Technological Prospecting for Enhanced Oil Recovery Methods in Onshore Scenarios for the Brazilian Field Application – A Literature Review

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Enhanced oil recovery (EOR) methods are adopted when the reservoir is not auto-sufficient energetically or even after secondary oil recovery and the reservoir is not producing satisfactorily. This article aims to perform a literature review of EOR methods, starting from the applied techniques worldwide in onshore fields and proposing implementation in Brazilian onshore scenarios. This initial work studied polymer flooding combustion in situ and cyclic steam in onshore fields. The most promising studied method was combustion in situ due to its higher recovery factor. However, further studies are necessary to understand better more cases of EOR methods applied in onshore scenarios.
Keywords: Onshore. EOR. Polymer Flooding. *In situ* Combustion. Cyclic Steam.

Introduction

Oil use has been presented in the history of human life since antiquity. However, the Nineteenth century became an energy source on a large scale nowadays due to its versatility and wide usability. However, this energy source is not renewable, and after continuous production, oil reservoirs mature, and consequently, its production declines and becomes not economically viable. Therefore, it is necessary to use non-conventional oil recovery methods [1].

Enhanced oil recovery (EOR) methods are implemented when reservoirs cannot produce satisfactory using their energy or after a secondary recovery method. Among these EOR methods, thermal methods provide heat to the reservoir, raising the temperature to reduce the oil viscosity and allowing higher mobility. As examples of EOR thermal methods, we can cite cyclic steam injection and *in situ* combustion [2-4].

Another way to improve the oil recovery factor is by injecting chemical agents, such as polymers and surfactants. This method usually changes the property of the injected fluid to increase its viscosity, reducing the injected fluid's mobility and consequently generating a better oil sweep. Another approach of this method changes the wettability alteration of the reservoir or interfacial tension between oil/water by chemical adsorption in the surface reservoir and oil/water interface, respectively [1,5].

In this context, this article aims to perform a literature review of advanced oil recovery methods used worldwide to identify the most promising method for later implementation in Brazilian onshore fields. In this initial work, we studied and understood EOR methods such as polymer flooding, in-situ combustion, and cyclic steam injection for further possible application in Brazilian onshore scenarios.

Materials and Methods

This paper provides a literature review of the most used EOR in onshore scenarios. We conducted the research from April to August 2021. First, we investigated the main methods of enhanced oil recovery to increase the oil recovery factor in onshore fields worldwide. The selected keywords to find the papers, articles, and all material used in this work were: Enhanced Oil Recovery; EOR; and Onshore. The combination of these three elements provides the following search string: [(Enhanced Oil Recovery OR EOR) AND Onshore")]. The inclusion criteria used to develop this literature

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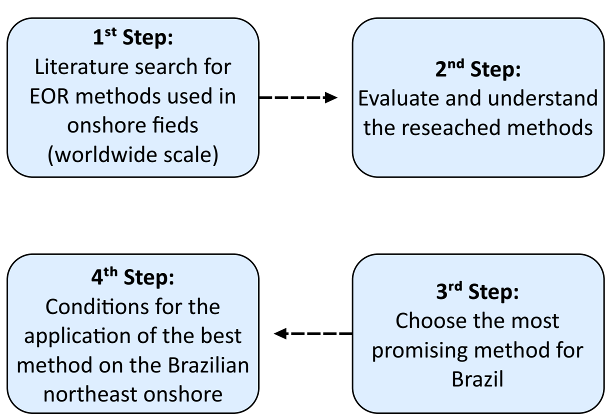
review were: (i) Only articles in Portuguese or English language were mapped; (ii) EOR methods worldwide were considered; (iii) Only articles from 2011 to 2021 were considered. The exclusion criteria were: (i) EOR methods applied on offshore fields; (ii) articles with titles and abstracts not compatible with the objective of this research. The search base of this work was: ScienceDirect, OnePetro, COBEQ (Congresso Brasileiro de Engenharia Química), and Scholar google in general. The first base provided 1,110 articles, then 1,061, 1, and 6,740 at the final. The sum of the three platforms results in 7912 works. We chose three papers based on their application for this initial study.

