Analysis of enhanced oil recovery of mature oil fields and gas: using the analytic hierarchy process

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Abstract
In the oil and gas sector there are multiple techniques and methods of oil recovery that can be implemented to increase efficiency in oil production. The objective of this research is then examines the methods of special oil and gas recovery from mature wells used in order to know the most appropriate method following environmental criteria. Therefore this analysis is used in the multi-criteria method of analytic hierarchy process (AHP) developed by Thomas L. Saaty. As a result it has to be the most appropriate method following environmental criteria is the biological followed by miscible, thermal and lastly chemical methods. This result can be used in decision-making as a parameter to choose the special recovery methods.

Keywords: Oil and gas, EOR, AHP

INTRODUCTION

According to Wolff (2008) at the Academy, as the business community is frequently the need for decision-making. An example can be cited the decision making in choosing projects, prioritization of investment, economic strategies, choice of techniques and methods, location of facilities, factory sizing and employees. When it comes to the business community decisions usually makes the decision based primarily on costs. In fact the cost is an important criterion in a project, but there are other criteria that may be important for decision making. These criteria may be quantitative or qualitative, tangible or intangible. When you have more than one evaluation criterion for decision-making analyses are directed to the Multicriteriais studies.

In the oil and gas sector there are multiple techniques and methods of secondary oil recovery that can be implemented to increase efficiency in oil production. Among them are the special methods or tertiary recovery methods.

The overall objective of this research is to analyse the methods of special oil and gas recovery from mature fields used in order to know the most appropriate method following environmental, economic and social criteria. The specific objectives are:

- Study the existing and being implemented in mature fields methods;
- Collect data through similar information necessary to make the AHP;
- Review by the method of AHP;

METHODOLOGY

The analysis is understood in this qualitative study aimed mainly to the most appropriate choice of a process capable of recovering more efficiently and effectively oil and gas from mature fields / marginal. This choice will be made by Process Analytic Hierarchy methodology modelled after Thomas L. Saaty. The basic principle of the hierarchical analysis is that a decision-making problem can be structured in a hierarchical manner, where the top of the hierarchy has its general description and the levels are below the criteria or attributes that are considered for analysis. These criteria may be divided into other criteria and so forth. The last level of the hierarchical structure will be found alternatives highlighted in the hierarchical analysis. The positioning of the alternatives in the base means they will be analysed individually, with the vision of those criteria and sub-criteria in the outer branches of the analysis of the structure. Thus the decision problem will be subdivided into smaller problems that will be analysed separately and in the end will be put together to aggregate the main problem.

Ending the definition of the criteria to be used, the problem can be analysed into smaller parts, the effects of perceived criteria in different ways. As an example we can deliver the specific aspects for area specialists' study, which will evaluate your area more properly, or can be studied in the literature and fetch data that give a valid proposition.

The comparison between two elements AHP may be performed in different ways. Among them the use of the scale of relative importance between two alternatives proposed by Saaty (2008) is the most widely used. Assigning values ranging from 1 to 9, the scale determines the relative importance of alternative with respect to each other.

From the data provided by the judge is constructed comparison matrix. The comparisons are subjective, which makes it necessary to evaluate the proximity between λ max and n. For such uses the ratio of consistency (RC), which is calculated as follows: CI = RC / CR. Where IC is = ((γ max-n)) / ((n-1)) and CR is the random consistency index.

If the consistency of the attributes of the comparison matrix is confirmed, the next step is to find what attribute is the most important in the opinion of the judge.

ANALYTIC HIERARCHY PROCESS

Problem definition, criteria, sub-criteria and alternatives

The problem in question this study is the analysis of alternatives from special recovery processes of oil and gas. The decision to be made is the choice of process or composition processes, more appropriate with regard to environmental and economic aspect. The criteria and sub-criteria were defined to meet the objective of the research, environmental aspects and efficiency are the criteria, energy consumption, water consumption, waste generation (solids, sewage, gas), process time, process cost and percentage of recovery are sub-criteria that will be analysed. Below is the figure 01 for AHP diagram illustration:

