Experimental study of in-situ combustion process in One Iranian Carbonate heavy oil reservoir

Mohammad Masoumi[1*], Riyaz Kharrat[2], Abdolnabi Hashemi[2], Mohammad Ali shojaiepour[1], Mohammad Nikokar[3]

[1)] Department of Petroleum Engineering, Science and Research Branch, Islamic Azad University, Tehran, IRAN.
[2)] Department of Petroleum Engineering, Ahwaz Faculty of Petroleum Engineering, Petroleum University of Technology, Ahwaz, IRAN.
[3)] IOR Research Institute, National Iranian Oil Company, R & T, Tehran, IRAN.
[*)] Corresponding Author: Science and Research Branch, Islamic Azad University, Tehran, Iran, TEL: +98-9177048972
Email: m.masoumi46@yahoo.com

Abstract: The purpose of this study is feasibility study of in-situ combustion process in one heavy oil reservoir in Iran, under experimental conditions. This paper includes the results of two experiments. The maximum temperature Combustion front in the two experiments was 573.13 and 512.8°C, respectively. The amount of produced oil in the combustion process approximately 34% and 84%. In addition, the amounts of oxygen, carbon dioxide and carbon monoxide were measured using gas analyzer. Due to the success achieved in this experimental study, it can be concluded that EOR combustion method can be considered as an important option for development and exploitation of such reservoir.

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1. Introduction

Application of in-situ combustion or fire-flooding process, as the oldest method of enhanced oil recovery in the petroleum industry has been proved successful all over the world since nearly 100 years ago. Lewis (1916) broke the ice and contemplated the possible occurrence of combustion in projects where warm air was injected into the formation to dominate paraffin deposition problems His work was documented in an unpublished internal U.S. Bureau of Mines memo. After lots of similar attempts the first successful field study of in-situ combustion process was reported in the USA, Ohio, in 1920 (Mills, 1923).

Excluding some successful experiences of ISC in the light oil reservoirs in the United States in 1985 and 1996 (Sarathi), ISC as a thermal oil recovery method has been wildly used for heavy oil, shale oil and tar sand reservoirs with an average oil recovery of 80%. With the field operations, there has been a laboratory attempt for identification of important features of ISC by testing different type of topics related to ISC.

In 2001, Bagci S. et al. conducted both dry and wet experiments on the Turkish heavy oil reservoir samples; they concluded that the front temperature and fuel consumption rate were higher in the dry process. Perozo et al. (2011) investigated different features of a pilot ISC test and technical economical feasibility analysis. Kok (2009) studied the effect of different litho logy (limestone and sandstone) on the combustion by thermal analysis techniques. Mendoza A. J. et al. (2010) investigated the effect of nonconventional additives in the ISC process in Venezuela. They showed that using specified concentration of such additives would increase the ignition production, decrease the H/C and Air/C fractions, increase the need for the injected air, decrease the front speed of propagation, increase the production of light hydrocarbons (C_1-C_6), and increase the maximum temperature during the combustion process. Olurotimi G. Awoleke (2007) studied the role of heterogeneity in the success of the process. He concluded that in small-scale heterogeneities, there would be successful process; however, in large-scale heterogeneities, where the air can escape from the thief zones, the process fails to be unsuccessful. In 2008, Lignuo, by performing laboratory experiments, came to this conclusion that ISC is one of the best choices for shallow thin together with multilayered oil reservoirs.

A general investigation of the ISC literature results in the fact that the most accepted type of the ISC is the dry forward combustion, which has primarily less complexities and operational difficulties. As a result, the main scope of current research is focused on the identification of effective parameters of a typical dry forward combustion based on laboratory recordings.

