m³/m³. Compared to conventional steam generator, such compact multiple thermal fluid generator is easy to be installed on the offshore oil production platform, and the generated multiple thermal fluid is potential to enhance heavy oil production in mechanisms of reducing heavy oil viscosity by both heating and injected gas, enlarging the heating reservoir chamber, and pressure by injected gas. In the past 10 years, the multiple thermal fluid generator has been applied to more than 40 wells in Bohai Offshore Oilfield and Xinjiang Oilfield in cyclic multiple thermal fluid stimulation (CMTFS in short) process. As a result, the multiple thermal fluid generators were operated soundly, and the heavy oil production of these wells was enhanced remarkably. (The oil production rate was 2–3 times more than cold production.)

Keywords Multiple thermal fluid generator · Cyclic steam and gas stimulation · Heavy oil · Field application

Introduction

Steam injection processes such as CSS and SAGD are effective and used worldwide to enhance heavy oil production, the steam generator with large weight and volume is used to generate HTHP steam, and such conventional steam generator is difficult to be installed onto the offshore production platform (Zhong et al. 2013; Wu et al. 2016; Wang et al. 2020a, b). As a result, steam injection processes such as cyclic steam stimulation (CSS in short) are not put into effect in past, and most heavy oil reservoirs in Bohai Oilfield are developed by cold production methods such as primary

production and water injection in past years, and the oil production rate is usually lower than 20 m³/day.

In order to enhance offshore heavy oil production and recover sufficient heavy oil at economical rate within the limited lifetime of the production platform, thermal processes such as CSS and CMTFS (cyclic multiple thermal fluid stimulation) were taken into consideration to enhance Bohai offshore heavy oil recovery. Multiple thermal fluid is a new heat carrier introduced in heavy oil reservoir development in recent decades (Liu et al. 2011; Tang et al. 2011; Dong et al. 2014, 2015; Han et al. 2020). It is a gas mixture of steam and non-condensable gas, and the main components include steam, nitrogen gas (N₂) and carbon dioxide (CO₂). But multiple thermal fluid is different from the conventional mixture of steam and non-condensable gas. First, multiple thermal fluid is a high-temperature and high-pressure mixture, which is produced from the combustion process in multiple thermal fluid generator. The non-condensable gas in multiple thermal fluid is the gas mixture of N₂, CO₂, CH₄ and CO. Second, in field application, multiple thermal fluid is injected into the reservoir directly after generation. In

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other words, steam and gas are injected simultaneously into the reservoir, unlike conventional separate injection (Sun et al. 2011; Liu et al. 2012; Dong et al. 2014).

The multiple thermal fluid technology has been tested in Shengli Oilfield, Bohai Oilfield, Daqing Oilfield and other Chinese oilfields and has been proved to be an efficient thermal recovery technology for heavy oil. At present, most of the studies are focused on application effect evaluation and parameter optimization. In 2009, a multiple thermal fluid stimulation process was performed in a typical multicycle CSS well, GDN5-604 well in Shengli Oilfield in China (Li 2013). During this stimulation process, the cycle N_2 and CO_2 injecting volume is $21 \times 10^4 \text{ m}^3$ and $3.7 \times 10^4 \text{ m}^3$, respectively, and the cycle steam injecting volume is 480t. After operation, the average water cut of this well is reduced by about 27.2%, and the oil daily rate is increased from 2.8t to 10.1t. The cumulative oil increment is about 1009t. Considering the successful operation of multiple thermal fluid stimulation technique in this well, two well groups in the C20 block of Shengli Oilfield were operated in 2013, and a more obvious oil increasing effect was obtained (Liang et al. 2014). In 2010, multiple thermal fluid stimulation technique was also introduced into the development of NB35-2 heavy oil block of Bohai Offshore Oilfield in China (Liu et al. 2010, 2011; Sun et al. 2011; Yu et al. 2014; Han et al. 2020). More than 20 stimulation cycles of cyclic multiple thermal fluid stimulation (CMTFS) were performed by the end of 2018, and this test achieved great oil production increment results.

However, there are few studies and reports on how the multiple thermal fluid is generated. Different from the conventional saturated steam, multiple thermal fluid is produced from the multiple thermal fluid generator. In this paper, a modular multiple thermal fluid generator is introduced in detail including its operating principle, composition and characteristics, and its application in Bohai Oilfield and Xinjiang Oilfield in China.