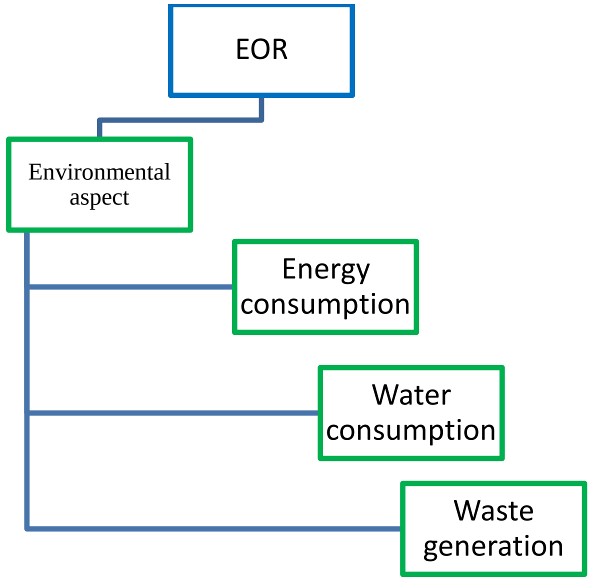

Figure 01 – Diagram of AHP

Enhanced oil recovery methods:

Figure 02 - Alternatives

Enhanced Oil Recovery

The special methods are divided into four categories: Thermal methods, miscible methods, chemical and biological methods.

According to Hernandez (2009) reservoirs whose eyes are very viscous, the use of a conventional recovery process inevitably results in failure.

The high oil viscosity hampers their movement within the porous medium, while the injected fluid, water or gas, and have a much higher mobility resulting in low sweep efficiencies and, consequently, a normally very low recovery. Initially, the research on thermal methods focused on reducing the viscosity of oil by heating to increase oil recovery. As other equally beneficial effects were appearing, the processes have been modified, resulting in various types of methods that currently have.

There are two types of thermal methods differ in the way how is the heating of the reservoir fluid. In one of the heat is generated on the surface and then carried into the formation using a fluid. It's called Heated Fluid Injection. In the other group the heat is generated inside the container itself from the existing there of the oil combustion. This second process is called in situ combustion.

According to Alvarado (2010) are some examples of recent steam injection projects reported in the literature are the "steamfloods" in Crude And Field in Trinidad published by Ramlal (2004), the oilfield Schoonebeek the Netherlands published by Jelgersma (2007).

Gillham et. al (1998) cited by Alvarado (2010) has shown in his research that applications successful combustion in situ in light oil reservoirs as West Hackberry in the US show that this recovery process is a viable strategy for EOR applied in high angle reservoirs Immersion combined with other techniques.

According Senocak et. al. (2008) when it comes to low efficiencies of displacement, ie the injected fluid cannot remove the oil out of the pores of the rock due to high interfacial tensions, miscible methods are indicated. These are processes which seek to significantly reduce and if possible eliminate the interfacial tensions.

The methods concerned with the miscible fluid injection which may become or are miscible with the oil tank, so that there are no interfacial tensions. In this way, the oil will be completely moved out of the area that is contacted by the injected fluid. The fluids that may be used in miscible displacement is preferably carbon dioxide, natural gas and nitrogen.

Zubari et. al (2003) cites as chemical methods some processes that presupposes a certain chemical interaction between the injected fluid and the reservoir fluids. These are: the injection of polymers, surfactant solution, injection microemulsion, alkaline injection solution, etc. Tabary et. al (2009) there is no single point of attack as in other categories, and some processes could be framed within the miscible methods.

According Curbelo (2006) microbiological recovery of hydrocarbons (Microbial Enhanced Oil Recovery - MEOR) is the addition of bacteria by the injection of water in the formation. The increase in production can be made by biological or biochemical effects.

With regard to biological effects, the bacteria in contact with the aqueous medium filled with nutrients, perform metabolic reactions include the breakage of longer chains of hydrocarbons, producing a lighter oil, is equivalent to a biological oil cracking.

Comparison of alternatives to criteria

Energy consumption

So then we have the order of priorities in energy consumption:

- Chemicals scored as the highest value 5;
- Biological punctuated with the second value 5;
- Thermal set to 1;
- Miscible with the value 3.

Array of preferences - criteria and normalization of the matrix:

Table 01: preferably the criterion energy consumption Matrix.