With regard to the heavy oil reservoirs in Iran, initial reservoirs, their lack of production, drop of light oil production in near future, increased domestic consumption, rising global demand for oil and OPEC keep production stable, laboratory and field studies are undertaken to determine the best way to produce. Also, using this type of technology to identify, extract, and accelerate the development and operation. However, this recovery method of carbonate heavy oil reservoirs has not been seriously examined. Thus, targeted, systematic and extensive library and pilot operation studies at different levels are very important.

This paper contains the result of feasibility study conducted experiments on in-situ combustion process of Iranian heavy oil reservoir.

2. Material and Methods

At first, sand and oil are mixed. Figure 1 shows the stages of mixing sand into oil.

sand after the mixing with oil sand when mixing with oil Sand before mixing

Figure 1- Mixing stages of sand and oil

Then mixture must be put and packed in the tube. Packing is done by a plunger. First put about 5 cm of coarse sample in the end of combustion tube to prevent from plug of production well and also easier production. Replace 55 cm of sample with 30-50 mesh size and 40 cm with 50-100 mesh size upper combustion tube. Add some linseed oil (about 10 ml) to sample in upper part of the combustion tube because the combustion process initiation will be faster. Also close the door of tube and heating jacket made of silicone (to prevent burning) and ceramic wool (to prevent heat loss), close around it. Then set heater temperature on 63°C until porous media reaching to reservoir temperature. Then, due to opening the path of injection gas, pressure regulator of combustion tube and check out leak in connections, nitrogen was injected into the system. The system is now ready for experiment. In this paper, two experiments have been performed; the experimental conditions are in Table 1 and oil properties are in Table 2 and also, initial conditions for oil, water, sand and initial saturations are given in Table 3.

Table 1- Experimental conditions

	Run 1	Run 2
Pressure (psi)	460	400
Air Injection Rate (m^3/hr)	.1980	.1440
Oxygen Concentration in the injected gas (%)	60	60
Pre-heat Cell Temperature (°C)	63	63
Ignition Temperature (°C)	410	350
Porosity (%)	36.2	36.2
Permeability (Darcy)	10	10
Communication Fluid	N□	N□

Table 2 – Oil properties

API	13
Saturated (wt.%)	21.83
Aromatic (wt.%)	53.59
Resin (wt.%)	9.58
Asphalting (wt.%)	15
Viscosity (cp)	2680@130°F @100°F15763 @70°F114540

Table 3- Mass fraction of sand pack composition and initial saturations

	Run 1	Run 2
Sand (%)	83.21	83.21
Oil (%)	16.79	16.79
Water (%)	0.0	0.0
So (%)	0.80	0.80
Sw (%)	0.0	0.0
Sg (%)	0.20	0.20

First Experiment

In this experiment, no water was added to the mixture. Initial fluid saturations in this test are about 80% oil, 0% water, and 20% inert gas. The igniter temperature was gradually raised until 410°C. When igniter temperature reached to 410°C, the combustion process started. The first injection rate was set on 0.12 m^3/hr and after five hours, as the combustion process did not start, the rate was increased to 0.198 m^3/hr. this rate was kept constant until end of the experiment. Oxygen concentration in the injection air was equal to 60%. In this experiment, when the combustion front reached to the seventh thermocouple that suddenly the system was plugged and production stopped. Maximum temperature during combustion process has been equal to 573.13°C observed on the 4th thermocouple. The amounts of oil production at the end of the test have been reported about 34%. In-situ Combustion process parameters for the first test are shown in Table 4.

Table 4- Calculated parameters for experimental run 1

Maximum temperature (°C)	573.13	Average combustion front velocity (cm/hr)	8.73
Air injection rate (m^3/hr)	0.198	Oil recovery (%)	34
Average temperature of the combustion front (°C)	480.75	O_2 Utilization (%)	95.8
H/C Ratio	0.4274	Excess air (%)	4.38
O_2/Fuel Ratio (m^3/Kg)	1.922	$(CO_2+CO)/CO$ Ratio	3.3722
Air/Fuel Ratio (m^3/Kg)	3.193	$(CO_2+CO)/N_2$ Ratio	1.4905

Figure 2 shows the diagram of temperature versus time for each thermocouple which is obtained from the first test.

