

EOR SCREENING METHOD COMPARISON BETWEEN ANALYTICAL SCREENING AND QUALITATIVE SCREENING APPLICATION

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ABSTRACT

More than 60% of oil production in Indonesia come from the mature fields. Enhanced Oil Recovery (EOR) activities have been proven capable extending the economic life of the mature fields by significantly increase the oil production recovery. However, the success of EOR implementation in the field depends on the careful planning in the early stage by selecting the suitable EOR method that matches the reservoir characteristics. The purpose of this study is to provide a comparison of EOR screening using an application which combine static and dynamic conditions of the reservoir and able to perform the preliminary analysis needed for EOR planning in the early stage which also incorporates industry guidance as a reference of EOR method implementation in the field with similar reservoir characteristics. The study will be conducted in a field X clastic with single zone. This field will firstly be performed history matching and analytical screening before running the EOR screening application. In the EOR screening application, the field will be performed data validation and qualitative screening based on agent compatibility, macro ranking, pore scale ranking and industry guidance. Based on the application, the field X is more suitable to be injected by Polymer in the first rank and ASP in the second rank which is close to the analytical screening that results ASP in the first rank and Polymer in the second rank.

Keywords: *EOR Screening, Analytical Screening, Displacement Efficiency, Compatibility, Industry Guidance*

I INTRODUCTION

EOR or Enhanced Oil Recovery activities have been proven capable of extending the economic life of mature fields, by significantly increasing the oil recovery up to 35% to 60% in the other countries. However, the implementation of EOR activities requires large investment costs and sophisticated technology. A proper EOR planning in the initial stages is very important in reducing the risk of implementation failure and maximizing return on investment and this requires the selection of appropriate EOR methods (screening) and feasibility studies on a simulation scale before carrying out a pilot test which will require a lot of costs. In this study, the selection of the EOR method will be carried out using the EOR Screening & Decision (EOR S&D) application plugin – which is a part of the Petrel Reservoir Engineering software. This application is equipped with a comprehensive evaluation of static and dynamic reservoir conditions that can be calibrated with

the EOR project database global (2800 projects) to see the successful EOR projects for similar reservoir characteristics.

The field data being used has only one zone C and is located at depth 792.5 m (2600 ft) to 1309.6 m (4295 ft) TVDSS with lower structure at South East (SE) direction and top structure at North West (NW) direction. The oil water contact in this zone C is found at depth 1225 m (4019 ft) TVDSS. The salinity of the reservoir in field X is about 10000 ppm and the Net-to-Gross (NTG) value is 83.89% which indicate medium salinity and less clay content. In the initial condition at year 1961, the field X had oil saturation of 64.65%, before waterflood at year 1995, the oil saturation became 51.36% (reduced by 13.29%), and after waterflood at year 2019, the field X oil saturation became 43.59% (reduced by 21.06%) with total oil recovery 27.63% and remaining pressure at 677.62 psi. The field X model data after history matching will be inputted into the EOR S&D application.

1.1 Backgrounds

The topic of EOR method screening has been discussed by different authors with different levels of complexity and with different approaches, but in most cases, it gives contradictory results and is difficult to validate (Moreno, Jaime., et al., 2014). Many operators feel that the selection & ranking of EOR methods are difficult due to the high uncertainty, heterogeneity, and incomplete input data, thus it will require a long period of time to design the EOR. In addition, the selections of the current EOR method are also limited to the use of artificial neural network (ANN), machine learning and analytical analysis, which do not consider the static and dynamic conditions of the reservoir. Hence, this research will accommodate the EOR method selection by considering it and compare it with EOR database. And accordance to field X study case, this EOR screening and decision plugin will be compared to the analytical screening in determining the EOR method which suits the reservoir condition.

1.2 Objectives

The objective of this study is to compare the EOR method selection between the analytical screening from textbook with the application to perform EOR method screening by considering pore displacement efficiency, compatibility, macro scale filtering and industry guidance.

II. LITERATURE REVIEW

The general analytical screening of EOR method can be found from several references such as: Lyons, William C., et al (2016), Ahmed, Tarek and Meehan, D. Nathan., (2012), also Taber, J.J., and Martin, F.D. (1983). While, the EOR method classification has been discussed by several authors using a similar approach namely Bayesian & ANN (Suleimanov, BA, et al., 2016), Statistical Pattern Recognition (Afra, Sardar., Tarrahi. , M., 2016), Integrated Workflow IOR / EOR (Chen, Peila., et al., 2018), Fuzzy Logic as an Artificial Intelligence (Nageh, M., et

al., 2015) and Machine Learning (Tarrahi et al., 2015), and Integrated Screening with Risk Analysis (Al-Mayan, Haya., et al., 2016). However, of the overall selection methods available, there is no single platform or application that can produce a comprehensive analysis.

