TECHNOLOGICAL PROSPECTING FOR ENHANCED OIL RECOVERY METHODS IN ONSHORE SCENARIOS FOR THE BRAZILIAN FIELD APPLICATION – A LITERATURE REVIEW

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Abstract: We adopted the Enhanced oil recovery (EOR) methods 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 onshore fields 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.

PROSPECÇÃO TECNOLÓGICA PARA MÉTODOS DE RECUPERAÇÃO AVANÇADA DE ÓLEO PARA EM CENÁRIOS ONSHORE PARA APLICAÇÃO NO CAMPO BRASILEIRO – UMA REVISÃO DA LITERATURA

Resumo: Métodos de recuperação avançada de óleo (EOR) são implementados quando o reservatório não é energeticamente autossuficiente ou mesmo após a recuperação secundária de óleo, o reservatório é incapaz de produzir de forma satisfatória. Nesse contexto, este artigo tem como objetivo realizar uma revisão da literatura sobre os métodos de EOR, a partir das técnicas aplicadas em campos onshore em todo o mundo, visando sua implementação em cenários onshore brasileiros. Neste trabalho inicial, estudamos injeção de polímero, combustão in-situ e vapor cíclico, todos processos aplicados em campos terrestres. O método estudado mais promissor foi a combustão in-situ, devido ao seu maior fator de recuperação. Porém, para um melhor entendimento do tema de pesquisa, é necessário estudar mais casos de métodos de EOR aplicados em cenários onshore.

Palavras-chave: Onshore, EOR, Injeção de Polímero, Combustão In-situ, Vapor Cíclico.

1. INTRODUCTION

Oil has been presented in the history of human life since antiquity. This energy source has its use on a large scale since the nineteenth century, and it has been used until nowadays due to its versatility and wide usability. However, this energy source is not renewable, and after continuous production, oil reservoirs become mature, and consequently its production declines and it 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 are unable to produce satisfactory using just their energy, or after secondary recovery method has been implemented. Among these EOR methods, there are thermal methods that provide heat to the reservoir, raising the temperature to reduce the oil viscosity, 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 oil recovery factor is through injection of chemical agents, such as polymers and surfactants. This method, usually, changes the property of the injected fluid to increase its viscosity and therefore reducing the injected fluid 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 in onshore fields all over the world to identify the most promising method for later implementation in Brazilian onshore fields. In this initial work, we studied and understood EOR methods as polymer flooding, in-situ combustion, and cyclic steam injection for further possible application in Brazilian onshore scenarios.

2. METHODOLOGY

This paper provides a literature review of the most used EOR in onshore scenarios. The research was conducted from April to August of 2021.

First, we investigated the main methods of enhanced oil recovery to increase the oil recovery factor in onshore fields on a worldwide scale. 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, provide the following search string: (("Enhanced Oil Recovery " OR "EOR") AND " Onshore ").

The inclusion criteria used to develop this literature 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 title and abstract not compatible with the objective of this research.

The search base of this work was: ScienceDirect, OnePetro, COBEQ (Congresso Brasileiro de Engenharia Química), Scholar google in general. The first base provided 1110 articles, the second 1061, the third 1, and the fourth one, 6740. The sum of the three platforms results in 7912 works. We chose 3 papers based in their application for this initial study.

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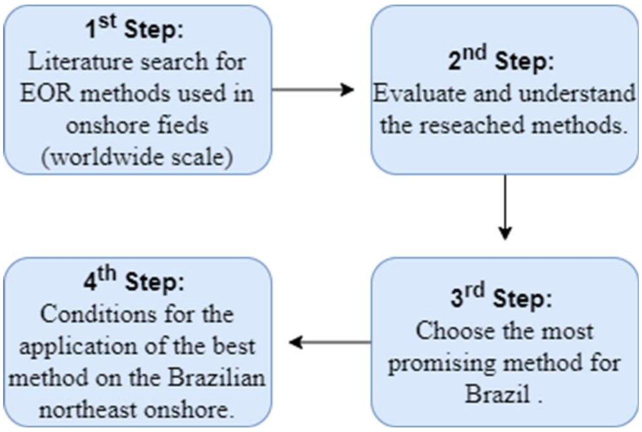
After all this stage, we herein evaluate and understand each EOR method already used in different countries to afterwards use the promising method in Brazil onshore scenarios. We make a critical analysis of each case reported in the literature as presented in block diagram of Figure 1.

Figure 1. Description of literature research methodology.



3. RESULTS AND DISCUSSION

In this section, it is presented a brief literature review of three EOR methods applied in different countries in onshore fields. In this systematic mapping, only journals and cases that were applied in the filed were considered.

3.1 Polymer Flooding

Polymer injection is an advanced oil recovery method used around the world for several decades. The injected polymers increase the viscosity of the injected water, improving the oil-water mobility ratio, bringing it closer to the viscosity of the oil, to achieve a unity mobility rate, enabling a greater oil recovery due to the efficiency of the vertical sweep and the area of water injection being larger [6,7].

