Experimental Study on the Mechanism of Thermal Composite Chemical Efficiency Enhancement in Offshore Heavy Oil Reservoir

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Abstract. X Oilfield is a representative of Bohai Extra Heavy Oil Reservoir, with high crude oil viscosity, large oil layer thickness, and large reserve scale. However, based on the current experience of thermal recovery experimental areas, the simple use of steam stimulation development method has low production capacity, short validity period, and low recovery rate, making it difficult to meet the threshold of offshore economic development and achieve large-scale and effective development. It is urgent to explore efficient thermal recovery technologies suitable for offshore heavy oil. This study designed three sets of thermal recovery physical experiments for comparison. The total recovery rate of composite thermochemical huff and puff mining is 21.5%, which is 7.50% higher than that of steam huff and puff mining. It can be seen that composite chemical efficiency enhancement based on steam stimulation can further expand the heating radius, extend the thermal recovery validity period, and improve development effectiveness. Through this technological research, a set of offshore heavy oil thermal composite chemical efficiency enhancement technology has been formed, thereby enriching and developing a new efficient development model for Bohai heavy oil fields, and achieving economic and efficient development of offshore heavy oil reservoirs.

Keywords: Bohai heavy oil field, thermal combined chemical huff and puff, performance evaluation.

1 Introduction

Heavy oil refers to crude oil with high viscosity. Heavy oil has the characteristics of high viscosity and high freezing point. As an essential part of unconventional energy, heavy oil production concerns people[1-2].

Thermal recovery is the most widely used method in heavy oil recovery. Reducing crude oil viscosity is achieved by increasing formation temperature [3]. When the temperature is relatively low, the crude oil viscosity changes obviously with temperature, and a slight increase in temperature can significantly reduce the crude oil viscosity. The standard thermal recovery methods of steam injection heavy oil include steam huff and puff, steam drive, and steam-assisted gravity drainage (SAGD)[4].

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Thermal compound chemical synergistic technology refers to applying various chemical additives and gases to improve the effect of thermal recovery and development. Such as adding multiple chemical agents (surfactants, solvents, etc.) and gases (carbon dioxide, nitrogen, flue gas) while injecting steam and using the synergistic effect of thermal and chemical agents/gases to efficiently recover heavy oil and realize the thermal, chemical compound synergistic effect[5]. In other words, based on the heat carried by steam, make full use of the interface characteristics of the chemical system and the changes in the formation fluid's physical and chemical properties to improve oil recovery significantly. Its core is to improve oil recovery considerably by using heat and chemistry synergistic effects[6-7].

Thermal compound chemical huff and puff is a method to improve the recovery of heavy oil reservoirs by giving full play to the synergistic effect of steam, gas, and chemical agents with the mixed injection or slug injection of gas and chemical agents in the process of steam huff and puff. As an effective stimulation method in the later stage of huff and puff, it has been adopted by some oilfields, but due to its high cost, it is still in the experimental stage, and relevant research is rarely involved. There is little research on evaluating thermal compound chemical huff and puff performance, and the action mechanism of heat/chemical agent/reservoir fluid/core is not precise [8-10]. This study verifies the improvement of oil recovery of extra-heavy oil by thermal compound chemical technology through thermal compound chemical experiments. At the same time, the wetting, adsorption, foaming, oil displacement, and other thermal composite chemical agent experiments were carried out to study the mechanism of oil displacement efficiency of the thermal mixed chemical system. It guides the effective development of extra-heavy oil fields.

2 Study on two-dimensional large-scale physical simulation experiment of thermal compound chemical synergistic effect

Simulate the thermal recovery characteristics of the reservoir, such as the variation law of temperature field and pressure field, the law of water cut rise and recovery degree in the development process of three different development modes of steam huff and puff, thermochemical huff and puff and compound thermochemical huff and puff of extra-heavy oil (36000-55000mPa·s) in X oilfield, and quantitatively evaluate the ability of thermal compound chemical efficiency technology to improve recovery degree.

2.1 Experimental sample

Experimental sand: 40-60 mesh glass beads (simulating formation permeability of 3000-4000mD), and the porosity and permeability data are adjusted according to the situation.

Experimental gas: N_2 sample is compressed gas in a steel cylinder, and the purity of N_2 is 99.5%.

Experimental chemical agent: high temperature resistant foaming agent. High-temperature oil displacement agent OD-2 (a sulfonate surfactant with a temperature resistance of 320 °C, is formed with a certain proportion of nanoparticles and quaternary ammonium salt surfactants as auxiliary agents. Its formula is surfactant YF-H, nano solid particle N, and surfactant TC, with a mass ratio of 87:3:10).

