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Fuzzy-Based Screening System for Determination of Enhanced Oil Recovery (Eor) Method in Reservoir

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ABSTRACT

The petroleum industry is developing technology to increase oil recovery in reservoirs. One of the technologies used is Enhanced Oil Recovery (EOR). Selecting an EOR method for a specific reservoir condition is one of the most challenging tasks for a reservoir engineer. This study tries to build a fuzzy logic-based screening system to determine the EOR method. It created the system intending to assist in selecting and determining the appropriate EOR method used in the field. There are nine input criteria used to screen the EOR criteria: API Gravity, Oil Saturation, Formation Type, Net Thickness, Viscosity, Permeability, Temperature, Porosity, Depth criteria. The output criteria generated from the calculation of the EOR screening criteria are 14 outputs, namely: CO2 MF Miscible Flooding, CO2 IMMF Immiscible Flooding, HC MF Miscible Flooding, HC IMMF Immiscible Flooding, N2 MF Miscible Flooding, N2 IMMF Immiscible Flooding, WAG MF Miscible Flooding, HC+WAG IMMF Immiscible Flooding, Polymer, ASP, Combustion, Steam, Hot Water, Microbial. In this system, 512 rules are generated to produce 14 different outputs of the EOR method, with Mamdani's Fuzzy Inference reasoning. This fuzzy-based screening system has an accuracy rate of 80.95%, so this system is suitable to assist reservoir engineers in determining the appropriate EOR method to be used according to the conditions in the reservoir. The sensitivity level of the system only reaches 53.1%, while the specificity level reaches 94%.

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1. INTRODUCTION

Currently, the oil industry is developing technology to increase oil recovery in reservoirs. According to Aladasani[1]–[3], increasing oil recovery is presently focusing on research and development of the proper Enhanced Oil recovery method in a field. Screening Criteria can be used as a guide or the first step in implementing Enhanced Oil Recovery (EOR). If the Screening

Criteria are successfully implemented, selecting the following stage method becomes easier [4]–[6].

Screening Criteria is a step to identify known parameters of a reservoir. Meanwhile, Enhanced Oil Recovery is a method used to increase the recovery of oil reserves[7]–[12]. Of the 15 parameters that exist in the EOR Screening Criteria such as: API Gravity, Oil Saturation, Formation Type, Net Thickness, Viscosity, Permeability, Temperature, Salinity, Depth, and so on, a minimum of two parameters is required to determine the method in Enhanced Oil Recovery (EOR). Namely, the degree of API and reservoir depth [13]–[15].

Based on these problems, this research will build an EOR filtering system based on fuzzy logic that can help and simplify reservoir work carried out by reservoir engineers or students in the oil sector in determining the EOR method suitable for use in a reservoir.

In the screening system to be built, nine input criteria will be used to screen EOR criteria, namely: API Gravity, Oil Saturation, Formation Type, Net Thickness, Viscosity, Permeability, Temperature, Porosity, Depth criteria.

Nageh conducted similar research, Mohamed. et al., regarding applications using fuzzy logic on the screening criteria of EOR technology. Screening tool developed with Matlab programming language[16]–[19].

2. RESEARCH METHOD

According to Trujilo [14], the filtering criteria is the step of identifying the known parameters of a reservoir. Meanwhile, Enhanced Oil Recovery (EOR) is a method used to increase the recovery of oil reserves based on the input and output parameters produced. Table 1 describes the units used for each parameter[20], [21].

Table 1. Input parameters and units used

No	Parameters	Units
1	API Gravity (^{0}API)	Derajat Gravity
2	Oil Saturation (%)	Percent
3	Formation Type (SC	Sandstone and Carbonate
4	Net Thickness (ft)	Feet
5	Viscosity (Cp)	Centipose
6	Permeability (mD)	Mili darcy
7	Temperature ^{0}F	Derajat Fahrenheit
8	Porosity (%)	Percent
9	Depth (ft)	Feet

The domain set of each input parameter used to screen the EOR criteria is as follows:

1. API Gravity Criteria (0-60), consisting of Low (0-20), Medium (5-60), and High (40-60)
2. Oil Saturation Criteria (0-1), consisting of Low (0-0.6), Medium (0.4-1), and High (0.8-1)
3. Formation Type Criteria (0-18), consisting of Sandstone (0-5), Sorc (2-18), and Carbonate (10-18)
4. Net Thickness Criteria (0-20), consisting of Thin (0-10), NC (5-20), and Width (15-20)
5. Viscosity Criteria (0.0001-100000), consisting of Low (0.0001-1000), Medium (1-10000), and High (5000-10000)
6. Permeability criteria, consisting of Low (0-100), Medium (10-100000), and High (10000-100000)
7. Temperature Criteria (0-400), consisting of Low (0-200), Medium (100-400), and High (300-400)
8. Criteria for porosity (0-70), consisting of Low (0-30), Medium (10-70), and High (50-70)
9. Depth Criteria (0-20,000), consisting of Low (0-10000), Medium (5000-20000), and High (15000-20000)