After all this stage, we herein evaluate and understand each EOR method already used in different countries to use the promising method in Brazil's onshore scenarios. We critically analyze each case reported in the literature (Figure 1).

Figure 1. Description of literature research methodology.



Results and Discussion

This section presents a brief literature review of three EOR methods applied in different countries in onshore fields. We used only journals and cases applied in the field in this systematic mapping.

Polymer Flooding

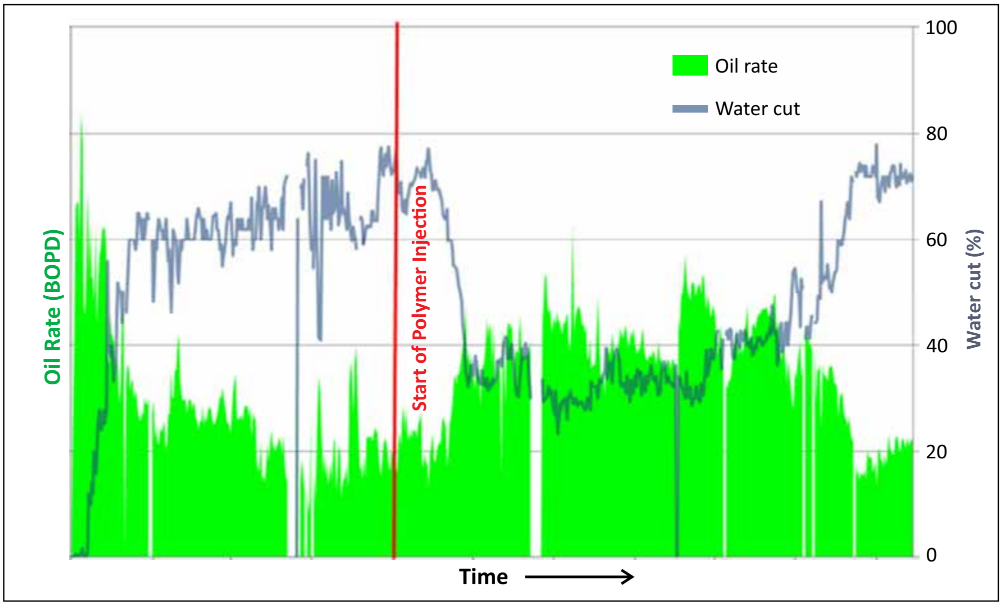
Polymer injection is an advanced oil recovery method used worldwide for several decades. The injected polymers increase the viscosity of the injected water, improving the oil-water mobility ratio. In addition, it brings the viscosity closer to the oil to achieve a unity mobility rate, enabling a more significant oil recovery due to the efficiency of the vertical sweep and the larger water injection area [6,7]. Prasad and colleagues (2014) performed a study in Mangala (India), which contains sweet crude oil, where its density ranges from 20 to 28º. API and implementation of hot water injection from the beginning of production, aiming to keep the pressure of the reservoir. After evaluations, a 60% water cut and simulation studies verified that Mangala field was a candidate for a polymer injection such as the EOR method, making it possible to conduct a pilot project. This trial consisted of 8 wells, four injectors, one producer, and three for observation, this last type with a 100m x 100m area. The pilot project results showed that the addition of the polymer matched the expectations and was promising, with an increase in oil recovery and a decrease in the water cut (Figure 2).

After the positive pilot project results, the authors intend to inject polymer throughout the field. The results obtained from the simulation (Figure 3) demonstrated a higher oil sweep in polymer injection compared to hot water injection. It occurs due to the rising water viscosity, which becomes closer to the oil viscosity, thus improving the ratio of oil-water mobility.

