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Research on characteristics of fire flooding zones based on core analysis

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ABSTRACT

In order to better understand the combustion process and to make a better displacement of fire flooding, it is necessary to study the zone characteristics and the advancing law of fire flooding. Firstly, temperature dynamic characteristics of observation well reveal that the combustion of HQ1 fire flooding pilot test is characterized by wet combustion. Then, a series of core tests (rock pyrolysis, mercury intrusion, crude oil group composition analysis, rock and mineral composition) are utilized to analyze the cores from Xinjiang HQ1. By comparing the difference of characteristics between the burned and unburned zone, the result shows that coke deposition occurs under the burning surface, where the coke deposition zone is. And above the surface, kaolinite is converted into illite or montmorillonite. There is evidence to show that montmorillonite will converted into illite under a dry combustion condition(35 °C). These features of rock and mineral can be used to evaluate fire flooding process.

1. Introduction

Fire flooding technology is a type of thermal oil recovery method with obvious technical advantage and potential. It is characterized by high oil displacement efficiency (generally 80%–90%), low unit thermal cost, wide range of reservoirs adaption (from thin oil layer to thick oil layer, from shallow oil layer to deep oil layer, from thin oil to heavy oil and developed reservoirs) (Ning et al., 2010; Wang et al., 2000). Since 1958, China has carried out the fire flooding test in Xinjiang, Yumen, Shengli, Jilin and Liaohe oil fields. Of all these successful projects, the recovery is about 11.6% (Venezuela's Miga field) to 70% (US Mid-Libby, LA field) (Ning et al., 2010). It is generally accepted that there are obvious zone characteristics during a fire flooding process (Guan et al., 2010). Heat and mass transfer are held between zones. So how to control and adjustment the combustion surface well is the key to maintain combustion and to ensure the recovery efficiency. Core analysis is widely used to study the state of fire flooding. It can analyze zone characteristics (Shi et al., 2016), sweep efficiency (Liu et al., 2010; Ostapovich and Ross, 1991; Pareek et al., 2017; Yu and Hu, 2015) and the corresponding conversion of rock and mineral (Cheng et al., 2014; Kuzina et al., 2015; Liu et al., 2015a). But previous works generally study on single aspect and are lack of comprehensive and systematic research. Through analyzing rock pyrolysis, rock mercury intrusion and crude oil group composition in burned and unburned zone, this paper has made a further understanding of the characteristics, reaction principle and process in each zone during the fire flooding.

1.1. Introduction of fire flooding in HQ

HQ1 fire flooding pilot is located in northwestern margin of Junggar Basin, China. This oilfield commenced in 1991 with steam stimulation and steam flooding. Because of low production and poor efficiency, the reservoir was abandoned in 1999, and all the producers were used to develop another reservoir. After this, a fire flooding pilot test was conducted in 2009. HQ1 is a typical pilot that switched to fire flooding after steam flooding. A total of 55 vertical wells are deployed in the pilot and the original steam flooding well pattern are sufficiently utilized. The pilot has achieved remarkable success.

There are two observation wells (Fig. 1)to monitor formation temperature, well h2071 and well h2072 as shown in Fig. 2. In well h2071, the average temperature of the combustion front was 400 °C, and lasted for 14 days. Then the temperature decreased. In addition, the temperature at 5 m radius is relatively balanced. It indicates that gravity overlapping of combustion front is not obvious, and the vertical sweep is efficient in the fire flooding process.

Jacques et al. (1991) has reported the temperature profile characteristics of dry fire flooding and wet fire flooding (Zhang et al., 2015). There are three obvious stages shown in well h2071 temperature profile (Fig. 2): thermal liquid flowing period, combustion front advancing period and air cooling period. Before the combustion front advancing period, there is a long interval period that the temperature maintains at 200 °C. According to the temperature and flow rate of production liquid, it can be identified as the thermal liquid flowing period. This is

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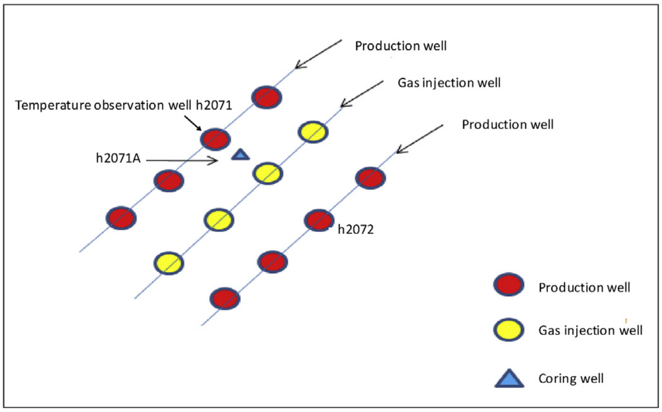

Fig. 1. Well location diagram in fire flooding pilot.