	Thermal	**Miscible**	**Chemical**	**Biological**	**PML**
Thermal	1,00	3,00	5,00	5,00	0,58
Miscible	0,33	1,00	1,67	1,67	0,19

Chemical	0,20	0,60	1,00	1,00	0,115
Biological	0,20	0,60	1,00	1,00	0,115
SUM	1,73	5,20	8,67	8,67	

Normalized matrix

$$\begin{vmatrix} 0,58 & 0,58 & 0,58 & 0,58 \\ 0,19 & 0,19 & 0,19 & 0,19 \\ 0,12 & 0,12 & 0,12 & 0,12 \\ 0,12 & 0,12 & 0,12 & 0,12 \end{vmatrix} \quad (1)$$

Obtain the V matrix (following table IR = 0.9):

Table 02: consistency ratio of the cost of the process criterion.

AV	ƛmáx	IC	RC
2,31 0,77 0,46 0,46	4,0005	0,00016	0,00018

Saaty (2008) suggests that a ratio of consistency is acceptable (RC) lower than 0.10. That is, 0.00018 consistent.

Water consumption

So then we have the order of priority in water consumption:

- Miscible scored as the highest value 3;
- Thermal punctuated with the second value 5;
- Biological the value 7;
- Chemicals with the value 1.

Array of preferences - criteria and normalization of the matrix

Table 03: Preferences criteria matrix water consumption

X	Chemical	Miscibles	Thermal	Biological	PML
Chemical	1,00	3,00	5,00	7,00	0,59

Miscibles	0,33	1,00	1,50	2,50	0,20
Thermal	0,20	0,60	1,00	1,50	0,12
Biological	0,14	0,50	0,80	1,00	0,09
SUM	1,68	5,10	8,30	12,00	

Normalized matrix

0,60	0,59	0,60	0,58
0,20	0,20	0,18	0,21
0,12	0,12	0,12	0,13
0,09	0,10	0,10	0,08

(2)

Obtain the V matrix (following table IR = 0.9)

Table 04: Consistency Ledger percentage criterion recovery.

AV	**ƛmáx**	**IC**	**RC**
2,42			
0,80	4,08	0,027	0,030
0,49			
0,37			

Saaty (2008) suggests that a ratio of consistency is acceptable (RC) lower than 0.10. That is, 0.030 is consistent.

Generation of waste

So then we have the order of priorities in waste generation:

- Chemicals scored as the highest value 1;
- Biological punctuated with the second value 3;
- Thermal with the value 5;
- Miscible with the value 7.

Array of preferences - criteria and normalization of the matrix

Table 05: preferences of discretion waste generation Matrix.

	Chemical	**Biological**	**Thermal**	**Miscible**	**PML**

Chemical	1,00	3,00	5,00	7,00	0,59
Biological	0,33	1,00	1,50	3,00	0,21
Thermal	0,20	0,60	1,00	1,40	0,12
Miscible	0,14	0,43	0,71	1,00	0,08
SUM	1,68	5,03	8,21	12,40	

Normalized matrix

$$\left| \begin{matrix} 0,60 & 0,60 & 0,61 & 0,56 \\ 0,20 & 0,20 & 0,18 & 0,24 \\ 0,12 & 0,12 & 0,12 & 0,11 \\ 0,09 & 0,09 & 0,09 & 0,08 \end{matrix} \right| \quad (3)$$

Obtain the V matrix (following table IR = 0.9)

Table 06: Consistency of discretion ratio waste generation

AV	λmáx	IC	RC
2,39 0,83 0,48 0,34	4,05	0,015	0,016

Saaty (2008) suggests that a ratio of consistency is acceptable (RC) lower than 0.10. That is, 0.016 is consistent.

Overall assessment of all alternatives

In defining the global objective criteria we can make the following weighting, the priority is that you have processes that consume less energy, less water and generate less waste. The priority is energy consumption, followed by waste generation and water consumption.

Table 07: Global objective of the environmental aspect criteria.

	Energy consumption	Water consumption	Waste generation	PML
Energy consumption	1,00	5,00	3,00	0,65
Water consumption	0,20	1,00	0,60	0,13

Waste generation	0,33	1,67	1,00	0,21
SUM	1,53	7,67	4,60	

Normalized matrix

$$\begin{vmatrix} 0{,}65 & 0{,}65 & 0{,}65 \\ 0{,}13 & 0{,}13 & 0{,}13 \\ 0{,}22 & 0{,}22 & 0{,}22 \end{vmatrix} \quad (4)$$

Table 08: Global Final evaluation of the alternatives the discretion of the environmental aspect.