In situ Combustion (ISC)

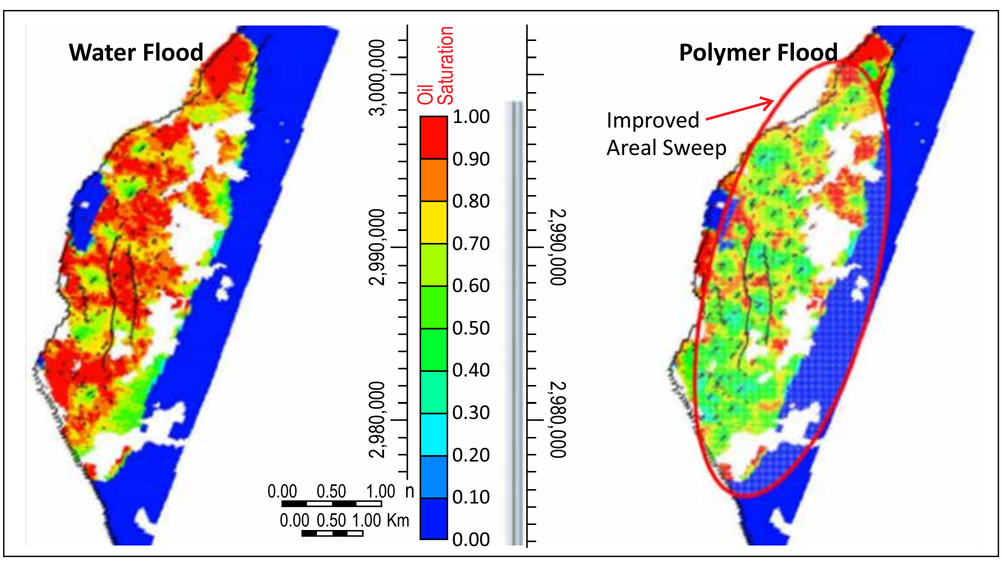
In heavy oil reservoirs, an appropriate oil recovery method is in-situ combustion. In this process, the oxygen in the injected air reacts with the hydrocarbons in the reservoir, releasing heat in the combustion zone. Then, the heat released vaporizes the lighter fraction of the oil, forming a steam zone that heats it, decreasing its viscosity. This process allows it to move towards the producing well, forming a zone of heated oil, and

Figure 2. Pilot project performance.



Source: Prasad and colleagues (2014) [5].

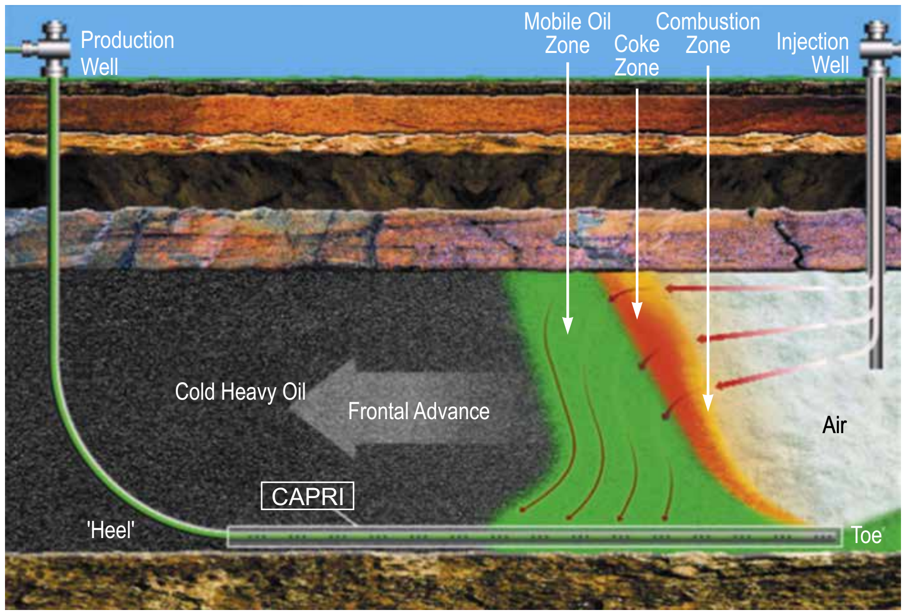
Figure 3. Improved areal sweep in one of the top layers in Mangala after ten years of polymer flooding.