Modular multiple thermal fluid generator

Offshore oilfield production platform is highly integrated and limited in operating area, load and hoisting capacity. Traditional steam boilers occupy a large area and weigh too much to adapt to offshore operations. The modular multiple thermal fluid generator was first introduced to heavy oil thermal recovery in the Bohai Offshore Oilfield, and a good effect of increasing production has been achieved.

Operating principle

The modular multiple thermal fluid generator utilizes the combustion and jetting mechanisms of rocket engine and follows the law of conservation of matter, conservation

of energy and chemical balance. By deflagration of fuel and oxidant in the combustion chamber, high-temperature mixture is produced, and chemical energy is converted into heat energy. As shown in Fig. 1, the central burning and heat exchanging system comprises burning chamber, steam chamber and mixing chamber, the water is injected into the steam chamber and is heated by the burning chamber, and the generated hot water or steam is mixed with flue gas in the mixing chamber. Then, the high-temperature and high-pressure multiple thermal fluid was generated at the outlet.

The calculated composition and GWR (ratio of the volume of gas to the equivalent water volume of steam under standard conditions) of multiple thermal fluid generated are listed in Table 1. The composition and GWR are varied as water injection rate increases at given heat capacity of the burning chamber in which limited fuel and air could be injected. Therefore, higher temperature could be obtained by decreasing water injection rate. The GWR of 200 °C multiple thermal fluid generated is $166.8 \text{ m}^3/\text{m}^3$, and the GWR of 300 °C multiple thermal fluid is increased to $290.1 \text{ m}^3/\text{m}^3$.

Theoretically, each generator unit could generate 166 tons 300 °C steam and $4.82 \times 10^4 \text{ m}^3$ flue gas per day, and the enthalpy generated per day is about $2.6 \times 10^8 \text{ kJ}$, equal to 196 tons of 300 °C water, or 96 tons of 300 °C pure steam. In fact, the field steam injection rate is usually 80–120 tons per day because of high reservoir pressure and reduction in thermal efficiency. Therefore, much more steam could be generated with two or three generators at the same time. Figure 2 shows the schematic diagram of the main engine room of three multiple thermal fluid generators.

Composition

The modular multiple thermal fluid generator is mainly composed of a raw material supply system, multiple thermal fluid generation system and waste liquid collection system.

Fig. 1 Diagram of modular multiple thermal fluid generator

Table 1 Composition and GWR of multiple thermal fluid generated

Air injection rate (m ³ /h)	Water injection rate (m ³ /h)	Temperature (°C)	Content of CO ₂ (wt%)	Content of N ₂ (wt%)	Content of steam/hot water (wt%)	GWR (m ³ /m ³)
2400	19.46	130	2.46	8.38	89.16	89.2
2400	16.25	150	2.98	10.16	86.85	111.1
2400	13.00	180	3.73	12.70	83.57	144.3
2400	11.44	200	4.20	14.32	81.48	166.8
2400	9.18	240	5.11	17.41	77.48	213.3
2400	6.92	300	6.43	21.90	71.68	290.1
2400	6.02	330	7.13	24.30	68.57	336.4

Fig. 2 Schematic diagram of main engine room of three multiple thermal fluid generators

Raw material supply system

The raw material supply system mainly consists of air compressor, water supply equipment and fuel supply equipment, as shown in Fig. 3.

The air compressor is to transfer high-pressure air from the nozzle to the burning chamber to provide oxidant for fuel

combustion and pressure for injection of multiple thermal fluid. The air compressor system consists of low-pressure screw air compressor, high-pressure air compressor, low-pressure gas buffer tank and electrical control cabinet. After three-stage compression, high-pressure air is output to the generator. At present, the maximum output pressure of the air compressor is 25 MPa and the maximum output air volume is 1200 m³/h.

The water supply equipment pressurizes desalinated qualified water to provide high-pressure water for the burning chamber. The water supply equipment consists of a water tank, globe valve, filter, front water pump, flowmeter, high-pressure water pump, safety valve, pressure sensor, etc., as shown in Fig. 3. The water used is pumped from a water source well and treated by the reverse osmosis membrane treatment system. (The diameter of the pore is about 1 nm.) More than 97% of the dissolving salt, microorganisms and organics could be removed at lower pressure.