X	**Energy consumption**	**Water consumption**	**Waste generation**	**Overall assessment**
Thermal	0,08	0,19	0,59	0,21
Miscibles	0,12	0,58	0,09	0,17
Chemicals	0,59	0,12	0,20	0,44
Biological	0,21	0,12	0,12	0,18

The order of priority in choosing the most suitable process following the environmental aspect parameters is shown in figure 03.

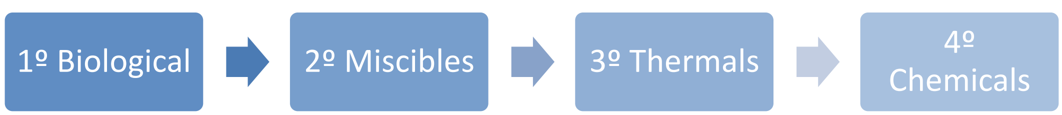

Figure 03: Order of priority in the choice of the recycling process.

In the final evaluation of alternatives following productive efficiency criteria we have as the most suitable method followed by the Biological miscible methods, thermal and lastly chemical.

CONCLUSION

With the analysis of special recovery methods were identified in order of suitability following environmental criteria such as energy consumption, water and waste generation through the technique of Analytic Hierarchy Process. The established order was: biological methods, followed by miscible methods, thermal and lastly chemical. This analysis can be used in decision-making in the oil and gas sector for the implementation of special recovery techniques.

Bibliography

Alvarado, V.; Thyne, G.; Murrell, G.R. 2008. Screening Strategy for Chemical Enhanced Oil Recovery in Wyoming Basins (SPE-115940). In Proceedings of SPE Annual Technical Conference and Exhibition, Denver, CO, 21–24.

Curbelo , S. D. F., 2006. Recuperação avançada de petróleo utilizando tensoativos. Tese de doutorado programa de pós graduação em engenharia química UFRN. 45-49.

Ernandez J. 2009. EOR Projects in Venezuela: Past and Future. Presented at the ACI Optimising EOR Strategy 2009, London, UK, 11–12.

Gillham, T.H.; Cerveny, B.W.; Fornea, M.A.; Bassiouni, D.Z. 1998. Low Cost IOR: An Update on the W. Hackberry Air Injection Project (SPE-39642). In Proceedings of SPE/DOE Improved Oil Recovery Symposium, Tulsa, OK, USA, 19–22.

Jelgersma, F. 2007. Redevelopment of the Abandoned Dutch Onshore Schoonebeek Oilfield With Gravity Assisted Steam Flooding (IPTC-11700). In Proceedings of International Petroleum Technology Conference, Dubai, 4–6.

Ramlal, V. 2004. Enhanced oil recovery by steamflooding in a recent steamflood project, Cruse "E" Field, Trinidad (SPE-89411). In Proceedings of 14th SPE/DOE IOR Symposium, Tulsa, OK, USA, 17–21

Senocak, D.; Pennell, S.P.; Gibson, C.E.; Hughes, R.G. 2008. Effective Use of Heterogeneity Measures in the Evaluation of a Mature CO2 Flood (SPE-113977). In Proceedings of SPE/DOE Symposium on Improved Oil Recovery, Tulsa, OK, USA, 20–23.

Saaty T. L. 2008. Decision making with the analytic hierarchy process. Int. J. Services Sciences, Vol. 1, No. 1 USA. 85-89.

Tabary, R.; Fornari, A.; Bazin, B.; Bourbiaux, B.; Dalmazzone, C. 2009. Improved Oil Recovery With Chemicals in Fractured Carbonate Formations (SPE-121668). SPE International Symposium on Oilfield Chemistry, The Woodlands, TX, USA, 20–22.

Zubari H.K.; Sivakumar, V.C.B. 2003. Single Well Tests to Determine the Efficiency of Alkaline Surfactant Injection in a Highly Oil-Wet Limestone Reservoir (SPE-81464). In Proceedings of 13th SPE Middle East Oil Show & Conference, Bahrain, Kingdom of Bahrain, 5–8.