Source: Prasad and colleagues (2014) [5].

the water in the reservoir is also heated. Gases from the combustion reaction, oil vaporization, and water steam are also sought with the oil [2,8]. Using the STARS simulator ("Steam, Thermal, and Advanced Processes Reservoir Simulator") from the CMG group ("Computer Modelling Group"), Rocha and colleagues (2014) conducted a study of an *in situ* combustion application in a homogeneous reservoir with similar characteristics of Brazilian's northeastern. This work aims to analyze the recovery of oil and the percentage of oxygen consumed, varying the air injection flows, the completion of the injector well, and oxygen concentration. The process begins with air injection in the reservoir to ignite part of the existing oil, producing heat. In this technique, the air is injected through a vertical well while a horizontal well extracts the oil, called the Toe-To-Heel Air Injection (THAI) (Figure 4).

Figure 4. Schematic of the THAI™ and CAPRI™ processes showing the vertical air injector, combustion zone, coke zone, mobilized oil zone, and the catalyst-lined horizontal production well.



For better analysis of the influence of each parameter, the authors created a table containing the 18 simulated cases, considering the variation of injection flow, well completion, and oxygen concentration. We organized the cases in a decreasing way of the oil recovery factor (%FR) found in 20 years of production (Figure 5).

Among the simulated cases, the best result achieved was when oxygen concentration and air injection flow at a minimum level were 21% and 15,000 m³ std/day, respectively. We plotted a Pareto diagram to verify the influence of each of the variables (Figure 6). We checked it when the oxygen concentration had the most significant effect on the oil recovery factor (%Fr) and related to the excellent completion configurations, and the lower completion demonstrated the best results.

Cyclic Steam

Cyclic steam injection is a process that performs a good stimulation that involves the transfer of heat to the reservoir near the wellbore by a periodical injection of steam [9,10]. Beallessio and colleagues (2021) reported using cyclic steam as an advanced recovery method (EOR) in Kazakhstan. By possessing heavy oil in shallow depths, the Kenkiyak field was an excellent candidate for this EOR method, and since 1975 wet steam (saturated) has been injected into the well, obtaining good results. In 2006, a pilot project using an overheated cyclic steam injection proved promising. This method was able to increase 61.9% the oil recovery rate.

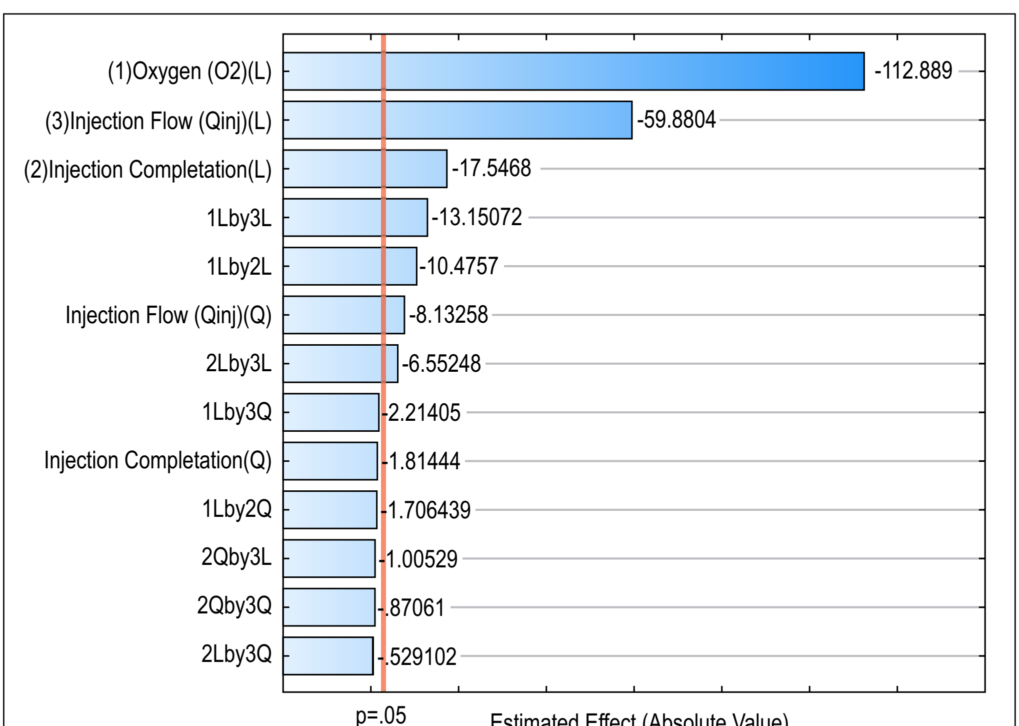
This advantage is due to the temperature of overheated steam, which is higher than the water boiling temperature. This fact allows it to travel through the surface infrastructure, decreasing until the well and not condensing, despite the heat loss, reducing the viscosity of the oil and increasing recovery. However, this process has a more efficient sweep concerning saturated steam, and more combustible gas is needed to generate overheated steam compared to the expenditure on saturated steam, increasing the financial cost. Table 1 compiles the methods found, referring to each country that has used the aforementioned methods, the size of the field, and the additional recovery factor found.