The work of Prasad et al. (2014) was performed in the Mangala field in India, which contains sweet crude oil, where its density ranges from 20 to 28º API and an implementation of a 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 EOR method, making it possible to conduct a pilot project. This trial consisted of 8 wells, being four injectors, one producer and three for observation, this last type with a 100m x 100m area. The results of the pilot project showed that the addition of the polymer matched the expectations and was promising, with the increase of oil recovery and decrease of the water cut, as shown in Figure 2.

Figure 2. Pilot project performance.

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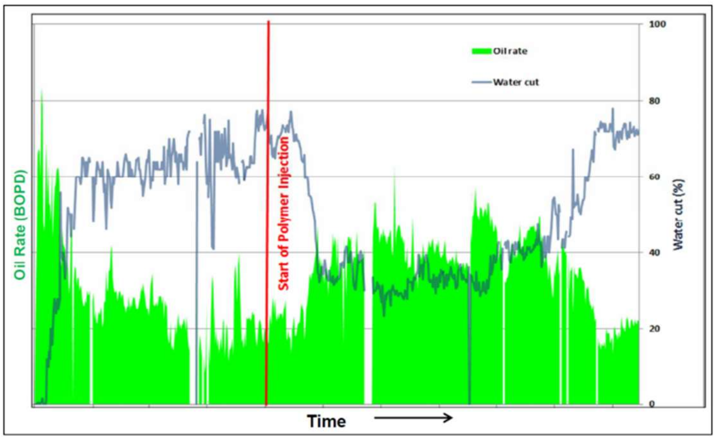
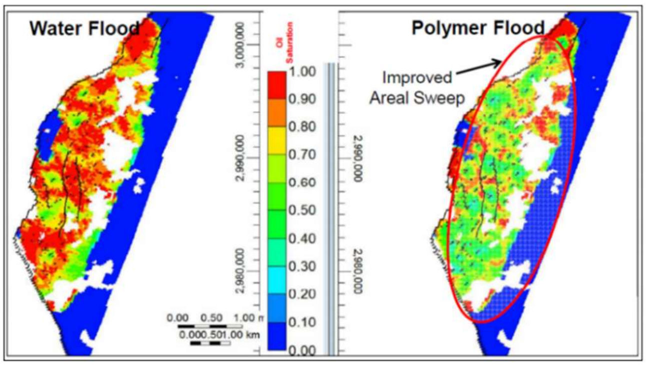


Prasad et al. (2014)

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

Figure 3. Improved Areal Sweep in One of the top Layer in Mangala after 10 years of Polymer Flooding.



Prasad et al. (2014)

3.2 In-situ Combustion (ISC)

In heavy oil reservoirs, an appropriate method of oil recovery is in-situ combustion. In this process, the oxygen present in the injected air reacts with the hydrocarbons into 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 the oil decreasing its viscosity. This process allows it to move towards the producing well, forming a zone of heated oil and the water present 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 et al. (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

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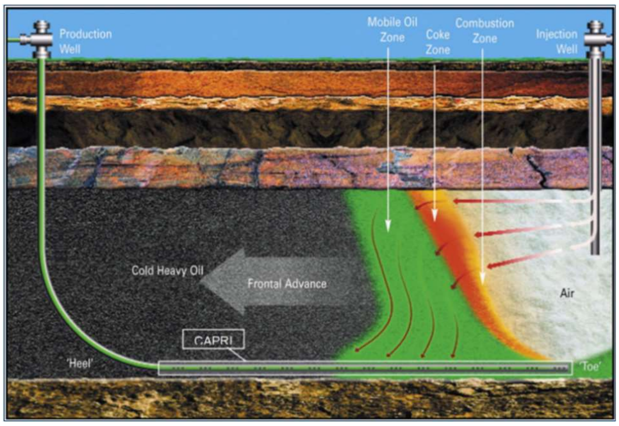
analyze the recovery of oil and the percentage of oxygen consumed, varying the air injection flows, the completion of the injector well and oxygen concentration.

The process begins from air injection in the reservoir in order to ignite part of the existing oil, producing heat. In this technique, the air is injected through a vertical well while the oil is extracted by a horizontal well, called the Toe-To-Heel Air Injection (THAI), illustrated in 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.



KENDALL (2009)

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. The cases were organized in a decreasing way of the oil recovery factor (%FR) found in 20 years of production. The cases are described in Figure 5.

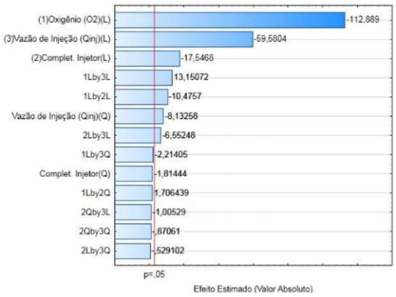
Figure 5. Fator de recuperação para casos simulados.

