PERFORMANCE EVALUATION OF IN-SITU COMBUSTION ENHANCED OIL RECOVERY METHODS FOR HEAVY OIL RECOVERY: A REVIEW

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Abstract

Any mature oil field with high-medium viscous, along with a low gas content-heavy oil and high mobility contrast between oil and water results in a rapid decline in production resulting in a phase where conventional oil recovery methods seem ineffective. Thus, it is necessary to develop new technologies to enhance the oil recovery from these reservoirs. In-Situ combustion (ISC) is a relatively effective technique for enhanced oil recovery of the reservoir that involves the process of the multi-phase fluid flow through porous media with the chemical and physical transition of crude oil components under the application of high temperature and pressure conditions. This study identifies and reviews the technique which is based on the principle of reducing the viscosity of heavy oil by heating oil in the reservoir itself. The process is initiated in the reservoir by injecting oxygen or air. Part of the oil is burned (oxidized) to produce heat and combustion gases that help to drive the (unburned) oil from the system. Extensive review has been put forward on the field tests conducted on small oil field in North of Thailand, Mehsana Gujarat (India), and Shengli, Liaohe, Xinjiang (China) oil regions. Results concludes that the feasibility of ISC technology for heavy oil reservoirs in similar oil fields. The work also provides developments, adaptability, and advantages of ISC technology for heavy oil reservoirs in the fields.

Keywords: In-Situ Combustion (ISC), Enhanced Oil Recovery (EOR), Heavy oil reservoir, Combustion Override Split Production Horizontal Well (COSH), Toe-to-Heel Air Injection (THAI), Combustion Assisted Gravity Drainage (CAGD)

Introduction

Enhanced oil recovery (EOR) techniques are needed when unfavorable conditions such as heavy-oil reservoir, high-medium viscous, low matrix permeability, oil-wet matrix, and poorly connected fracture network exist in an oil reservoir. Accordingly, effective technology used for heavy-oil production nowadays is thermal recovery such as cyclic steam stimulation, steam flooding, steam assisted gravity drainage (SAGD) and in ISC [1]. EOR processes can be divided into thermal and non-thermal recovery processes and In-situ combustion is a thermal process. The adaptability of In-situ combustion is that In-situ combustion is not limited by reservoir depth, due to the air or oxygen is hardly influenced by reservoir depth and combustion heat is generated inside the oil layer. Also, it has several advantages, including higher thermal performance, low overburden heat loss, no heat losses in the wellbore, and the ability to use it in deeper and higher-pressure reservoirs. ISC, on the other hand, can cause significant corrosion, toxic gas emission, and gravity override, and it is difficult to regulate inside the reservoir. There are two forms of ISC processes: forward combustion and reverse combustion. The combustion front that travels in the direction of production is known as forward combustion. Reserve combustion is described as combustion that moves in the opposite direction of the fluid flow, towards the injection. There are two forms of forward combustion: dry and wet ISC. In dry forward combustion, only air or oxygen-enriched air is injected, while in wet forward combustion, water is injected alternately or concurrently with air. Most of these failures occurred because, successful methods were applied to the wrong reservoirs or with the worst prospects [2].

Methodology

Qualitative efforts were adopted to understand the deep investigation over ISC. The paper adopted analytical method to investigate new fields of study about the In-Situ Combustion in North of Thailand, Mehsana Gujarat (India), and Shengli, Liaohe, Xinjiang (China) oil regions. Each field have a different perspective and used wide varieties of techniques for ISC technology. The methods are: Toe to Heel Air Injection (THAI), Combustion Override Split Production Horizontal Well (COSH), Combustion Assisted Gravity Drainage (CAGD), 1 Dimensional Combustion tube, Using Tri-ethyl borane, and artificial ignition, scaled model.

The same can be done through the stimulation software's, which gives a more realistic approach in 1-D, 2-D, 3-D and 4-D such as STARS, IMEX, GEM, Reservoir Grail, Jewel Suite [3]. The study is purely based on secondary resources of articles, books, and journal publications. Data is collected using internet resources and Website resources. This research is descriptive-analytic.

The paper stressed on two key areas:

- The study identifies the techniques, based on the principle of increasing the mobility of the oil by reduction the oil viscosity, done by heating the residual oil in the reservoir itself.
- The work also discusses different fields to identify the development and adaptability ISC and comparison among them.

Comparison of Fields

In-Situ Combustion in Heavy Oil Fields in The North of Thailand

An application of in-situ combustion Toe to Heel Air Injection (THAI) technology developed by Petro bank Energy and Resources Ltd. This is a very new and experimental method that combines a vertical air injection well with a horizontal production well in a single system. However, a major problem of in-situ combustion is the control of the movement of the combustion front. Depending on the reservoir characteristics and fluid distributions, the combustion front may move in a non-uniform manner through the reservoir, resulting in poor volumetric sweep [4] [5] [6].