The fuel supply equipment provides fuel for the burning chamber by filtering, pressurizing and atomizing the diesel fuel. The fuel supply equipment is composed of an oil tank, globe valve, filter, flowmeter, high-pressure oil pump, safety valve, high-pressure nozzle, etc., as shown in Fig. 3. According to the characteristics of material distribution for offshore platform, the oil tank volume must meet the requirement of

Fig. 3 Schematic diagram of multiple thermal fluid generating system

the daily heat consumption of multiple thermal fluid injection. The oil tank volume is generally not less than 14 m³, which can meet the maximum fuel consumption of multiple thermal fluid generator.

Multiple thermal fluid generation system

The multiple thermal fluid generation system consists of multiple thermal fluid generator and supervisory equipment. The multiple thermal fluid generator is the core part of the whole system, and its composition and operating principle have been described in detail in the operating principle part. The supervisory equipment is the key part to control the whole system. It has the function of monitoring the operation parameters and adjusting the material proportion automatically or manually. The supervisory equipment is composed of a computer, PLC control cabinet, frequency converter cabinet and low-voltage electrical control cabinet.

Waste liquid collection system

The waste liquid collection system is used to collect and centralize treatment of the gas–liquid mixture discharged by the multiple thermal fluid generator during startup and shutdown to reduce environmental pollution. This system is mainly composed of T-junction, emptying valve and waste liquid collection tank.

When the multiple thermal fluid generator is started, the unstable multiple thermal fluid generated in the early stage should be drained into the waste liquid collection tank for debugging. After the heat injection parameters meet the design requirements and remain stable, the waste liquid collection system is shut down and the multiple thermal fluid is injected into the well.

Characteristics

The characteristics of the multiple thermal fluid generator include: (1) modular and lightweight. All the equipment pieces are placed in the containers, and the net weight of each piece is less than 20 T. (2) Automatic control, fully closed combustion, and thermal efficiency up to 99%. (3) Temperature controlled and wide range of application. The injection temperature can be controlled according to the requirements of the process scheme by controlling the water supply. (4) Zero carbon emission. The generated multiple thermal fluid is all injected into the oil layer, which is conducive to environmental protection.

EOR mechanisms

Viscosity reduction in heat and gas dissolution

It is well known that viscosity of heavy oil decreases with the increase in temperature, which is the basic mechanism of thermal production. Figure 4 shows the oil viscosity–temperature curves of typical heavy oilfields in Bohai Bay. With the increase in temperature, the viscosity of heavy oil decreases substantially, and when the temperature rises to 120 °C, the viscosity of heavy oil decreases below 100 mPa s, and it has fluidity in formation conditions. It is a certainty that viscosity reduction by heating plays the most important role in multiple thermal fluid stimulation.

Besides temperature, gas dissolution has an important effect on viscosity of heavy oil (Svrcek and Mehrotra 1982; Redford 1982; Sinanan and Budri 2012; Wang et al. 2015). Figure 5 shows the effect of dissolution of nitrogen and carbon dioxide on NB35-2 heavy oil viscosity. It can be seen that gas dissolution can result in viscosity reduction and carbon dioxide has a greater effect on viscosity reduction than nitrogen.

Increase in heated chamber and pressurized chamber

Compared to steam injection, multiple thermal fluid injection can increase heating chamber and pressurized chamber because of gas injection, which could decrease steam pressure at equal injection pressure and keep steam in gaseous state under reservoir condition.

Based on the simplified NB35-2 reservoir model with 50 × 40 × 25 grids and a 340-m-long horizontal well, numerical simulation of CSS and CMTFS is conducted by the THERMAL simulator of ECLIPSE. The depth of middle formation is 1000 m, formation thickness is 25 m,

Fig. 4 Oil viscosity–temperature curves of typical heavy oilfields in Bohai Bay

permeability is 2000 mD, viscosity of heavy oil at 50 °C is 1600 mPa s, initial reservoir temperature is 56 °C, and initial reservoir pressure is 10 MPa. The horizontal well is located at 17 m from the top of the reservoir. As for injection and production parameters for both CSS and CMTFS, injection volume of 200 °C steam is 3000 m³ and injection volume of 300 °C steam is 1860 m³. GWR is 200 in CMTFS. The temperature cross sections of the horizontal well after steam injection in CSS and after multiple thermal fluid injection in CMTFS are shown in Fig. 6. It indicates that the volume of

the heating reservoir chamber in CMTFS is up to two times than CSS for such high-pressure heavy reservoir.

