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The Engineering Models of Multi-Component Thermal Fluid Technology to Enhance Oil Recovery on Shallow Water Heavy Oil

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Abstract

This paper discusses engineering models of the multi-component thermal fluid technology (MCTF) on shallow water heavy oil to enhance oil recovery. Offshore heavy oil reserves are abundant, which accounts for 70%, but due to the high viscosity of heavy oil and poor mobility, it is difficult to extract except thermal recovery. The practices of onshore oilfields at home and abroad prove thermal recovery can be the best way to extract. However, for shallow water (water depth is less than 500 m) oil field, the presence of sea water makes huge difference between onshore and offshore oilfields. This also brings difficulties and challenges, such as integrated equipment, water supply, electricity power supply, and production fluid processing. The authors used analysis of the resources situation of offshore platform and integrated optimization of multi heat transfer equipment. Finally three offshore oilfield thermal recovery engineering models have been developed.

The first is the offshore production platform alone placed two sets of type II MCTF device, which can achieve simultaneous thermal recovery operations in two wells. The second is a multifunctional platform (it is also called LIFTBOAT) supports production platform, placed three sets of MCTF device, can complete operations three wells at a time. It is also used for 1-2 wells thermal operations. Meanwhile, the other is for workover operations. The third is drilling platform alone placed a type II MCTF equipment, and test operation can be carried out in thermal recovery wells. The field practices of more than 20 wells in shallow heavy oil prove MCTF engineering models meet present demand of sea thermal recovery; and it has great application potential.

Key words: Shallow water; Multi-component thermal fluid; Heavy oil; Offshore oilfield; Thermal recovery; Engineering model

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INTRODUCTION

Offshore heavy oil reserves are abundant on Bohai Bay of China. By the end of 2010, heavy oil reserves of Bohai Bay takes up 85% of proven offshore oil reserves, and water depth is less than 500 m. The conventional water-injection cold development has difficulty in greatly enhancing oil recovery. Take Bohai NB35-2 Oilfield South as an example which has surface degassed crude viscosity 1,654~3,893 mPa·s under temperature 50℃, but current recovery percentage 1.2%, oil production rate 0.3% and composite water cut 74%. For the heavy oil with in-situ viscosity higher than 400mPa·s must be developed by thermal methods[1].

In order to enhance offshore oil production in limited lifetime of the production platform and recover much more heavy oil effectively in the oil-short era, new production technology must be considered. Conventional cyclic steam stimulation (CSS) is an effective production practice for onshore heavy oil fields, but CSS cannot meet the requirement of the efficient development of offshore heavy oil. It is difficult to introduce conventional steam injection devices such as cyclic steam stimulation to offshore heavy oil production because the available area on platforms is limited to accommodate the steam generator and auxiliary equipments. Therefore, new kinds of steam generator or some innovative thermal methods should be developed to enhance offshore heavy oil production. Multi-component thermal fluid (MCTF) technology is a new type of thermal recovery technology[2], developed on the basis of traditional thermal recovery technology.

1. THE DEVICES OF MCTF

By using the space rocket engine's combustion jet mechanism and taking industrial diesel (oil or natural gas) as fuels, the multi-component thermal fluid recovery technology simultaneously injects high-pressure air and high-pressure water into the high-pressure combustion chamber to produce high-temperature and high-pressure mixed gas of steam, CO_2 and N_2. Figure 1 shows the generation mechanism[3].

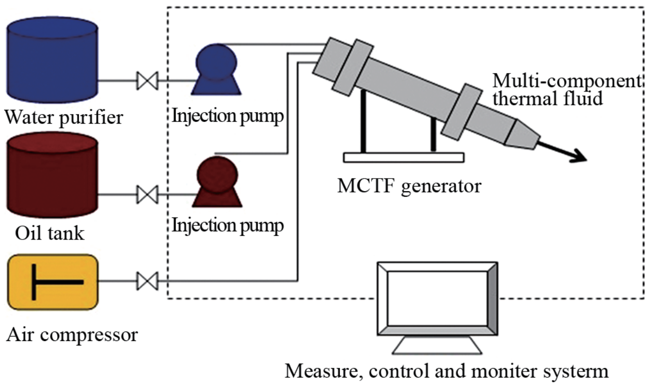

Figure 1
Multi-Component Thermal Fluid Generation Flow Chart

Fuel (diesel oil or nature gas) and compressed air are injected into combustion chamber where fuel combusts and water is heated and vaporized, generating the multi-component thermal fluid including hot water/steam, N_2 and CO_2, which has the effect of gas displacement and thermal recovery.

