Investigation of Microbial Enhance Oil Recovery's (MEOR) performance as a candidate In Iranian Southern Oil Fields

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ABSTRACT

Enhanced Oil Recovery (EOR) process is used to recover additional oil left in place after primary recovery. The prediction of its performance is of great importance in selection and design of certain EOR process and future planning for oil production. Microbial Enhance Oil Recovery (MEOR) is friendly with environment, and it is applied as ex-situ and in-situ in oil reservoirs. In microbial flooding, in the water oil contact the microorganisms consume the nutrition and produce bioacid, biopolymer, biosurfactant, biogas and solvent, which improve the oil recovery and yield the less harmful product for a green environment with respect to other types of EOR methods. This study was investigated potential of applying MEOR by oil recovery prediction in five different carbonate reservoirs. The study is conducted utilizing 100 laboratory data with valid references. In all of these references, MEOR processes are obtained based on porosity, permeability, salinity, temperature, pressure and PH. Clostridium Acetobutylicum are also used as microbe. From this laboratory data different data clusters are tested by Adaptive Neuro Fuzzy Inference System (ANFIS). The best modeling (four or five clusters) obtained based on Mean Square Error (MSE) and correction factor (R-Value) by employing reservoir parameters as inputs and oil recoveries as outputs. Five different reservoirs selected from Iranian southern oil fields, which have not experienced any EOR processing before. Reservoir properties entered as inputs in obtained ANFIS model, which result five output as oil recovery prediction. Results reveal 36.71- 40.68% oil recovery, which conform to previous studies. Besides, considering green technologies, it is shown that MEOR can be one of the best options among EOR techniques for carbonate reservoirs.

INTRODUCTION

Naturally, oil is produced from reservoir by its potential energy or pressure gradient between surface and subsurface condition. Then this energy reduces and so the oil production using the primary recovery would not be economical. In next step, the secondary and tertiary methods are used as EOR [1]. While primary recovery stage produces generally between 5-10% of the total oil reserves, recovery efficiencies in the secondary phase varies from 30-40% [2], [3].

The various methods such as thermal methods, chemical flooding, gas injection and biological methods are used for EOR. The thermal methods are primarily intended for heavy oils and tar sands mainly to supply heat to the reservoir. These methods include steam or hot water injection and in situ combustion technique. Chemical flooding involves injection of certain chemicals that might change either the characteristics of the reservoir fluids or improve the recovery mechanisms. These include polymer, surfactants and alkaline flooding. Miscible flooding (either first- or multi- contact miscible) includes CO_2 miscible gas injection, N_2 miscible injection and others. Now, more advanced technologies are being implemented in the oil industry to recover the trapped oil. These include seismic/sonic stimulations and electromagnetic methods [2]. However, economics are the major

deterrent in the commercialization of the above-mentioned EOR methods. MEOR have several advantages compared to conventional EOR processes where it does not consume large amounts of energy, as do thermal processes, nor does it depend on the oil price, as do many chemical processes [4]. MEOR could be applied in oil reservoirs using ex-situ and in-situ methods. In ex-situ recovery methods, microbes are cultured in industrial laboratories and then the microbes and their products are injected into the reservoirs using water flooding methods. The in-situ method is categorized to microbial flooding method and stimulation of single wells. Microbial flooding method uses the microorganisms and the nutrition in water flooding while in stimulation of wells the anaerobic microorganisms are injected into the wells and then the wells are shut off for days or weeks so that the porous medium is soaked [5]. In all mentioned methods, the microorganisms diffuse into the porous medium, consume the nutrition and produce bioacid, biopolymer, biosurfactant, biogas and biosolvent and which they increase the efficiency of oil displacement in reservoir [6].
Together with experimental procedures such as core floodings and field trials, a step on the way is the development of simulation tools in order to understand and reveal the full potential of MEOR. In this study the application of MEOR for Clostridium Acetobutylicum microbe with utilizing effective carbonate reservoir parameters is investigated. ANFIS is also implemented to produce a simulation model to predict the oil recovery percent from experimental data.