The pressure cross sections after steam injection in CSS and multiple thermal fluid injection in CMTFS based on reservoir numerical simulation are shown in Fig. 7. It shows that larger pressurized volume is obtained by CMTFS than CSS because of the injected gas, and more pressure increase is observed as well (more than 2 MPa larger than CSS in the central pressurized zone around the horizontal well).

Fig.5 Effect of gas dissolution on viscosity of NB35-2 heavy oil

Fig.6 Reservoir temperature profiles of steam injection and multiple thermal fluid injection at the end of soak

Fig.7 Pressure cross sections after steam injection and multiple thermal fluid injection

Gas-assisted gravity drainage

The gravity difference between heavy oil and injected gas is beneficial to oil drainage under gravity. Larger gravity difference between N_2 and oil is obtained compared to CO_2 because of the compressibility difference. And the gravity drainage effect increases with the decrease in reservoir pressure.

The gravity difference between heavy oil and gas in the CMTFS process is calculated with an oil density of 950 kg/m^3 and formation thickness of 20 m without considering gas solution in oil and water. Negative values of gravity difference are obtained under higher reservoir pressure than steam saturation pressure, so gravity difference between hot water and oil can push oil upward. It is just the limitation for recovering deep heavy oil reservoir by CSS process, and keeping steam in “gas phase” at the bottomhole pressure is significantly important for CSS process. At the same time, larger gravity difference between N_2 and oil is obtained compared to CO_2 , the maximum gravity difference is about 0.2 MPa, while 200–300 °C N_2 is injected into heavy oil reservoir with pressure 5 MPa. Therefore, the gravity difference between heavy oil and gas will improve gravity drainage, especially for the depleted heavy oil reservoir (Zhong et al. 2013; Sun et al. 2013).

Reduction in heat loss

The thermal conductivity of nitrogen and carbon dioxide is far less than that of steam. After multiple thermal fluid is injected into formation, the gas will migrate up to the top of formation and form an insulation layer which restrains heat loss to the top layer, as shown in Fig. 8.

Field application

NB35-2 Oilfield

NB35-2 Oilfield is located in the west of Bohai Bay and consists of two blocks: south block and north block. South block, developed by water flooding in 2005, had produced $29.08 \times 10^4 \text{ m}^3$ heavy oil, about 1.2% OOIP, by June, 2009 (Wu et al. 2016). In order to explore thermal recovery mode for offshore heavy oil and improve oil production rate, a field test of CMTFS was carried out in the south block in 2009.

The modular multiple thermal fluid generator has been successfully applied to more than 15 offshore horizontal wells in Bohai Oilfield since 2009, of which two wells are non-thermally completed and the others are thermally completed. Both single burner and double burner are used to meet the requirement of multiple thermal fluid injection rate. Considering the limited platform space and convenient transportation and lifting, most of the equipment pieces are installed in skid containers. After stress distribution testing, the equipment pieces are arranged in reasonable position on the upper deck of the platform according to their weights, as shown in Fig. 9. The result shows that the modular multiple thermal fluid generator is soundly operated under 300 °C and 20 MPa, and no leakage occurred.

Up to December 2018, 27 cycles of multiple thermal fluid stimulation had been conducted. The stimulation effect of multiple thermal fluid was obvious, and the cumulative oil production was $145 \times 10^4 \text{ m}^3$. There were four wells (namely A, B, C and D) which had performed three cycles of multiple thermal fluid stimulation. The parameters of these four wells are given in Table 2. All wells had a vertical depth of 930–950 m, but the hole depth was more than 1500 m, or even close to 2000 m, which increased heat loss during steam injection. Multiple thermal fluid injection can reduce heat loss due to the low

Fig. 8 Heat insulation effect of gas in reservoir

Fig. 9 The equipment pieces' layout on the upper deck of the platform

Table 2 The wells' parameters in NB35-2 Oilfield

Well name	A	B	C	D
Along hole depth (m)	1752	1549	1578	1944
True vertical depth (m)	946	951	935	945
Horizontal length (m)	225	207	184	279
Casing diameter (inch)	9 ^{5/8}	9 ^{5/8}	9 ^{5/8}	9 ^{5/8}
Open hole diameter (inch)	8 ^{1/2}	8 ^{1/2}	8 ^{1/2}	8 ^{1/2}
Well completion	Screen pipe + gravel packing			

thermal conductivity of gas. Screen pipe + gravel packing completion method was used in all wells. Considering the corrosion problem and productivity of the wells, the newly designed screen pipe had the characteristics of larger-flow area, better strength and reliable corrosion resistance and strength (Deng et al. 2017).