There are many advantages for devices of MCTF, such as: the first one is its small equipment occupied area, whose space is saving. The second one is totally-enclosed compact combustion system which is safe and could be controlled automatically and artificially. The third one is adjustable injection temperature (120~350℃) and suitability in non-thermal completion wells and thermal completion wells. At last it is energy saving, environment friendly, and carbon emission reduction for flue gas sequestration, and high thermal efficiency because of co-injection of steam and flue gas.

Multi-component thermal fluid equipment has been integrated designed and applied for different stage of thermal process, technical parameters of which are shown in Table 1. The advantages of MCTF are shown in Table 2.

Table 1
Technical Parameters of MCTF Equipment

Type	Injection temperature/°C	Outlet pressure /Mpa	Maximum flow rate/m^3/h
I	120-350	20	1,000
II	120-350	20	2,400
III	120-350	20	3,600

Table 2
Advantages of MCTF Compared to Previous Technology

Item	Thermal efficiency	Waste gas treatment	Environmental pollution
MCTF	>95%	Injection in viscous	No
Previous Technology	85%-90%	Discharge	Yes

There is a high standard for the water used in the technology, which is shown in Table 3.

Table 3
Water Standard for MCTF Recovery

No.	Items	Unit	Quantity
1	Dissolved oxygen	mg/l	<0.05
2	Total solidity	mg/l	<0.1
3	Total iron	mg/l	<0.05
4	Silica	mg/l	<50
5	Suspended substance	mg/l	<2
6	Total alkalinity	mg/l	<2,000
7	Oil	mg/l	<2
8	Soluble solids	mg/l	<500
9	pH	mg/l	7.5-11

2. CHARACTERISTICS OF OFFSHORE PLATFORM AND THE CHALLENGES

There are many aspects should be considered when applying multi-component thermal fluid technology, including efficiency and integration capabilities of MCTF equipment, safety and convenient of the process, and lower heat loss. Three operation models have been developed.

2.1 Mode 1

Two MCTF equipments are applied on the offshore platform for simultaneous operation for two wells.

2.1.1 Basic Parameters of Offshore Platforms

A-1 platform, for example, is located in Bohai Bay, which is six-legs jacket production platform, including offshore jacket, topside module (four layers), drilling module (drilling rig module and supporting module) and living module (holding 80 people). Structure of platform is shown as Figure 2.

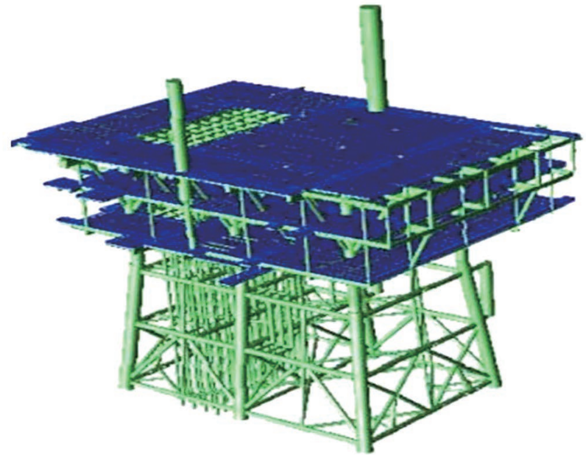

Figure 2
Structure of A-1 Platform

If the MCTF technology is applied on A-1 platform, some problems must be solved. The first one is that resources of A-1 can meet the requirements. The data is shown in Table 4.

Table 4
Resources of A-1 and Requirements

Item	Available resources	Requirements	Remark
Effective operation area	300 m^3	＜200 m^3	Satisfied
Hoisting capacity	Main hang (40 t) auxiliary hang (20 t)	Single piece＜20t	Satisfied
Water source	Geothermal water (with degassing system)	See Table 2	Cannot reach
Electric power	500 kW	1,490 kW	Reconstruction
Diesel	120 m^3 oil tank	6.5-10 m^3/d	Satisfied
Surface pipeline	None	Rigid pipe, insulation	Preset

2.1.2 Technological Processes

The technology cannot be applied directly because of integrated equipment, water & electricity power supply and production fluid processing, new designs are needed as follows:

(a) MCTF equipment should be put centrally for management and operation.

(b) Platform resources should be made fully used for material supply. The process should be low cost, simple and rightful.

(c) Production safety requirements should be fully considered when putting the ground thermal pipeline. Advisability layout and heat loss along the pipeline should also be considered.

This paper forms a relatively complete technological process with the principle of thermal recovery process layout, the demand of thermal recovery process, rightful configuration and optimization of Type Ⅱ equipment required for space, water, electricity, oil supply process, which is shown as Figure 3.