The set of output criteria domains resulting from the calculation of the EOR filtering criteria is as follows:

1. Criteria for Miscible Flooding MF CO2 (0-100), consisting of Unsuitable (0-60), Eligible (40-100), and Very Eligible (80-100)
2. MMF CO2 Flooding Immiscible Criteria (0-100), consisting of Unsuitable (0-60), Eligible (40-100), and Very Eligible (80-100)
3. Criteria for Miscible Flooding HC MF (0-100), consisting of Inappropriate (0-60), Eligible (40-100), and Very Eligible (80-100)
4. Criteria for Immiscible Flooding HM IMMF (0-100), consisting of Not Eligible (0-60), Eligible (40-100), and Very Eligible (80-100)
5. Criteria N2 MF Miscible Flooding (0-100), consisting of Inappropriate (0-60), Eligible (40-100), and Very Eligible (80-100)
6. Criteria N2 IMMF Immiscible Flooding (0-100), consisting of Not Eligible (0-60), Eligible (40-100), and Very Eligible (80-100)
7. Criteria for WAG MF Miscible Flooding (0-100), consisting of Inappropriate (0-60), Eligible (40-100), and Very Eligible (80-100)
8. IMMF Immiscible Flooding Criteria HCTWAG (0-100), consisting of Not Eligible (0-60), Eligible (40-100), and Very Eligible (80-100)
9. Polymer Criteria (0-100), consisting of Inadequate (0-60), Eligible (40-100), and Very Eligible (80-100)
10. ASP Criteria (0-100), consisting of Not Eligible (0-60), Eligible (40-100), and Very Eligible (80-100)
11. Burning Criteria (0-100), consisting of Unfit (0-60), Eligible (40-100), and Very Eligible (80-100)
12. Steam criteria (0-100), consisting of Not Eligible (0-60), Eligible (40-100), and Very Eligible (80-100)
13. Criteria for Hot Water (0-100), consisting of Inappropriate (0-60), Decent (40-100), and Very Decent (80-100)
14. Microbial Criteria (0-100), consisting of Not Eligible (0-60), Eligible (40-100), and Very Eligible (80-100)

This fuzzy-based screening system consists of 9 (nine) fuzzy input parameters. Each input has 3 (three) fuzzy sets, as shown in table 2.

Table 2. Input Parameters with Fuzzy Set

No	Input parameter	Fuzzy Set
1	API Gravity	Low, Medium, High
2	Oil Saturation	Low, Medium, High
3	Formation Type	*Sandstone, Sorc, Carbonate*
4	Net Thickness	Thin, NC, wide
5	Viscosity	Low, Medium, High
6	Permeability	Low, Medium, High
7	Temperature	Low, Medium, High
8	Porosity	Low, Medium, High
9	Depth	Low, Medium, High

The output of this system is the screening criteria of the EOR method, which consists of 14 categories. The number of fuzzy sets from each type consists of 3 (three) groups, as shown in table 3.

Table 3. Output Parameters with Fuzzy Set

No	Output Parameters	Fuzzy Set
1	CO_2 MF	Not Eligible, Decent, Very Decent
2	CO_2 IMMF	Not Eligible, Decent, Very Decent
3	HC MF	Not Eligible, Decent, Very Decent
4	HM IMMF	Not Eligible, Decent, Very Decent
5	N_2 MF	Not Eligible, Decent, Very Decent
6	N_2 IMMF	Not Eligible, Decent, Very Decent
7	WAG MF	Not Eligible, Decent, Very Decent
8	HCTWAG IMMF	Not Eligible, Decent, Very Decent
9	*Polymer*	Not Eligible, Decent, Very Decent
10	ASP	Not Eligible, Decent, Very Decent
11	*Combustion*	Not Eligible, Decent, Very Decent
12	*Steam*	Not Eligible, Decent, Very Decent
13	*Hot Water*	Not Eligible, Decent, Very Decent
14	*Microbial*	Not Eligible, Decent, Very Decent