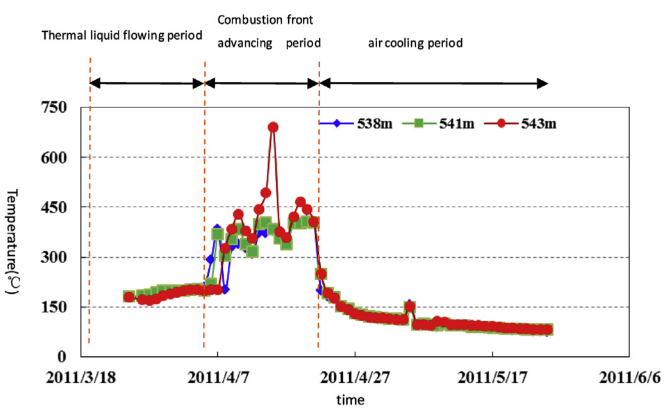

Fig. 2. Temperature monitoring of h2071 well.

similar to the wet combustion characteristics described by Bourges. So, the HQ fire flooding process has the characteristics of high temperature combustion and wet combustion.

The analysis show that in the formation of HQ pilot, there is amount of water residue after a long time development of steam stimulation. Although the injection is dry air, but the underground water makes the fire flooding represent wet combustion characteristics.

2. Core analysis of fire flooding pilot

In order to further study the inner changes and characteristics of each zone, it is necessary to study the combustion reaction and the mechanism. And then formulate the operation technology to improve the performance of in-Situ combustion. The coring well h2017 (7 m away from well h2071) is drilled between the gas injector and well h2071. And the length of coring is 14.7 meters. The characteristics of the zone and the migration of rock can be provided by core analysis on various sections of the coring well.

2.1. Zone characteristic of fire flooding in the core well

It is generally accepted that fire flooding process has significant zone characteristics. The reservoir can be divided into seven zones between the injector and the producer (Guan et al., 2010). They are burned zone, combustion zone, cracking zone, condensing zone, water bank, oil bank and initial zone.

As shown in Fig. 3, the characteristics of the temperature, pressure and pressure gradient in each zone are obviously different. According to these distinctions, flowing temperature and flowing pressure measured by test device setting at the bottom of observation well (or production well) can be used to figure out the position of each zone relative to the

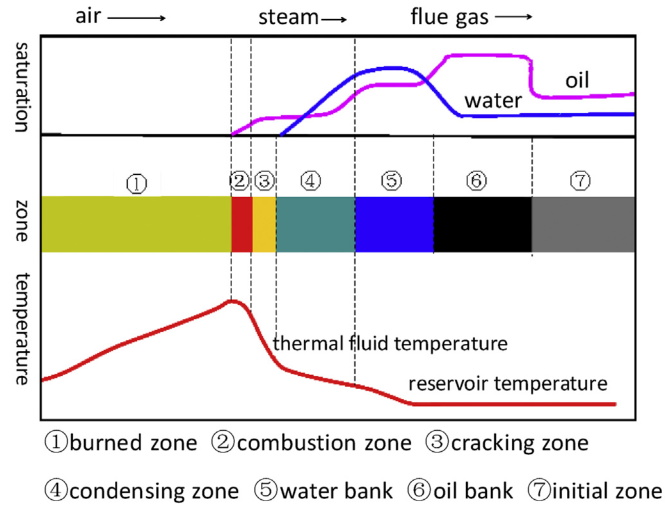

Fig. 3. Zone characteristic schematic diagram in fire flooding.

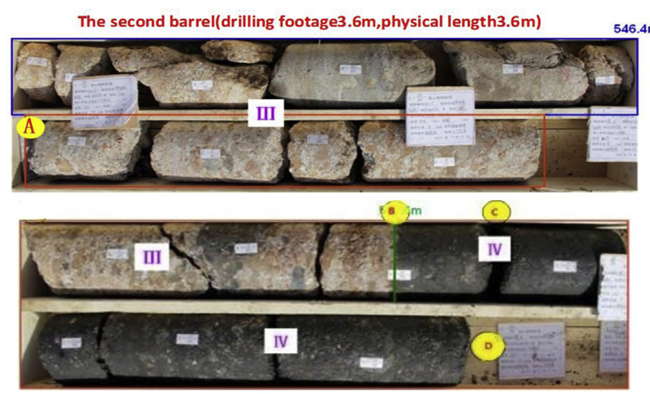

Fig. 4. Core picture from coring well h2017A.

well, further to analyze the advancing of combustion front in the formation.

The core from well h2071A (Fig. 4) shows that the characteristics of fire flooding burned and unburned section, and the interface (B point). The oil saturation below C point is 53.2%, much higher than elsewhere. It indicate the "oil bank" effect (Table 2). The displacement effect of fire flooding is mainly determined by the movement of the oil bank.

The A-B section is the burned zone. Its temperature was higher than the ignition point of coke which is 343 °C (Jacques et al., 1991). Almost all crude oil in the section has been swept away after high temperature oxidation. HTO can break carbon chains of organics and produce CO, CO_2 and water. After fire flooding, the color of the rock is brown and red. Limonite and ilmenite fully indicate the existence of oxidation environment.

The B-C section is the unburned zone between combustion zone and oil bank. The change of material and properties of core material show the influence of combustion. It is necessary to analyze it and its surrounding.

Table 1
Hydrocarbon content comparison by pyrolysis analysis(mg/g).

Temperature	90 °C (S0)	200 °C (S11)	200–350 °C (S21)	350–450 °C (S22)	450–600 °C (S23)	residual (S4)
B-C section	0	1.27	10.96	3.69	0.99	22.5
C-D section	0.65	15.58	30.75	15.67	3	12.1

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