Figure 3
Thermal Recovery Process Based on the Platform

2.2 Mode 2

It is offshore thermal recovery operation mode based on multifunction supporting platform (LIFTBOAT), which means three wells can be operation at the same time or parallel working for thermal recovery operation, other EOR working, and conventional workover operation.

2.2.1 Basic Parameters of LIFTBOAT

Multi-function supporting platform can provide sea life support, engineering support, well drilling, and workover engineering support. It can also provide services of exploration well, development well or adjustment well.

Take D-1 for example, this multi-function supporting platform is triangle hull with three cylindrical legs. It is also with electronically controlled hydraulic motor to drive rack. Meanwhile it is with propeller and the control system, which can rise and fall like jack-up drilling vessel. It is used for supporting the production platform of Bohai Bay for these kinds of work, such as EOR, well completion, workover, power support and so on.

Table 5
The Available Resources and the Demand of Thermal Recovery of Platform

Item		Available resources of D-1	Requirement of large scale thermal
Effective work area, m^3		900	＜400
Hoisting capacity (main hang, auxiliary hang), t		180, 30	Single piece＜20
Material supply	Water, t	sea	＜20
	Power, kW	2,000	3,000
	Diesel, m^3	390	12-16 m^3/d
Surface pipeline		None	Rigid pipe, insulation

LIFTBOAT can meet the requirements of large scale thermal recovery for just a little improvement.

The characteristics of LIFTBOAT are as follows:

(a) Life support module for the lives of at least 90 people.

(b) Site support module for providing a larger work area, strong carrying capacity, which can solve the problems of small area and material storage of production platform.

(c) Operations support module, having the strong ability of crane, large supply of oil, gas, water capacity, satisfying the demand for large-scale operations.

The available resources and the demand of thermal recovery of A-1 and D-1 platform are shown in Table 5.

2.2.2 Technological Processes

2.2.2.1 Ground Equipments Layout

D-1 and A-1 platform are independent platforms, causing the problem that the ground thermal pipeline crosses the two platforms. These platforms have some relative displacement because of different shake swing. Especially, the biggest shake of D-1 platform is about 0.4°, causing the shake of shelter deck up to 260 mm. Therefore, there are many potential safety hazards.

This process concentrates the ground thermal pipeline in A-1 platform by putting generator cabin and output section of main engine room together. Meanwhile, it puts the system pipeline across the bridge to connect the generator cabin and eliminates potential safety hazards by using high pressure hose with rigid pipe connection, which is shown as Figure 4.

Figure 4
Layout of MCTF Equipment Based on LIFTBOAT

2.2.2.2 Thermal Recovery Process

(a) Use 37° spherical type pipe joints for high pressure oil pipe, high pressure water pipe and high pressure air pipe.

(b) The Nominal pressure can be less than 35 MPa.

(c) The pressure test of pipeline is 40 MPa.

(d) Fix the pipeline with pipe clamp and buffer with 2 meters high pressure hose in the stockhouse between the two platforms.

(e) High pressure hose coated with metallic braid on.

(f) Placed three sets of MCTF device, can complete operations three wells at a time. It is also used for 1-2 wells thermal operations. Meanwhile, the other is for workover operations.

2.3 Mode 3

It is offshore thermal recovery operation mode based on drilling platform for thermal recovery test of single well.

2.3.1 Basic Parameters of Drilling Ship

The MCTF technology for testing in offshore heavy oilfield needs to consider the injection equipment and supporting platform. Drilling boats are usually used to carry out the testing, however, the area of the deck and the water and electricity provided on them are very limited. MCTF technology needs a large amount of electricity and water. Only when all these problems are solved, the testing can be processed smoothly.

The advantages of equipments of MCTF are light in weight, small floor space, and easy to carry. As is shown in Figure 5, the layout of them can be optimized to solve the space problem. A type II MCTF equipment is placed there. Auxiliary power devices can be modified at the same time to meet the electricity requirements. The water can be supplied by shipping or seawater purifying.

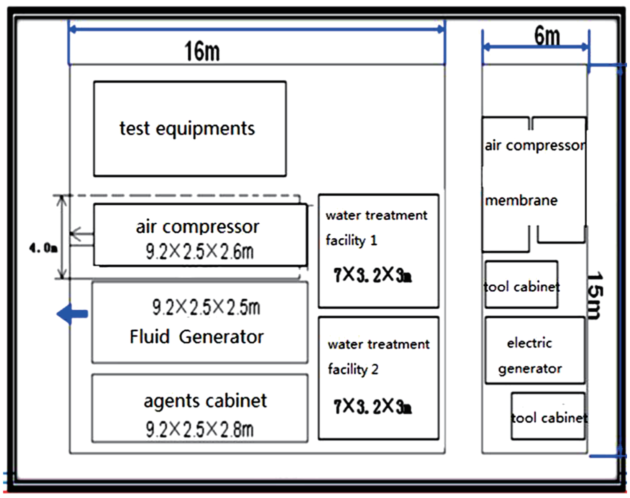

Figure 5
MCTF Equipments Layout

2.3.2 Water Supply

The analysis of the water provided by the platform is shown in Table 6.