2.2 Experimental scheme and parameter design

The two-dimensional large-scale physical simulation experiment of thermal recovery simulates the development process of 8 rounds in three groups (steam huff and puff, thermochemical huff and puff, and compound thermochemical huff and puff). The specific experimental scheme is as follows (Table 1).

Table 1. Experimental scheme design

Group I, Steam huff and puff		Group II, thermochemical huff and puff scheme I (single thermal agent combined huff and puff)		Group III, thermochemical huff and puff scheme II (thermal multi-agent compound huff and puff)	
Round	Injection composition	Round	Injection composition	Round	Injection composition
Steam huff and puff(1)	Steam 6000T	Steam +Oil soluble viscosity reducer	Steam 6000T+ Pre Oil-soluble viscosity reducer60T	Steam +Oil soluble viscosity reducer+Oil displacement agent	Steam 6000T+Oil soluble viscosity reducer 60T+Whole process injection0.5% oil displacement agent
Steam huff and puff(2)	Steam 6000T	Steam +Oil soluble viscosity reducer	Steam 6000T+ Pre Oil-soluble viscosity reducer60T	Steam +Oil soluble viscosity reducer+Oil displacement agent	Steam 6000T+Oil soluble viscosity reducer 60T+ Whole process injection0.5% oil displacement agent
Steam huff and puff(3)	Steam 6000T	Steam +Oil soluble viscosity reducer	Steam 6000T+ Pre oil-soluble viscosity reducer60T	Steam +Oil soluble viscosity reducer+Oil displacement agent	Steam6000T+Oil soluble viscosity reducer 60T+ Whole process injection 0.5% oil displacement agent
Steam huff and puff(4)	Steam 6000T	Steam +Oil displacement agent	Steam + Accompanying note 0.5% oil displacement agent	Steam + Foam +Oil displacement agent	Steam+ Slug injection 1% foam +Whole process injection 0.5% oil displacement agent
Steam huff and puff(5)	Steam 6000T	Steam +Oil displacement agent	Steam + Accompanying note 0.5% oil displacement agent	Steam + Foam +Oil displacement agent	Steam+ Slug injection 1% foam +Whole process injection 0.5% Oil displacement agent
Steam huff and puff(6)	Steam 6000T	Steam +Oil displacement agent	Steam + Accompanying note 0.5% oil displacement agent	Steam + Foam +Oil displacement agent	Steam+ Slug injection 1% foam +Whole process injection0.5% oil displacement agent
Steam huff and puff(7)	Steam 6000T	Steam + Foam	Steam + Slug injection 1% foam	Steam + Foam +Oil displacement agent	Steam+ Slug injection 1% foam +Whole process injection0.5%Oil displacement agent
Steam huff and puff(8)	Steam 6000T	Steam + Foam	Steam + Slug injection 1% foam	Steam+ Foam +Oil displacement agent	Steam+ Slug injection 1% foam +Whole process injection 0.5% oil displacement agent

2.3 Experimental device

The two-dimensional physical simulation experimental device of thermal recovery comprises an injection system, model system, data acquisition, processing system, and recovery processing system(Fig. 1).

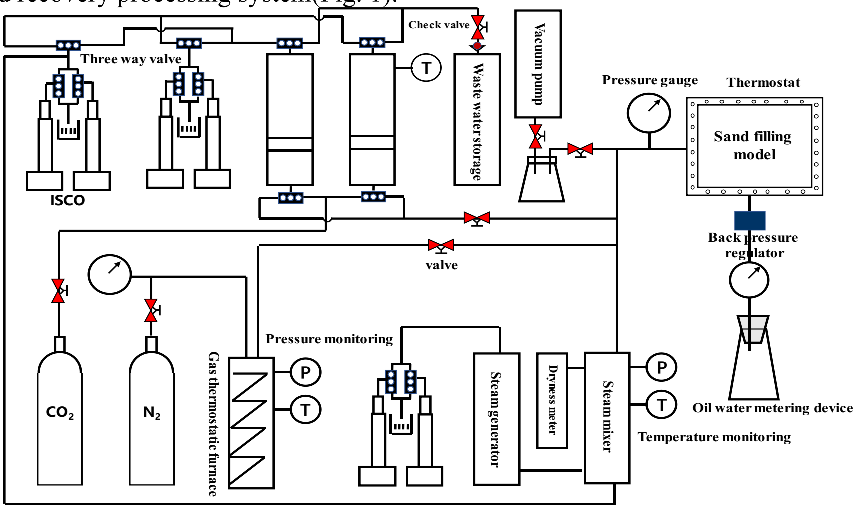


Fig. 1. Flow chart of two-dimensional large-scale physical simulation experiment of thermal compound chemical synergism

2.4 Experimental process

1) Experimental preparation. Prepare quartz sand and oil samples required for the experiment to ensure that the temperature and differential pressure sensors are suitable.