EOR screening & decision (EOR S&D) conducts detailed data and reservoir evaluation with a comprehensive process which support different reservoir types from single porosity to naturally fractured dual porosity reservoirs incorporating a large database of projects using EOR processes. According to Schlumberger (2017) and Moreno, Jamie et al (2014), in the qualitative screening of EOR S&D, the EOR screening is not only based on expert knowledge and experience of EOR database but also based on high-level rock-fluid compatibility and local displacement efficiencies for every EOR method. The screening is then performed whereby the Compatibility column is applied first, then the Macro scale filtering and Pore scaling ranking at the end. Industry guidance column shows the result of analogous field data mining in the global EOR project database. The color legend defined in the page shows the project frequency for training the method. The value indicates the confidence level of approaching the most frequent populations for each of the reservoir parameters. Compatibility shows whether the method is compatible with reservoir salinity. While, Macro scale filtering shows if the method is compatible with the area/formation geology type. Additionally, the Pore scale ranking, uses local displacement efficiency to rank all the user selected non-thermal methods in the Nonthermal analysis tab.

III. METHODOLOGY

Generally, after the data collection is complete, the data preparation should also be done to check the quality of the data, the correlations of the data into one another and complete the missing data which is required. After that, the history matching is firstly run by doing the initialization. If the model has been matched through history matching process, then run the EOR S&D application. There will be a question related to the reservoir, oil composition and operation consideration in the initial stage of screening. After that, the database of the similar EOR project can also be accessed through the software as another reference. Then, the software will generate EOR potential area and will generate the EOR ranking based on pore displacement efficiency, compatibility, macro scale and industry guidance. In the end, the interpretation result from analytical screening can be compared with the qualitative screening from EOR S&D.

According to Schlumberger (2017), when the history matched model is inputted into EOR S&D, the application will perform the following calculations:

- Calculate the average value of formation properties
 - Mean average (arithmetic average): for porosity, depth, pressure, R_s , and additional properties like fluid density, fluid viscosity, formation volume factor, net-to-gross, cell size (DX, DY, DZ) and pore volume (PORV).

- Mode average: for permeability (logarithmic mode average) & saturation.
- Viscosity calculation
- API calculation
- Calculate well spacing factor
 - Well spacing factor is formation area divided by number of connected wells to this formation, where the formation area is the formation volume divided by formation thickness.
- Identify EOR potential formations
EOR S&D checks all formations and identifies as EOR potential if:
 - There are more than 2 formation layers.
 - Formation well spacing factor is more than 200 acres.
 - Movable oil saturation by water is more than 10%.
 - Proportion of Rock quality (RQ) above range assigned as fair is more than 5%.
- Identify reservoir communications
In order to know if there are vertical communications among formations. EOR S&D identifies 2 formations as communicating formations by comparing if in these 2 formations:
 - More than 20% connecting cells have the same PVTNUM.
 - More than 20% connecting cells have the same EQLNUM.
 - More than 80% connecting cells have non-zero transmissibility.
- Classify formations based on rock quality
- Classify fracture types (for fracture model)
- Extract formation drive mechanism (optional)
- Calculate saturation function endpoints for areas of formation
 - EOR S&D extracts the Corey exponents from imported saturation function curve for each SATNUM.
 - The resulting Corey exponents and saturation function endpoints will be used in local displacement efficiency (LDE) calculations.
- Retrieve reservoir production history
 - EOR S&D reviews the reservoir production/injection history formation by formation and keeps mean value of well production/injection rates and maximum value of well production/injection rates. EOR S&D will use these values in RRE optimizations.
- Identify geology area
- Calculate reservoir volume for formation and areas
- Run screening algorithm

According to Schlumberger (2017), the reservoir volume calculations are as follow:

- Reservoir volume by water:

$$V_{oil\ by\ water} = \sum_{cell=1}^n (Remaining\ oil\ saturation\ SOWCR) PORV NTG \quad (I)$$