Figure 5. Recovery factor for simulated cases.

	O_2 Consumption	Injection Flow	Injection Completion	RF(%) 5 years	RF(%) 10 years	RF(%) 15 years	RF(%) 20 years
Case 13	21%	15,000	Bottom	2.38	17.00	58.12	63.09
Case 1	21%	15,000	Top	2.09	5.68	59.00	63.00
Case 7	21%	15,000	Middle	2.22	10.27	58.00	62.89
Case 14	21%	20,000	Bottom	2.38	43.46	59.00	59.77
Case 2	21%	20,000	Top	2.05	43.10	57.81	59.12
Case 8	21%	20,000	Middle	2.22	42.92	58.00	59.00
Case 15	21%	25,000	Bottom	6.27	52.59	56.77	57.16
Case 9	21%	25,000	Middle	5.55	52.24	55.73	56.37
Case 3	21%	25,000	Top	4.50	52.64	55.00	56.01
Case 16	50%	15,000	Buttom	20.06	52.86	53.73	54.44
Case 10	50%	15,000	Middle	19.60	51.73	52.62	53.83
Case 4	50%	15,000	Top	19.06	49.87	51.14	52.90
Case 17	50%	20,000	Buttom	33.35	50.47	51.87	52.17
Case 18	50%	25,000	Buttom	41.12	49.28	51.07	51.31
Case 11	50%	20,000	Middle	33.12	48.64	49.95	50.84
Case 5	50%	20,000	Top	32.82	46.65	48.17	49.56
Case 12	50%	25,000	Middle	40.58	47.32	48.98	49.48
Case 6	50%	25,000	Top	39.43	45.49	46.94	47.97

Source: Rocha and colleagues (2014) [3].

Figure 6. Pareto diagram of operational variables.



Purpose Function: oil recovered in 20 years.
Source: Rocha and colleagues (2014) [3].

Table 1. The method used in each country.

Countries	EOR Method	Field Size/Oil in Place	Additional Recovery Factor
India	Polymer Flooding	100 m x 100 m	~ 55%
Kazakhstan	Cyclic Steam	-	61.9%
Brazil	*In situ* Combustion	100 m x 100 m	63.9%

Conclusion

This initial study found in-situ combustion to be the most promising EOR method for onshore scenarios due to its higher oil recovery factor. However, to better understand the research topic and identify the best EOR technique for Brazilian onshore fields, it is necessary to study more articles and cases beyond the methods already mentioned. In parallel, we also intend to provide an economic feasibility study to evaluate the implementation of these methods in the Brazilian northeastern onshore fields.

Acknowledgments

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