2) Model preparation. Mixing oil sand in advance and then filling shall be adopted.

3) Model pressure test. Inject simulated formation water into the model, pressurize the internal pressure of the model to 9.5MPa, and close the injection end and the nitrogen bottle group switch simultaneously. Observe the pressure changes inside and outside the model. Within 30min, the pressure drop of the model high-pressure chamber shall not exceed 0.1MPa, and the pressure difference inside and outside the model shall not exceed 0.01MPa. The pressure test is qualified.

4) Establish the initial temperature field of the model

The model is kept at a constant temperature of 47 °C. The temperature difference of each point in the model is no more than 0.5 °C.

5) Huff and puff experiment

The computer starts the measurement and control system to monitor the temperature and pressure of the model body, steam generator outlet, and incubator. According to the huff and puff scheme, the production system collects the produced fluid in different periods and measures the total amount of oil and water.

2.5 Results and analysis

After multiple rounds of steam huff and puff, the temperature field develops and expands, and the steam-swept area expands. Still, the temperature field grows linearly along the horizontal well section, and the steam-swept area is limited(Fig. 2). After multiple rounds of thermochemical huff and puff, the temperature field develops and expands, and the steam-swept area expands(Fig. 3). After multiple rounds of compound thermochemical huff and puff, the temperature field develops and expands, and the steam-swept area expands(Fig. 4).

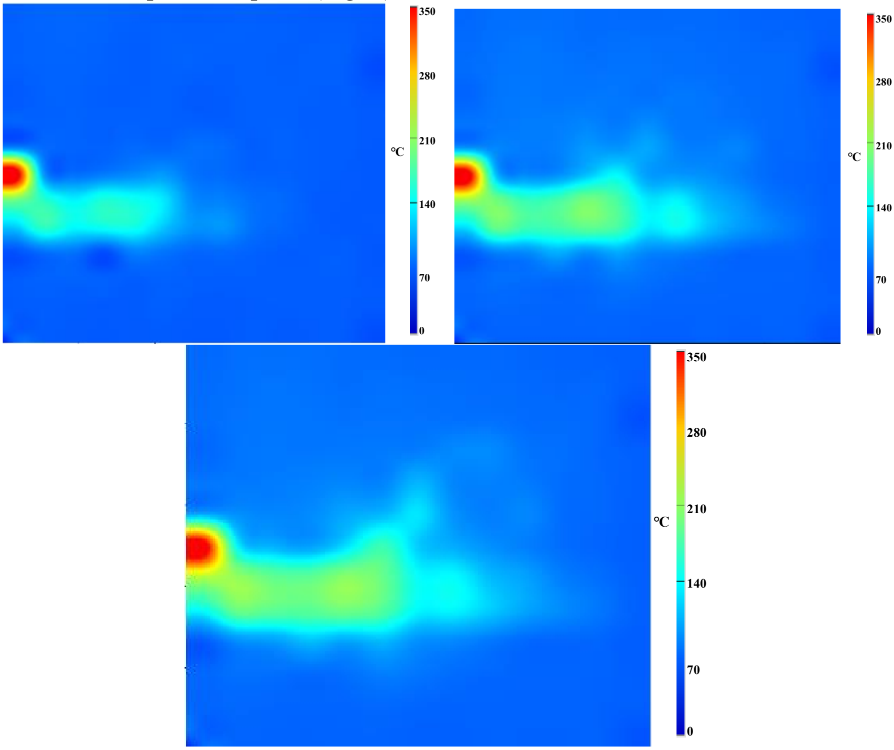
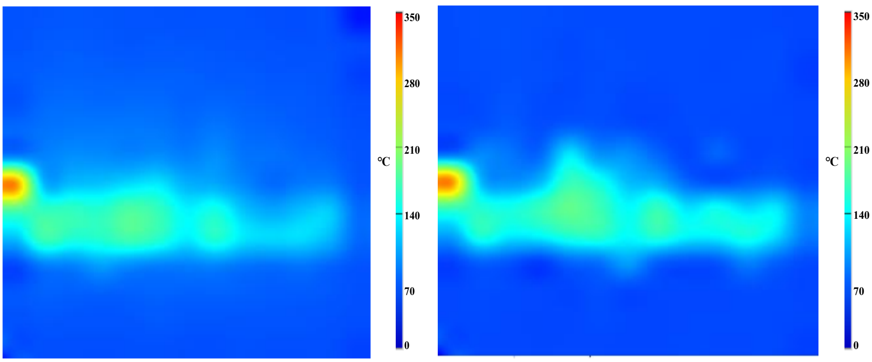