	C.Oxigênio	Vazão	Completação	FR (%) 5anos	FR (%) 10anos	FR (%) 15anos	FR (%) 20anos
Caso 13	21%	15000	Inferior	2,38	17,00	58,12	63,09
Caso 1	21%	15000	Topo	2,09	5,68	59,00	63,00
Caso 7	21%	15000	Meio	2,22	10,27	58,00	62,89
Caso 14	21%	20000	Inferior	2,38	43,46	59,00	59,77
Caso 2	21%	20000	Topo	2,05	43,10	57,81	59,12
Caso 8	21%	20000	Meio	2,22	42,92	58,00	59,00
Caso 15	21%	25000	Inferior	6,27	52,59	56,77	57,16
Caso 9	21%	25000	Meio	5,55	52,24	55,73	56,37
Caso 3	21%	25000	Topo	4,50	52,64	55,00	56,01
Caso 16	50%	15000	Inferior	20,06	52,86	53,73	54,44
Caso 10	50%	15000	Meio	19,60	51,73	52,62	53,83
Caso 4	50%	15000	Topo	19,06	49,87	51,14	52,90
Caso 17	50%	20000	Inferior	33,35	50,47	51,87	52,17
Caso 18	50%	25000	Inferior	41,12	49,28	51,07	51,31
Caso 11	50%	20000	Meio	33,12	48,64	49,95	50,84
Caso 5	50%	20000	Topo	32,82	46,65	48,17	49,56
Caso 12	50%	25000	Meio	40,58	47,32	48,98	49,48
Caso 6	50%	25000	Topo	39,43	45,49	46,94	47,97

Rocha et al. (2014)

Among the simulated cases, the best result was achieved when oxygen concentration and air injection flow at minimum level were 21% and 15,000 m³ std/day, respectively. A Pareto diagram was plotted to verify the influence of each of variables and is shown in Figure 6. It can be seen that the oxygen concentration had the greatest effect on oil recovery factor (%Fr) and related to the well completion configurations, the lower completion demonstrated the best results.

Figure 6. Pareto Diagram of Operational Variables- Purpose Function: oil recovered in 20 years.



Rocha et al. (2014)

3.3 Cyclic Steam:

Cyclic steam injection is a process that performs a well stimulation which involves the transfer of heat to the reservoir near the wellbore by a periodical injection of steam [9, 10].

The use of cyclic steam as an advanced recovery method (EOR) in Kazakhstan was reported by BEALESSIO et al. (2021). By possessing a heavy oil in shallow depths, Kenkiyak field was an excellent candidate for this EOR method, and since 1975 wet steam (saturated) is injected into the well, obtaining good results. In 2006, a

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pilot project using an overheated cyclic steam injection showed to be 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 condense, despite the heat loss, reducing the viscosity of the oil and increasing recovery. However, this process has a more efficient sweep in relation to saturated steam, 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 afore mentioned methods, the size of the field and the additional recovery factor found.

Table 1. 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%

4. CONCLUSION

From this initial study, in-situ combustion was found to be the most promising EOR method for onshore scenarios due to its higher oil recovery factor. However, for better understanding of the research topic and to be able to 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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5. REFERENCES

[1] MARQUES, Landson Soares et al. Prospecção tecnológica sobre recuperação avançada de petróleo (EOR) com associações de fluídos de naturezas químicas diferentes. **Cadernos de Prospecção**, v. 7, n. 2, p. 247, 2014.

[2] ARAÚJO, Edson de Andrade. **Estudo do processo de combustão in-situ usando poços horizontais como produtores de óleo (Toe-to-Hell Air Injection)**. 2012. Dissertação de Mestrado. Universidade Federal do Rio Grande do Norte.

[3] ROCHA, M. L.; ARAÚJO, E. A.; BARILLAS, J. L. M. Estudo Da Combustão In-situ Em Reservatórios Com Características Do Nordeste Brasileiro. In: **XX Congresso Brasileiro de Engenharia Química, Florianópolis, SC. 2014.**

[4] BEALESSIO, Bianca Anne et al. A review of enhanced oil recovery (EOR) methods applied in Kazakhstan. **Petroleum**, v. 7, n. 1, p. 1-9, 2021.

[5]PRASAD, Dhruva et al. Pilot to Full-field Polymer Application in One of the Largest Onshore Field in India. In: **SPE Improved Oil Recovery Symposium.** OnePetro, 2014.

[6]SILVA, Ivonete Gonzalez et al. Polymer flooding: a sustainable enhanced oil recovery in the current scenario. In: **Latin American & Caribbean Petroleum Engineering Conference**. OnePetro, 2007.

[7]FIROZJAII, Ali Mohsenatabar; SAGHAFI, Hamid Reza. Review on chemical enhanced oil recovery using polymer flooding: Fundamentals, experimental and numerical simulation. **Petroleum**, v. 6, n. 2, p. 115-122, 2020.

[8]KENDALL, Rob. Using timelapse seismic to monitor the THAI™ heavy oil production process. In: **SEG Technical Program Expanded Abstracts 2009**. Society of Exploration Geophysicists, 2009. p. 3954-3958.

[9]ALIKHLALOV, Kamil; DINDORUK, Birol. Conversion of cyclic steam injection to continous steam injection. In: **SPE Annual Technical Conference and Exhibition**. OnePetro, 2011.

[10]MUÑOZ, Miguel. Current overview of cyclic steam injection process. 2013.