The injection and production data are summarized in Table 3, and the production performance of each well is shown in Fig. 10. During multiple thermal fluid stimulation, the oil production rate was obviously improved, especially in the first and second cycles. In the early stage of production, the oil production rate was 40–60 m³/day, about 2–3 times as much as cold production. The production time of multiple thermal fluid stimulation, about 600–800 days in the first cycle and 800–1000 days in the second cycle, was much longer than that of common steam stimulation (about 300 days for horizontal well). This result has been verified by experiments in this paper. The water recovery rate was larger than 100%, which means that some formation water has been produced. The reason may be that the reservoir irreducible water saturation decreased due to reservoir temperature increasing and gas injection. Large water recovery rate meant less water was stored in the reservoir, which helped to reduce heat ineffective utilization in the next cycle.

The gas–water ratio of multiple thermal fluid stimulation wells was more than 300 m³/day. Large gas–water ratio helped to improve reservoir pressure and enhance oil recovery, but the gas recovery rate was low, which meant a large amount of gas exists in the reservoir. As mentioned before, N₂ has a low solubility in heavy oil, so most of the gas in the reservoir existed in free state. This can lead to injection difficulties and gas channeling after several cycles. In the design of multiple thermal fluid stimulation, the gas–water ratio and gas injection mode should be particularly optimized and the risk of gas channeling between wells should be evaluated.

Xinjiang Oilfield

In 2016, No.1 oil production plant of Xinjiang Oilfield conducted pilot tests of CMTFS in four different heavy oil blocks. The test results are shown in Table 4, with a total of 15 wells implemented and 13 effective wells. By the end of 2016, the CMTFS process has increased oil by 3784.9t, averaging 291.1t per well and 1.83t per day per well.

Taking Well H45299, a typical test well, as an example, the injection–production parameters of this well are shown in Table 5. After five cycles of steam stimulation, the cycle oil production of this well was only 14.9t and the oil–steam ratio was 0.01. The sixth cycle started CMTFS, the accumulated steam injection was 204.4t, and the gas injection was about 120,000 m³. The accumulated cycle oil production was 493.4t, and the oil–gas ratio increased to 2.44.

The successful application of CMTFS process in different blocks of Xinjiang Oilfield indicates that the CMTFS process is suitable for enhanced oil recovery in heavy oil reservoirs at different stages of production. The modular multiple thermal fluid generator is not only suitable for offshore oil fields, but also has great potential in onshore oil fields.

Conclusions

1. The modular multiple thermal fluid generator is potential to enhance heavy oil production for its convenient installation on production platform and improvement on oil production in mechanisms of viscosity reduction in heat and gas dissolution, increase in heated chamber and pressurized chamber, gas-assisted gravity drainage and reduction in heat loss.
2. The modular multiple thermal fluid generator is mainly composed of raw material supply system, multiple thermal fluid generation system and waste liquid collection system. The characteristics of the multiple thermal fluid generator include: modular and lightweight; automatic control, fully closed combustion, and thermal efficiency up to 99%; temperature controlled and wide range of application and zero carbon emission.

Table 3 The injection and production data of the four wells with three cycles of multiple thermal fluid stimulation