Fig. 2. Temperature field in different stages of steam huff and puff (before, during, and after)



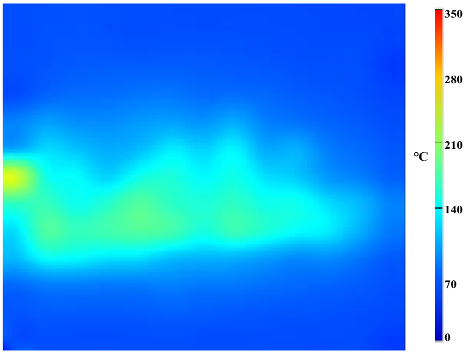


Fig. 3. Temperature field in different stages of thermochemical huff and puff (before, during, and after)

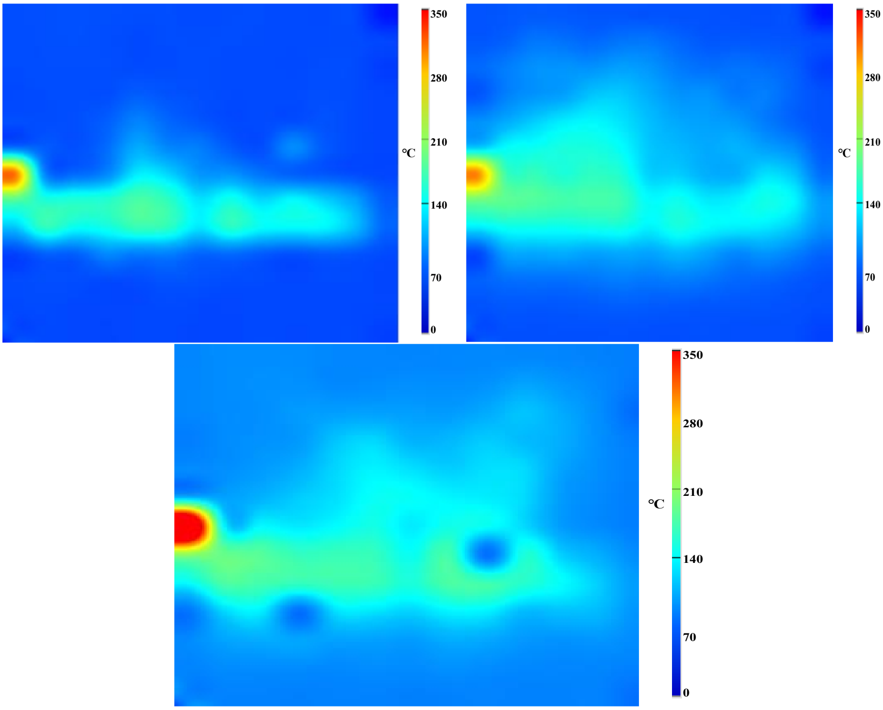


Fig. 4. Temperature field of different stages (before, during, and after) of compound thermo-chemical steam huff and puff

Analyze and compare other mining methods' periodic oil production and recovery degree. That thermochemical huff and puff can increase the cumulative oil production by 33% and the recovery degree by 4.65% based on steam huff and puff; Combined thermochemical huff and puff can increase the cumulative oil production by 53% and the recovery degree by 7.13% based on steam huff and puff (Fig 5).

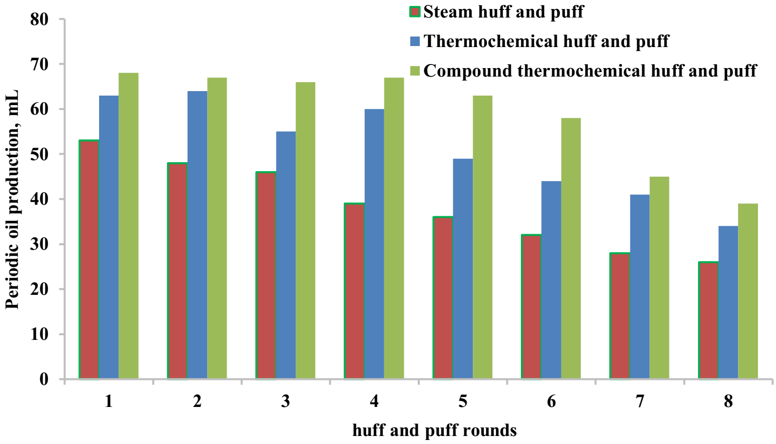


Fig. 5. variation of oil production in different development modes with huff and puff rounds