- Reservoir volume by gas:

$$V_{oil\ by\ gas} = \sum_{cell=1}^n (Remaining\ oil\ saturation\ SOGCR) PORV\ NTG \quad (II)$$

Table I. Geological properties and PVT data of the field X model

Geological Properties	Field (Reservoir/Tank)	Unit	PVT Data Summary		
			Properties	General	Unit
Grid Cell (nI x nJ x nK)	72 x 18 x 13		Initial Pressure	1744	Psi
Reservoir Depth	792.5 – 1309.6 m or 2600 – 4295 ft		Initial Reservoir Temperature	151	degF
			Reservoir Temperature after Water Injection	122	degF
OWC (Oil Water Contact)	1225	m	Oil Properties		
GOC (Gas Oil Contact)	-	m	Oil API	40.31	API
Average Porosity	0.1345	v/v	Oil Specific Gravity	0.824	-
Average Permeability -i	92.07	mD	Oil Density	724	Kg/m3
Average Permeability -j	92.07	mD	Pb	1298	Psi
Average Permeability -k	50.29	mD	Rsb	454	SCF/STB
Average NTG	0.8389		Bob	1.25	Rb/STB
Average Sw	0.3535	v/v	μ_{ob}	1.96	Cp
Porosity Range	0.0009 – 0.4940	v/v	μ_o (Vasquez-Beggs correlation)	2.05	Cp
Permeability -i & -j Range	0.005 – 3676.7	mD	μ_o (After water injection)	4.28	Cp
Permeability -k Range	0.0014 – 2259.3	mD	Gas Properties		
			Gas Specific Gravity	0.9327	-
			Gas Density	170	Kg/m3
			Molecular Weight (MW)	27.02	gr/mole
			Z – Deviation Factor	0.73	-
			Bq	1.3236	Rb/STB
			μ_g	0.0183	Cp
			Water Properties		
			Water Specific Gravity	1	-
			Water Density	981	Kg/m3
			Rsw	6.6	SCF/STB
			Bw	1.013	Rb/STB
			μ_w	0.44	Cp
			Salinity	9000	Ppm
			Compressibility	3.17×10^{-6}	1/psi
			Viscosity	4.4×10^{-6}	1/psi

IV. RESULT AND DISCUSSION

Based on the literature review from Taber, J.J et al (1983), it can be analyzed that field X reservoir is not suitable for thermal EOR process since the oil gravity is quite high (40.31°API) and the viscosity is quite low (4.28 cp) which doesn't fit the general thermal EOR screening requirements (oil gravity <25°API and viscosity >100 cp). The permeability requirement of more than 200 md also doesn't fit this field X reservoir with only 92.07 md so does the depth which requires the total depth less than 2500 ft. Hence, selecting thermal EOR methods (steam flood or in-situ combustion) in this field X reservoir would be incorrect. Additionally, it can be analyzed that the field X reservoir may fit some of the gas injection EOR method requirements in the pore scale displacement but failed in the operational and economical terms. Instead, this field X reservoir suited more with chemical EOR flooding. It is because the field X has oil viscosity < 30 cp, permeabilities > 20 md, reservoir temperature 151 degF (less than 175 degF), moderate water salinity (< 10000 ppm), no calcium and magnesium ions, no gas cap, and less clay content (NTG 83.89%).

From history matching result, the mobility ratio is one of the problems in this field X. The polymer flooding can improve the waterflooding technique by improving the displacement efficiency, meanwhile the field X suited almost all the polymer flooding requirements. On the other hand, the high remaining oil saturation 43.59% after waterflood can indicate the strong interfacial tension. The

wettability is possibly water-wet, but the quantitative value of wettability is unknown. The alkaline may be a good choice too to reduce the interfacial tension and emulsify the oil to be more mobile since it can generate surfactant-in-situ. Generally, the field X reservoir suited almost all alkaline flooding requirements except for the risk of alkaline reaction with shales. Similarly, the surfactant is also suited the field X reservoir (except the risk of shale reaction and the high cost of surfactant itself. Furthermore, the alkaline-surfactant might be a better choice if the cost of surfactant needs to be reduced, but both flooding is to reduce the interfacial tension of the oil, but the mobility control is missing in this process. And finally, the alkaline-surfactant-polymer (ASP) flooding could be the best choice to combine the mobility control, displacement efficiency and the reduction of interfacial tension. The cost would be slightly cheaper than the surfactant flooding alone but higher than the other chemical methods. Therefore, based on analytical screening result, ASP flooding comes as the first rank and polymer comes as the second rank.