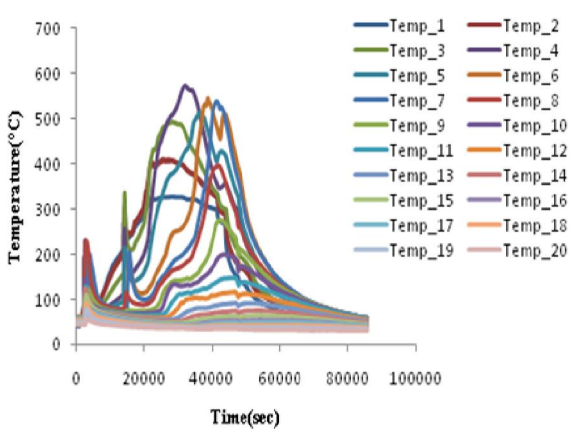


Figure 2 - Temperature versus time for each thermocouple

In addition, in figures 3 to 5, the percentages of effluent gases versus time are presented.

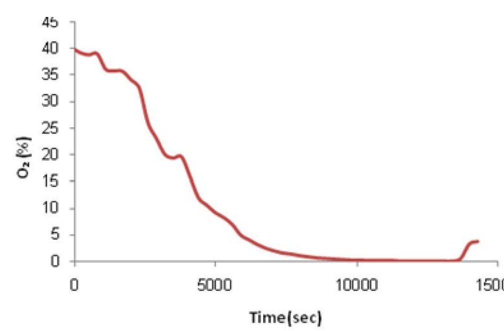


Figure 3- Oxygen concentration in the effluent gas vs. time

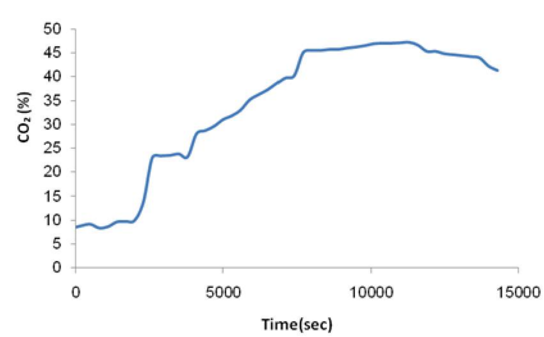


Figure 4 - Carbon dioxide concentration in the effluent gas vs. time

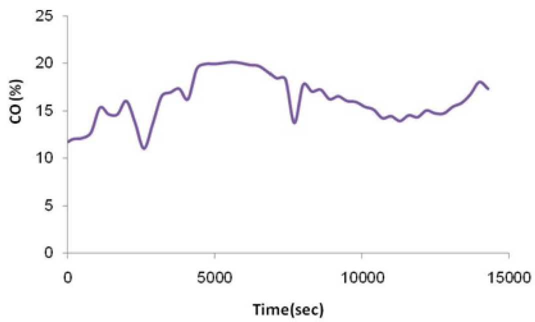


Figure 5- Carbon monoxide concentration in the effluent gas vs. time

In addition, Figure 6 shows rock appearance after in-situ combustion process from the top of the combustion tube.

20-0 cm 40-20c 60-40 80-60 100-80

Figure 6- Rock appearance after in-situ combustion process

As also figure 7 shows upper part of the combustion tube, before and after the in-situ combustion, process.

upper part of the combustion tube after combustion process

upper part of the combustion tube after combustion process

upper part of the combustion tube before combustion process

Figure 7 - Upper part of the combustion tube before and after in-situ combustion process

Second Experiment

In this experiment, no water was added to the mixture. Initial fluid saturation in this test is about 80% oil, 0% water and 20% inert gas. In this experiment, when igniter temperature reached to 350°C, the combustion process started. The air injection rate was equal to 0.144 (m^3/hr). Oxygen concentration in the injection air was equal to 60%. Combustion front moved forward to the sixteenth thermocouple and then, after cut off the oxygen injection, the combustion front was turned off and combustion process finished. Maximum temperature during the combustion process has been equal to 512.8°C observed at the eleventh thermocouple. The amount of oil production reported at the end of this test was about 84%. In-situ combustion process parameters for the second test are shown in Table 5.