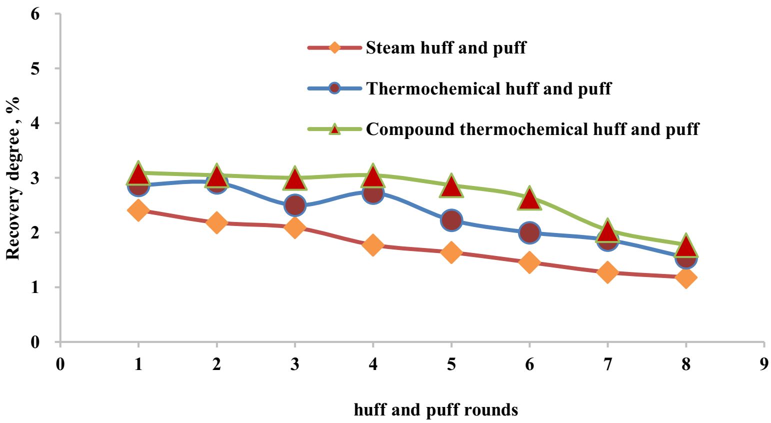


Fig. 6. variation of recovery degree of different development modes with huff and puff rounds

based on steam huff and puff, compound thermochemical huff and puff can increase the cumulative oil production by 53% and the recovery degree by 7.13%, indicating that compound thermochemical technology can significantly improve the recovery degree of crude oil. The compound thermochemical technology can improve recovery in the third to sixth cycles of thermal production huff and puff(Fig.6).

3 Thermal recovery mechanism of heavy oil

Oil soluble viscosity reducer is composed of aromatic solvents, dispersants, surfactants, etc. The complex structure of asphaltene and resin in heavy oil, as well as the interaction between the two, can lead to an increase in crude oil viscosity. The solvent interacts with gum and asphaltene molecules. Aggregation of colloids reduces the number of asphaltenes and reduces the cohesion of crude oil, thereby reducing the viscosity of the heavy oil system.

The addition of high-temperature foaming agents and high-temperature oil displacement agents significantly reduces the interfacial tension of extra heavy crude oil, while also reducing the adhesion work between the crude oil and rock interface. The crude oil is easy to detach from the rock surface, and the oil droplets are easy to deform. By significantly reducing the resistance of pores, the flowable part of the fluid in the pores increases, thereby reducing the residual oil saturation of thermal recovery and improving the development effect of heavy oil thermal recovery.

High temperature oil displacement agents exhibit strong emulsification, making it easy for crude oil to form O/W type emulsions, reducing crude oil viscosity, and increasing crude oil fluidity. At the same time, the emulsion droplets generate the Jamin effect, which plays a role in micro blocking and regulating, expanding the fluid sweep volume.

Due to the effects of high-temperature foaming agents and high-temperature oil displacement agents on reducing oil-water interfacial tension and changing wetting, the oil-water phase permeability curve shifts to the right, and the range of oil-water co permeability zone increases.

High temperature foaming agent and gas generate foam. Due to the Jamin effect of foam, the heat swept volume is significantly expanded, and the oil displacement efficiency is significantly increased.

4 Conclusions

(1)The total recovery rate of steam huff and puff mining is only 13.99%, and the cyclic oil production and cyclic recovery rate continuously decrease with the increase of mining cycles. The overall temperature field develops linearly along the horizontal well section, and the steam coverage area is limited. The mining effect is poor.

(2)After multiple cycles of composite thermochemical huff and puff, the development of relative steam huff and thermochemical huff and puff temperature fields expands significantly, and the affected range increases.

(3)The total recovery rate of composite thermochemical huff and puff mining is 21.5%, which is 7.50% higher than that of steam huff and puff mining. The cyclic oil production and cyclic recovery rate continuously decrease with the increase of mining cycles, but the stable production period is longer.

(4)In composite thermochemical huff and puff, high-temperature foaming agents and high-temperature oil displacement agents reduce the interfacial tension between oil and water, change wetting, and other effects, causing the oil-water phase permeability curve to shift to the right, and increasing the range of oil-water co permeability zone. High temperature foaming agent and gas generate foam. Due to the Jamin effect of foam, the heat swept volume is significantly expanded, and the oil displacement efficiency is significantly increased.

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