ANALYSIS AND MODELLING

Intelligent Control techniques are nowadays-recognized tools in both academia and industry. Methodologies coming from the field of computational intelligence, such as neural networks, Fuzzy systems and evolutionary computation, can lead to accommodation of more complex processes, improved performance and considerable time savings and cost reductions [7].
A notable contribution of Neuro-Fuzzy and Soft Computing is the exposition of ANFIS, a system developed by the authors which is finding numerous applications in a variety of fields. Functionally, there are almost no constraints on the node functions of an adaptive network except for the requirement of piecewise differentiability.
In this section, we propose a class of adaptive networks that are functionally equivalent to fuzzy inference systems. The proposed architecture is referred to as Adaptive Neuro-Fuzzy Inference System, which stands for adaptive network-based fuzzy inference system or semantically equivalently, Adaptive Neuro Fuzzy Inference System. The strength of ANFIS is the ability to handle linguistic concepts and find non-linear relationships between inputs and outputs [8]. Two learning methods are generally used in ANFIS to specify the relationship between input and output to determine optimized distribution of membership functions. These learning methods are propagation and hybrid. The hybrid system is a combination of propagation and least squares method [9]. In backward pass, descending gradient algorithm updates the desired parameters [10]. Parameters associated with membership functions will change through the learning process. Gradient vector facilitate the calculation of these parameters. Each time the gradient vector is obtained, an optimization procedure can be performed to adjust parameters to reduce errors [11]; [12].
In order to create FIS using ANFIS, fuzzy logic toolbox of MATLAB, version 7.10.0.499 (R2010a) was used [13]. The total number of inputs was six including: porosity (%), permeability (md), pressure (psi), temperature (k), salinity (ppm), PH (0-14) which shown in Figure 1.

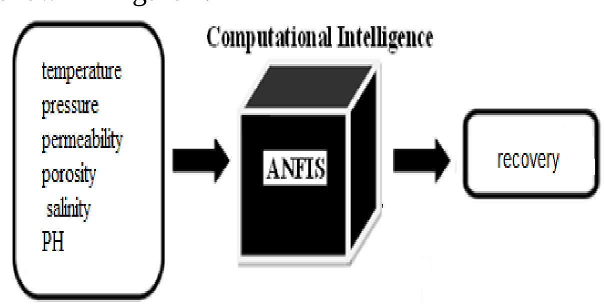

Figure 1

Input and Output in Computational Intelligence ANFIS

The purpose of this section is to develop an ANFIS model based on laboratory data and then predict oil recovery percent for 5 special reservoirs. 100 data used in this case study are divided into three subsets randomly; 80% was used for training, 10% for validation and 10% for testing. The output of this laboratory data is shown in Figure 2.

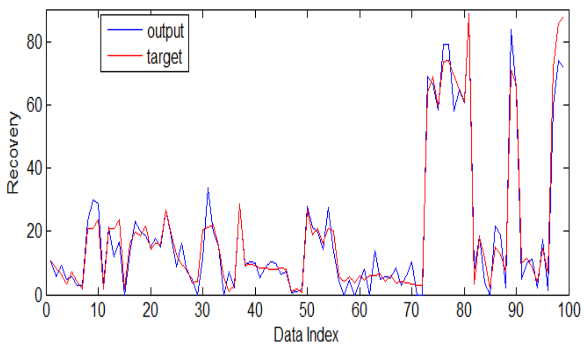

Figure 2

Diagram of recovery data

The general schematic of ANFIS structure for two clusters is shown in Figure 3.

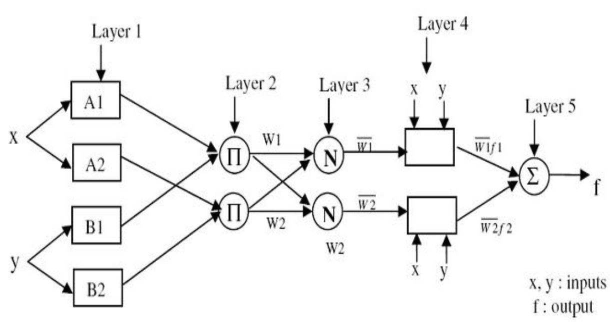

Figure 3
ANFIS architecture for the Sugeno fuzzy model

ANFIS Design for oil recovery prediction:

- Sugeno type of fuzzy structure
- Fuzzy c-mean clustering as initial FIS
- MSE as performance function
- Cluster number of 2,3,4,5,6,7,8,9,10,11
- Optimization method of hybrid (back-propagation, least square method

Good results obtained from oil recovery models are shown in Table 1 and dark raws are selected and results of the selected network are also shown in Figure 4.

Table 1
Results of ANFIS modeling

	Train		Validation		Test	
	MSE	R	MSE	R	MSE	R
2- Cluster	0.015	0.96	0.03	0.97	0.03	0.99
3- Cluster	0.007	0.98	0.07	0.93	0.02	0.99
4- Cluster	0.008	0.98	0.02	0.98	0.04	0.99
5- Cluster	0.008	0.98	0.02	0.98	0.04	0.99
6- Cluster	0.006	0.98	0.07	0.91	0.06	0.98
7- Cluster	0.004	0.99	0.05	0.93	0.08	0.97
8- Cluster	0.006	0.98	0.05	0.94	0.05	0.99
9- Cluster	0.005	0.99	0.06	0.93	0.02	0.97
10-Cluster	0.005	0.99	0.05	0.94	0.04	0.99
11-Cluster	0.006	0.98	0.07	0.91	0.04	0.99