Figure 8 obtained from the second test shows the diagram of temperature versus time for each thermocouple.

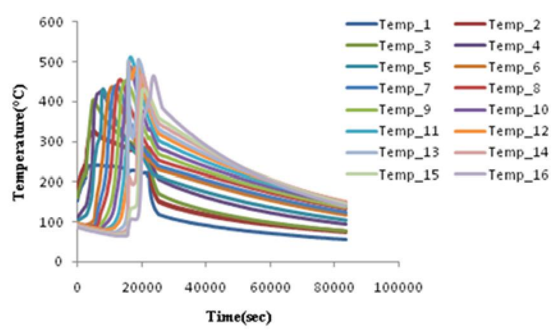


Figure 8 - Temperature versus time for each thermocouple

In addition, in figures 9 to 11, the percentages of effluent gases versus time are presented.

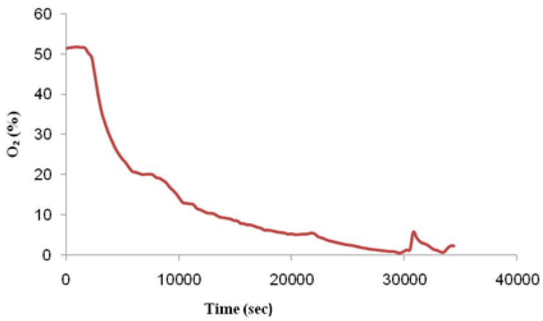


Figure 9- Oxygen concentration in the effluent gas vs. time

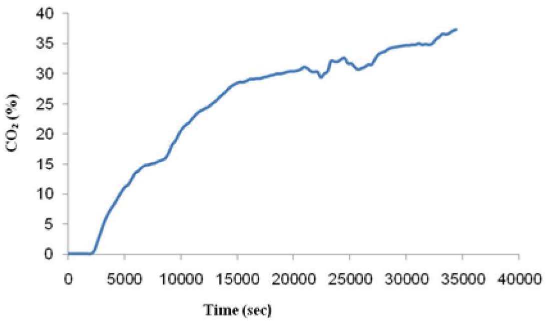


Figure 10- Carbon dioxide concentration in the effluent gas vs. time

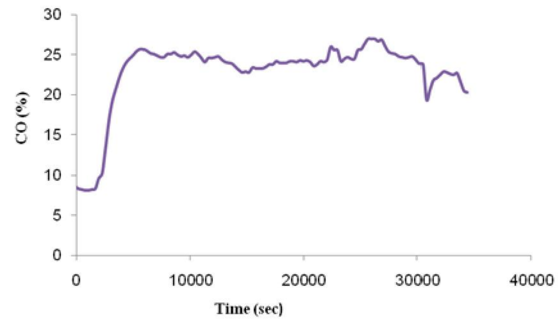
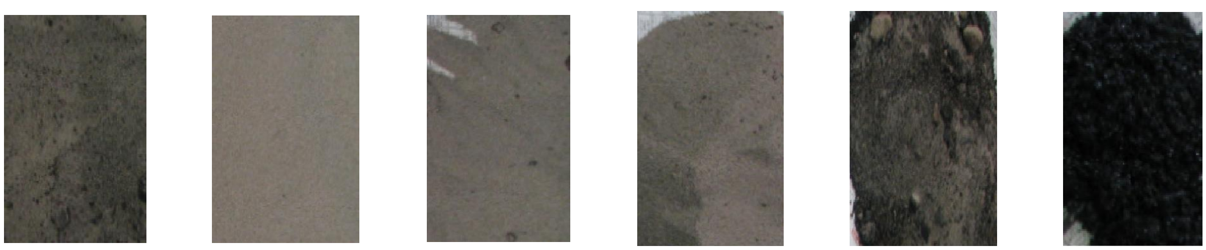