Cycle	Well name	A	B	C	D
First cycle	Injection temperature (°C)	264–266	263–267	265–267	261–269
	Injection pressure (MPa)	15–18.4	11.2–17.6	13–18.5	9.4–14.8
	Water injection rate (m ³ /h)	6.5–7.2	6.5–7.6	9–10.2	5–10.1
	Water injection volume (m ³)	3450	3000	2950	4000
	N ₂ injection volume (×10 ⁴ m ³)	111	79	93.1	139
	CO ₂ injection volume (×10 ⁴ m ³)	17	10	14.7	21
	Gas–water ratio (m ³ /t)	371	297	365	400
	Soak time (days)	3	3	3	3
	Production time (days)	650	663	830	639
	Oil production volume (m ³)	32,545	19,772	35,531	20,348
	Water production volume (m ³)	6251	3778	4638	5595
	Gas production volume (×10 ⁴ m ³)	44.19	54.43	66.83	60.6
	Water recovery rate (%)	181.19	125.93	157.22	139.88
	Gas recovery rate (%)	34.52	61.16	61.99	37.88
Second cycle	Injection temperature (°C)	263–267	263–267	260–270	262–269
	Injection pressure (MPa)	11–12.08	13.91–14.26	12.9–13.1	11–13.2
	Water injection rate (m ³ /h)	6.2–6.5	6.2–6.4	5.8–6.4	5.7–6.8
	Water injection volume (m ³)	4000	3900	2522	2937
	N ₂ injection volume (×10 ⁴ m ³)	120	101	91	93
	CO ₂ injection volume (×10 ⁴ m ³)	19	16	13	14
	Gas–water ratio (m ³ /t)	348	300	412	364
	Soak time (days)	3	3	3	3
	Production time (days)	995	803	1060	915
	Oil production volume (m ³)	20,393	21,161	29,446	16,892
	Water production volume (m ³)	8647	7528	5829	4004
	Gas production volume (×10 ⁴ m ³)	69.94	54.43	20.3	38.46
	Water recovery rate (%)	216.18	193.03	231.13	136.33
	Gas recovery rate (%)	50.32	46.52	19.52	35.94
Third cycle	Injection temperature (°C)	240–257	240–271	185–263	183–265
	Injection pressure (MPa)	9.3–13.05	9–12.48	7.98–12.8	9.94–13.3
	Water injection rate (m ³ /h)	2.8–3.8	2.8–3.8	3.4–3.8	3.4–3.8
	Water injection volume (m ³)	2112	2101	3002	3000
	N ₂ injection volume (×10 ⁴ m ³)	58	58	57	62
	CO ₂ injection volume (×10 ⁴ m ³)	9	9	10	10
	Gas–water ratio (m ³ /t)	317	319	223	240
	Soak time (days)	2	2	3	3
	Production time (days)	608	613	383	376
	Oil production volume (m ³)	10,243	13,394	5162	2325
	Water production volume (m ³)	6625	6138	2567	3275
	Gas production volume (×10 ⁴ m ³)	11.17	7.18	2.19	1.44
	Water recovery rate (%)	313.68	292.15	85.51	109.17
	Gas recovery rate (%)	16.67	10.72	3.27	2.00

Well A and B are still in production. Well C and D shut down because of pump problems in 2018.8 and 2018.2, respectively

3. Field tests result show that significant oil production increase is obtained by CMTFS process in both NB35-2

Oilfield and Xinjiang Oilfield. The oil production rate of CMTFS was 2–3 times than cold production. The modular multiple thermal fluid generator is not only suitable for offshore oil fields, but also has great potential in onshore oil fields.

Fig. 10 The production preference of wells with three cycles of multiple thermal fluid stimulation

Table 4 Test results of CMTFS in Xinjiang Oilfield

Development stage	Block	Reservoir type	Imple- mentation wells	Effective wells	Oil increment (t)	Average oil increase per well (t)	Average production days
Initial	KQ401	Fault-occluded structural	2	2	383.6	191.8	146
Middle	Hongyi4	Bottom water lithologic struc- tural	3	3	779.6	259.8	117.6
	Hong006	Lithologic structural	2	0	0	0	62.5
Last	Hong001	Lithologic structural	8	8	2621.7	327.7	100.1
Summation			15	13	3784.9	291.1	106.5

Table 5 Injection–production parameters of Well H45299

Cycle	Date of injection	Steam injection (t)	Cumulative fluid production (t)	Cumulative oil production (t)	Water cut (%)	Average daily fluid production (t/d)	Average daily oil production (t/d)	Oil–steam ratio (t/t)	Injection–production ratio (t/t)
1	2013.12.23–2014.01.06	1677	1347.4	782.8	41.9	4.73	2.75	0.47	1.24
2	2014.10.28–2014.11.13	1529	744.9	159.1	78.64	4.91	1.05	0.10	2.05
3	2015.04.20–2015.04.30	997	839.4	119.7	85.74	5.24	0.75	0.12	1.19
4	2015.10.13–2015.10.26	1436	1092.1	100.8	90.77	5.65	0.52	0.07	1.31
5	2016.05.11–2016.05.20	1143	507.4	14.9	97.06	9.09	0.27	0.01	2.25
6	2016.08.08–2016.08.21	Steam 204.4t Gas 120,000 m ³	1094	493.4	54.9	5.0	2.3	2.44	0.34

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The authors assure that this paper has not been previously published, and the manuscript reflects my own research and analysis in a truthful and complete manner.

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