Table 6
Offshore Water Quality

No.	Items	Unit	Quantity	Note
1	Dissolved oxygen	mg/l	-----	Untested
2	Total solidity	mg/l	2.00	ICP-MS mass spectrometer
3	Total iron	mg/l	2.22	
4	Silica	mg/l	4.09	
5	Suspended substance	mg/l	0.50	
6	Total alkalinity	mg/l	<2,000	
7	Oil	mg/l	0.00	
8	Soluble solids	mg/l	<500	
9	pH	mg/l	6.94	

It can be seen that all the items meet the water standard except total solidity. Membrane separation technology for water purification is used to provide water for MCTF system, and the process is as follows: water sump→ mud pit→ centrifugal pump→ RO water purification→ thermal fluid generator. Water is supplemented by tugboat.

2.3.3 Application & Effect

The MCTF recovery are applied in old wells, newly-drilled adjusting wells, production and exploratory wells in A-1 oilfield with huff & puff operations, resulting in great success and greatly meeting the offshore thermal recovery requiring. Mode 1 and Mode 2 are both used for more than 20 wells.

It can be seen from Figure 6 that the daily oil production of this oilfield is greatly increased since the multi-component thermal fluid application. The daily oil production is about 218 t/d for cold production, and after the thermal recovery applied from early 2008 to 2012, the maximum daily oil production reaches 620 t/d, which is dramatically promoted by 184%[4].

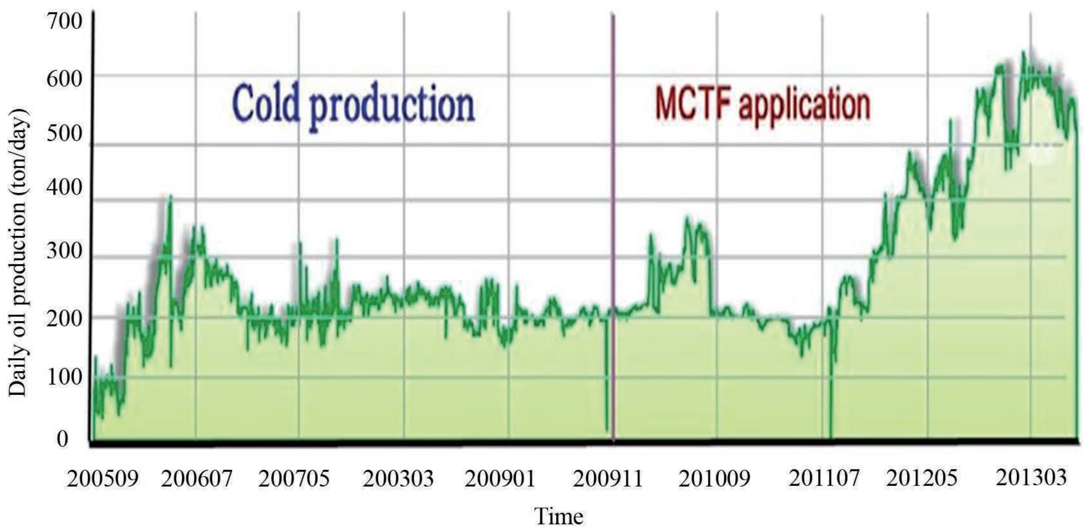

Figure 6
A-1 Oilfield Multi-Component Thermal Fluid Production Status

Mode 3 is used in testing by MCTF technology, which is successfully carried out in the two layers of a heavy oil well in Bohai Bay. The daily oil production of Guantaozu before the operation was 11.52 m^3/d, which became 28.3 m^3/d after the operation. The daily oil production of Minghuazhenzu before the operation was 12.48 m^3/d, which became 26.4 m^3/d after the operation[5].

CONCLUSION

It can be seen by study of MCTF engineering models that it can solves the problem including integrated equipment, water supply, and electricity power supply. The field practices in shallow heavy oil prove MCTF engineering models meet present demand of sea thermal recovery; and three offshore oilfield thermal recovery engineering models have been developed.

The applications of 3 modes of MCTF Technology show that it can meet different kinds of demand for thermal recovery, and it has great application potential.

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