Figure 11- Carbon monoxide concentration in the effluent gas vs. time

In addition, Figure 12 shows rock appearance after the in-situ combustion process from the top of the combustion tube.



20-0 cm 20-40 cm 40-60 cm 60-80 cm 90-80 cm 90-100 cm

Figure 12 – Rock appearance after the in-situ combustion process

Figure 13 - Coke formed during the experiment

Also, Figure 14 shows upper part of the combustion tube before and after the in situ combustion process.


upper part of the combustion tube after combustion process


upper part of the combustion tube after combustion process

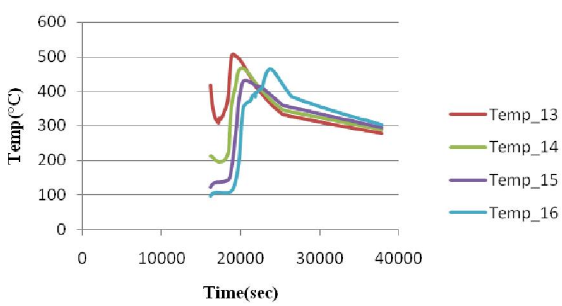

upper part of the combustion tube before combustion process

Figure 14 - Upper part of the combustion tube before and after the in-situ combustion process

4. Discussions

In the second test comparing to the first one, packing force of sample rose and the crude oil was very hot, unlike the first test. Consequently, the test was successful and the system was not blocked during the test. Therefore, we can conclude that the movement of particles due to poor packing and blockage of the path of oil production due to production of some cold oil, was the main reason to plug the system in the first test.

In the first test, it was observed during the experiment that the combustion front temperature of the fourth thermocouple gradually reduced and when the combustion front reached the seventh thermocouple the system was plugged. At this time the seventh to the twentieth thermocouple temperature decreased and the sixth thermocouple temperature increased. In the second test, as shown on Figure 13, the temperature of the 13^{th} to 15^{th} thermocouple combustion front gradually dropped. In addition, when the combustion front was in the 15^{th} thermocouple, blockage occurred for a few minutes but quickly the plug was removed and the path opened.



So it can be concluded that one sign of a blocked system is gradually reducing the combustion front temperature.

Average temperatures of the combustion front in the first and second tests were 480.75°C and 458.5°C respectively. This shows that the low-temperature oxidation reaction (LTO) that is an endothermic reaction and harmful for the in situ combustion process, has not occurred during the test. Also the amount of produced oil in the in-situ combustion process was about 84% at the end of the second test. After the success obtained in the experimental studies, it is concluded that in-situ combustion can be as an important option for development and exploitation of heavy oil carbonate reservoirs.

After opening the combustion tube's door at the end of the first and second tests, it was observed that the rock color has changed; But stone has kept its structure. This indicates that the degradation temperature of the reservoir is up to 566.1°C.

Conclusion

1) The results showed that in situ combustion process for this heavy oil carbonate reservoir can be feasible.

2) An indication of a plugged system can be gradually reduction of temperature of the combustion front.

3) Particle movement due to poor packing and blockage of the path due to production of cold oil are the main reasons for plug of the system.

4) No decomposition of the reservoir rock occurs in the in-situ combustion process.

Corresponding Author:
Mohammad Masoumi[1]
Department of Petroleum Engineering,
Science and Research Branch,
Islamic Azad University,
Tehran, IRAN.
TEL: +98-9177048972
Email: m.masoumi46@yahoo.com

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