Furthermore, if proper conditions are not preserved at the combustion front, the combustion reaction will weaken and eventually stop. If this happens, the process' effectiveness is compromised. In-situ combustion process parameters such as air injection levels, oxygen concentrations, and injected air temperature are important because they can govern the combustion front's sustainability. As a result, the aim of the study is to look into the effects of certain parameters on heavy oil production, as well as to use reservoir simulation to find the best conditions for increasing oil production quality. Characteristics of heavy oil from the north of Thailand can be concluded as shown in the Table below. This formation is an unconsolidated sandstone formation with permeabilities averaging 500 md containing medium-heavy oil with viscosity around 54 cP. In-situ combustion is one of the candidates for effective oil production for this type of reservoir as its properties are within the recommended range suggested by [7].

Table 1. Characteristics of reservoir and fluid (after Taber et al., 1997)

Characteristics of Oil and Reservoir Value	
Porosity (%)	18-35
Permeability (md)	500
Initial oil saturation (%)	55
Initial reservoir pressure (psia)	1430
Initial reservoir temperature (F)	140
Oil gravity (API)	17.2
Oil viscosity at reservoir conditions (cP)	53.7

Simulation software STARS was used for the field analysis and parameters such as block sizes, air-injection rates, oxygen concentrations, and injected air temperature were recorded. The 0.5m-block size was chosen because it provided the best running time and accuracy. Based on the findings, an improvement in injection rate from 100 Mscf/d to 400 Mscf/d has a negligible impact on cumulative oil production – less than 6% incremental recovery. Increased oxygen concentration from 29% to 100% resulted in a 40.67 percent rise in oil production. Furthermore, the rise in injection fluid temperature from 80°F to 500°F resulted in a 97.14 percent increase in total oil recovery. Subsequently, optimum operating conditions were changed to improve oil production recovery. As long as the process is at the maximum limit of combustion kinetics, optimal efficiency could be achieved [4-7].

In-Situ Combustion in Santhal Field, Mehsana, Gujarat, India.

Gujarat's Cambay basin is one of India's most promising petroliferous basins. A belt of heavy oil fields runs through the northern part of the basin. The Santhal field is part of this heavy oil belt, with crude oil viscosities varying from 50 to 200 cps at average reservoir pressure and temperatures of 1422 psi and 70 °C at 990 meters MSL, respectively. Because of the high mobility ratio between oil and water, a primary recovery factor as low as 13% has been predicted. In the northern part of the Santhal field, the ISC process was carried out in the KS-I reservoir using an inverted 5-spot injection production well pattern [8].

In the Santhal field, in-situ combustion primarily entails converting existing oil producers to air injectors by re-completing them with a heat shield, burner assembly, and thermocouple run over tubing for surface temperature monitoring. Following the start of the chemical method of ignition at the sand face, air injection in a pre-determined quantity is retained to keep the fire front burning.

This method has a multi-effect in terms of efficient crude oil displacement, reservoir pressurization with the creation of secondary gas caps, resulting in gravity drainage, flue gas stripping of reservoir oil, and oil swelling. Ahead of the high-temperature combustion front, there exists an LTO reaction zone forming coke which is utilized as a fuel for combustion front to sustain.

The anticlinal structure of Santhal field is oriented north-south. The reservoirs are sandstone, with a 3 to 5 degree west-to-east inclination. The reservoirs have a permeability of 3-5 d, an average porosity of 28%, and oil viscosity rises from south to north, from 50 to 200 cp. It has a 9-9.5 % asphaltene content and 10-13 % resins. At 15 °C, the crude has a density of 0.95 gms/cc.

The baseline data of oil, gas, water quality, and production testing parameters of the surrounding producers were produced before the ignition of an air injector. Via the injector, it first creates a fire front in the reservoir. The artificial spontaneous ignition process is used to carry it out. Detergents and hot water, followed by Nitrox solution, are used to prevent explosions that cause tubing and casing damage [8] [9].

The artificial ignition allows for the development of a fire front by generating additional heat. A gas burner, electric heaters, and other sources of heat are used. A gas burner is connected to a thermocouple in the Santhal ISC system to track the ignition at the surface. TEB, an explosive chemical is being used for artificial ignition.

Flue gas migration up-dip appears to be synchronized with an increase in liquid output and a decrease in water cut, resulting in an increase in net oil production. The AOR and cumulative injected air volume versus time are calculated. The AOR of less than 1000 Nm^3/m^3 suggests that the ignition process is well within the economic limit, which will, however, continue to decrease as oil production rises. The performance of typical in-situ combustion was significantly influenced. The overall output of the Santhal field demonstrates that as the number of injectors increases, oil production increases gradually over time.

So far 23 injectors are subjected to air and water injection in the Santhal field. The conversion of producers to injectors has been done in phases at different times to get the maximum recovery of oil. The wellhead Injection pressure with time shows that the air injection pressure had an increasing tendency during the initial phase which had later decreased with the initiation of the wet phase. This phenomenon may be attributed to the formation of coke during the combustion process that would have washed away during the wet phase [8] [9] [10].