a. API Gravity

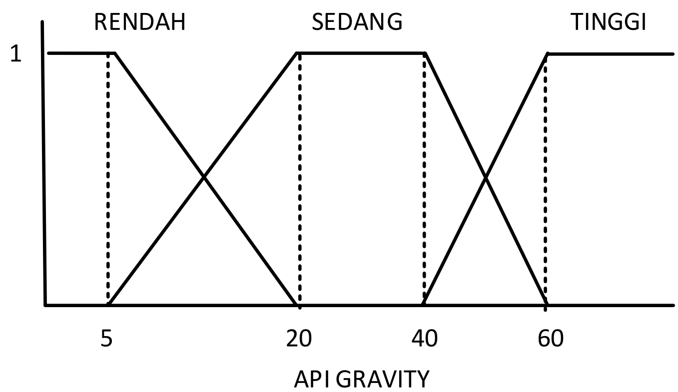

Fig 1. Membership Functions of the Gravity API

The Gravity API has 3 (three) fuzzy sets, namely: low, medium, and high groups with different domains, as shown in Figure 1. The membership functions of the three fuzzy sets are as follows:

Fuzzy Set = Low

$$\mu_{API\_low}[x] = \begin{cases} 1; x \leq 5 \\ \dfrac{20 - x}{15}; 5 \leq x \leq 20 \\ 0; x \geq 20 \end{cases}$$

Fuzzy Set= Medium

$$\mu_{API\_Medium}[x] = \begin{cases} 0; x \leq 5 \ or \ x \geq 60 \\ \dfrac{x - 5}{15}; 5 \leq x \leq 20 \\ \dfrac{60 - x}{20}; 40 \leq x \leq 60 \\ 1; 20 \leq x \leq 40 \end{cases}$$

Fuzzy Set = HIgh

$$\mu_{API\_High}[x] = \begin{cases} 0; x \leq 5 \\ \dfrac{x - 40}{20}; 40 \leq x \leq 60 \\ 1; x \geq 60 \end{cases}$$

3. RESULTS AND ANALYSIS

System capability testing in determining the EOR method will be carried out with 65 test data obtained from several research sources, namely:

Table 4. Testing Data from several research sources

Experiment	Data Source	Amount of Test Data
1	Research by P Sang Kang and J (2014) from the Korea Maritime State in the Brashear and Kuuskraa fields	10
2	Research by Nageh (2015) from the State of Egypt, namely the City of Cairo in the Egyption field,	30
3	Saleh's research (2014) from the United States of America, namely the City of Columbia in the Carcoana field and its surroundings	7
4	Hartono's research (2017) from Indonesia in several fields, namely Tempino Kenali Asam, Duri, Minas, Ledok, Klamono, and Handil	7
5	Research by Alvarado (2002) from the State of Indonesia in the Handil field.	4
6	Research by Elradi Abass (2011) from the State of Indonesia from the Handil field.	7
	TOTAL	**65**

Table 5 shows the results of comparing outputs between those generated from the fuzzy-based EOR screening system and the actual data from the research conducted by P Sang Kang and J (2014) shown in Maritime Korea, Brashear, and Kuuskraa fields.

Table 5. Comparison of Actual Data with System Prediction Results in Experiment 1

Case Data	Actual Data										Sytem Precition
	Criteria									EOR Used	Selected EOR
	API (Cp)	Oil Saturation (%)	Formation Type (%)	Net Thickness(ft)	Viscosity (Cp)	Permeability (md)	Temperature (^{0}F)	Porosity (%)	Depth (ft)		
1	26	25	1	5	20	4	200	20	4000	HC MF	HC MF
2	35	30	1	5	10	4	200	20	3937	HC MF	HC MF
3	23	30	1	5	3	4	200	20	4000	HC MF	HC MF
4	24	30	1	5	5	4	158	20	3937	HC MF	HC MF
5	23	30	1	5	3	4	200	20	4000	HC MF	HC MF
6	25	10	3	10	20	20	200	23	9000	HC MF	HC MF
7	15	50	3	10	150	10	200	23	9000	HC MF	HC MF
8	22	50	3	10	100	50	200	23	9000	HC MF	HC MF
9	25	60	3	10	150	50	158	23	9000	HC MF	HC MF
10	15	60	3	10	200	10	200	23	9000	HC MF	HC MF

4. CONCLUSION

From the results of the design and manufacture of an intelligent application system based on Mamdani fuzzy logic, it can conclude that the accuracy of the screening system based on Mamdani fuzzy logic from 65 test data, only reached 80.95%.

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