On the other hand, based on qualitative EOR S&D result (figure I to III), the application will firstly generate the potential area based on screening algorithm mentioned in the methodology (figure I), the area with highest moveable oil by water/gas should be chosen as the reference, where in this case, the area-1 with geology type coarsening upward for rock quality and moveable is having the highest moveable oil. While, the other area with geology type (figure II) is coarsening downward for both rock quality and moveable oil in area-2 and is a combination of coarsening upward for rock type and coarsening downward for movable oil in area-3 are not suitable for EOR injection. Hence, in the case of EOR injection, the geology type of area-1 should become the area of interest.

Furthermore, by looking into the screening result (figure III), in the pore scale point of view, the highest pore displacement efficiency based on Buckley-Leverett equation is given by ASP, followed by polymer, then surfactant and AS, then low salt. This ranking matches with the analytical analysis where the mobility ratio and interfacial tension are two key problems need to be addressed. Surfactant and AS may give the same pore displacement efficiency but differ in the economical perspective. And low salt would be another form of waterflood with different salinity which in the analysis is not quite effective. However, by referring to industry guidance, the polymer become on the first place, followed by surfactant and then ASP. And it can be concluded that, by combining the pore displacement and industry guidance, the polymer comes as the first rank and ASP comes as the second rank.

The EOR S&D application can also perform quantitative screening into the field X model by simulating each EOR agent in the field to predict the cumulative oil production several years ahead and field economic potential. However, the comprehensive analysis of the method will be discussed in another paper.