In-Situ Combustion in Heavy Oil Fields of China.

Heavy oil reservoirs in China face several production challenges: most heavy oil reservoirs are in the middle or final stages of steam stimulation, and the throughput effect has significantly deteriorated; despite the widespread use of steam flooding in shallow reservoirs, steam flooding technology suitable for medium-deep reservoirs is still in the experimental stage. As a result, new technologies to replace steam flooding are needed to improve the oil recovery of heavy oil reservoirs.

ISC pilot test was conducted on Du-66 reservoir in Liaohe oil region. The reservoir has medium depth thin bed oil layers and was producing at a rate of 0.5t/day prior to the application of ISC. After implementing ISC the production rate increased to 3.8t/day adding up to 619t/day of total reservoir daily production as of 2017.

Another test was conducted on the Gao3-6-18 reservoir in Liaohe oil field having burial depth of approx. 1540 – 1890m. The reservoir thickness is around 96.8m, porosity 20.6%, and permeability measures 1014.1 md. Production rate prior to ISC was 1.8t/day while daily average production was 184t/day. After the implementation of ISC the rates were increased by 8.4% of the initial production.

In China's Shengli, Liaohe, and Xinjiang oil regions, ISC is commonly used in heavy oil reservoirs. While compressed air absorbs energy, there is no heat loss from the air compressor to the gas pipeline, and from there to the bottom of the wellbore, while using the in-situ combustion process. Heat loss in the combustion front does not occur until oxygen from injected gas combines with the fuel in the oil layer to produce heat. A portion of the heat that remains in the rock can be retrieved during the phase of the injected gas following towards the combustion front. During the wet forward combustion phase, this form of heat recovery is more visible [11].

Other approaches of ISC that have been tested successfully in the fields of China includes:

1. In-situ Toe-to-Heel Air Injection (THAI)

   The use of THAI has been shown to increase in-situ combustion. THAI is a form of ISC that uses a horizontal production well to recover partially upgraded heavy oil that has been mobilized. The combustion front in THAI spreads from the tip to the heel of the horizontal well, rapidly creating a flowable oil region, where the high temperature within not only provides an important heat displacement source for the oil layer, but also produces an ideal environment for heavy oil thermal cracking. Meanwhile, the heated crude oil flows quickly due to gravity and travels a short distance to reach the horizontal production well, which avoids the long-distance displacement by using conventional in-situ combustion. Additionally, the length of the perforation section on the production well can be maintained by simply changing the inner sleeve by inserting a movable inner sleeve [4] [12] [13].

2. Combustion Override Split Production Horizontal Well (COSH)

COSH used a novel well arrangement to improve conventional in-situ combustion methodology. A horizontal well is used as a production well, while lateral wells are used to vent flow gases out of the reservoir. The horizontal production well, like the one in THAI, serves to increase the area of contact between the formation and the combustion front. Meanwhile, gravity drainage stabilizes the growth of the combustion front as well as the production well [14] [15].

3. Combustion Assisted Gravity Drainage (CAGD)

CAGD has recently been suggested as a viable alternative to in-situ combustion. By combining a horizontal injector near the top of the formation with a horizontal producer near the bottom of the reservoir, CAGD improves conventional in-situ combustion. The combustion front grows towards the heel-end of the injector and spreads laterally after initiation of combustion along the length of the injector in the CAGD phase, and then the heated oil flows downward towards the underlying horizontal production well due to gravity drainage [14] [16] [17].

Conclusion

There lies huge scope of success for implementing ER schemes in the O&G fields. ISC can be widely applied to fields. Enough methodologies have been adopted and many varieties of ISC have come up with varying results and good recovery techniques with less effort and less usage of components. A great future exists ahead for the O&G industry in the scheme of EOR especially ISC. A preliminary analysis can be used to forecast the production of medium-heavy oil. The in-situ combustion method appears to work best with medium to heavy crude oils. Under reservoir conditions, the process had to deal with multi-phase fluid flow through porous media as well as chemical and physical transitions of crude oil components. All the three fields exhibit positive attire towards ISC, even though there were some misfortunes in the field analysis the engineers were able to modify the issue with a positive approach and thus leading to a better way of Enhanced Oil Recovery. Furthermore, the studies conducted by the authors and scientists have helped many field personnel to identify their problem and cop up with that. Enhanced Oil Recovery is a vast topic in the field of O&G, it has a wider approach and still there are lot more to come up for EOR, more better ways of recovery and better approaches for the current modifications.

Acknowledgement

We would like to thank our professor Mr. Adityam Dutta, who has been constantly guiding us throughout our research. Nothing could have been possible without Lovely Professional University and the faculties and our colleagues who were with us. A big bow to the ones who had supported us immensely.

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