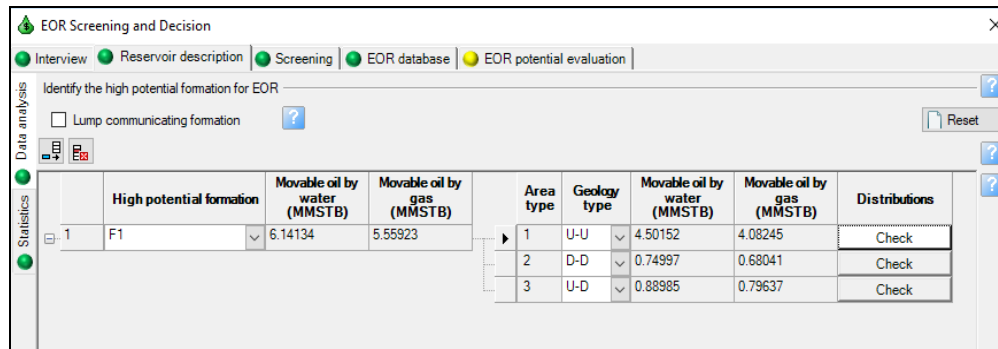


Figure I. EOR S&D Data Analysis on EOR Potential

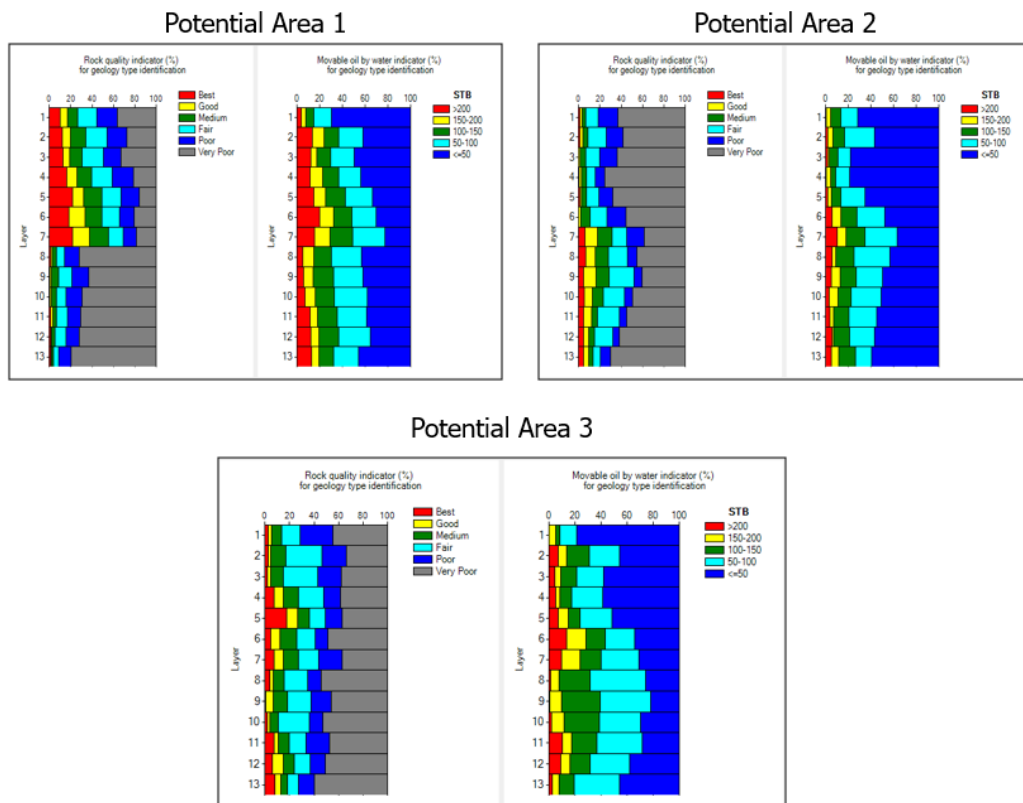


Figure II. EOR S&D EOR Potential Area

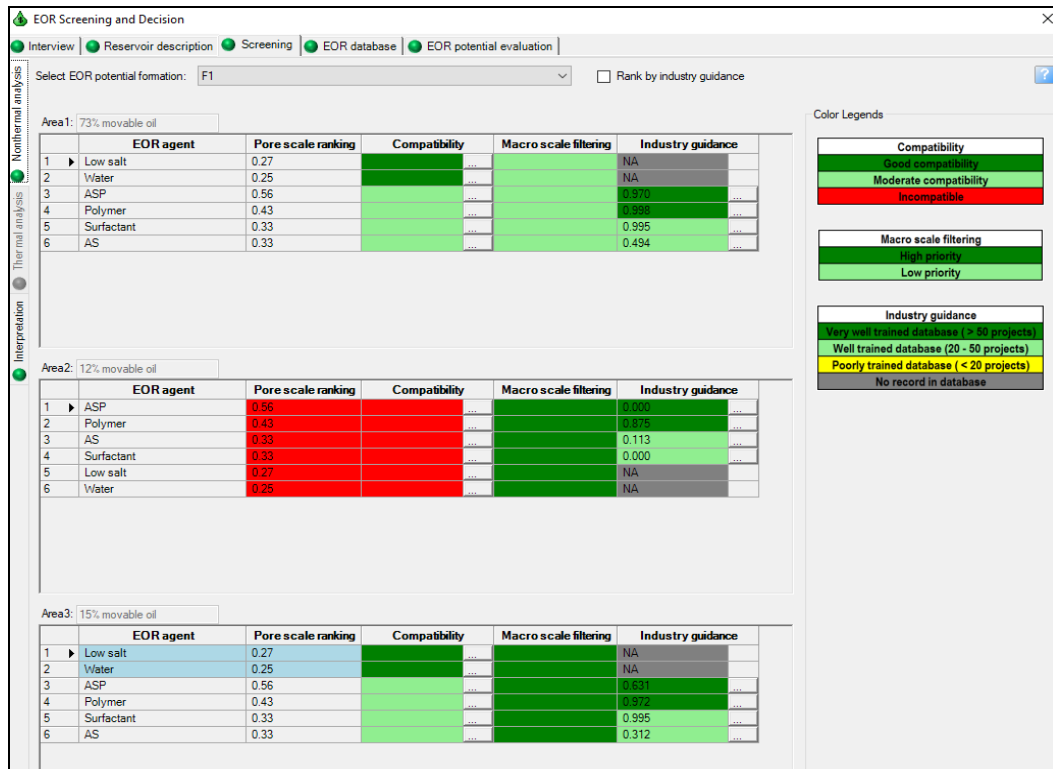


Figure III. EOR S&D qualitative screening for area 1, 2, and 3

V. CONCLUSION

- From the study, it can be concluded that EOR S&D can be a better alternative to the analytical screening method in determining the suitable EOR method (in the case of field X) since it can assess the suitable geological type to be injected by EOR and compute the ranking semi-quantitative from pore scale ranking to industry guidance.
- From the qualitative EOR S&D screening with the combination of pore scale ranking, compatibility, macro scale and industry guidance, polymer comes as the first rank and the ASP comes as the second rank. This result is close to the analytical screening result but presented in a more comprehensive way.

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