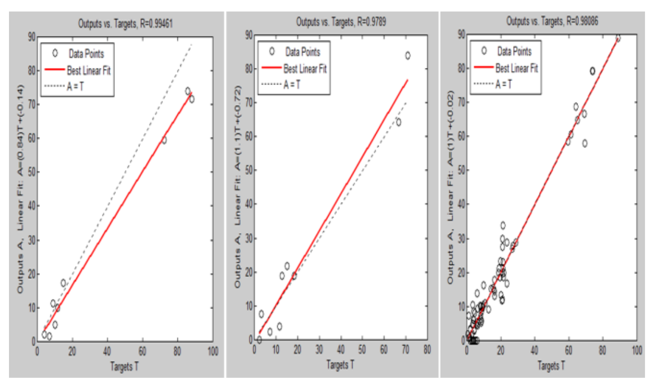

Figure 4

R-value in selected network

When the amount of MSE is reduced and the R-value approaches to one it gives better modeling of data, as seen by Figure 5 and 6, also the optimum number of cluster is clusters number 4 or 5.

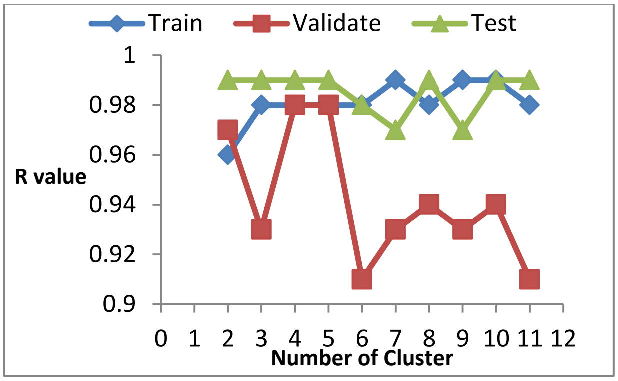

Figure 5

R-value of Recovery Prediction for Train, Validate and Test Data

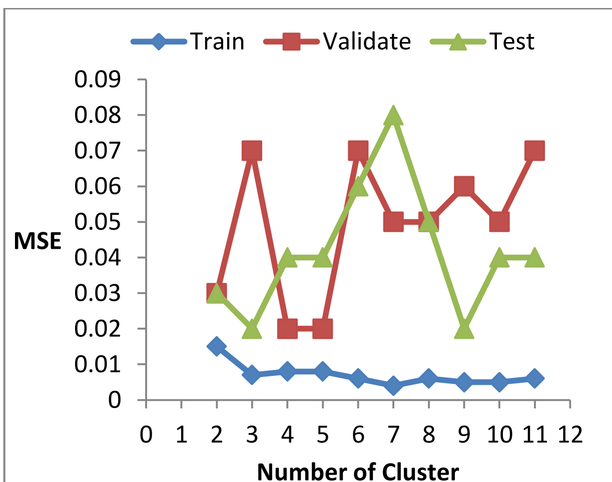

Figure 6

MSE of Recovery Prediction for Train, Validate and Test Data

In modeling, we used an optimum number of clusters that cause the amount of minimum squared error for validate and test data decreases and then by using this model and having reservoirs effective parameters predict recovery percent for these five reservoirs shown in Table 2.

Table 2

Input data of 5 reservoirs

Res. NO.	1	2	3	4	5
Porosity%	9	14	9	13.7	22.3
Permeability(md)	1.18	1.5	1.74	1.17	5.2
Pressure (psi)	6381	5947	5775	5880	3553
Temperature (k)	380.37	379.82	385.93	380.37	354.26
Salinity(ppm)	220000	220000	215000	215000	215000
PH(0_14)	6.5	5.2	7.3	6	6.7

We enter the above reservoir properties as input in optimized ANFIS modeling shown and gain 5 output as oil recovery percent prediction for these five reservoirs.

RESULTS AND DISCUSSION

The results of entering reservoir parameters as input in optimized ANFIS modeling, shows five output as oil recovery of these five reservoirs are mentioned here, for reservoir number 1 is 36.71%, number 2 is 39.83%, number 3 is 39.89%, number 4 is 39.73% and number 5 is 40.68%. The best expected result is belong to reservoir NO. 5 which have less pressure, less temperature, more porosity and more permeability.

SUMMARY AND CONCLUSIONS

Iranian southern oil fields are near to sea and water flooding is a common EOR process in these reservoirs. In most cases, any reservoir, which has undergone successful water flooding, can be a major candidate for application of MEOR process. Based on this special condition for these reservoirs and environmental aspect of MEOR and also increasing the upper limits which microorganism can grow, it is decided to investigate the application of MEOR in these reservoirs. We used ANFIS and choose the best modeling based on laboratory data and predict oil recovery percent in these reservoirs. Based on the results of this work the following conclusions were obtained:

- MEOR isn't only an environmental friendly process but also according to oil recovery prediction for Clostridium Acetobutylicum microbe, it is one of the best candidates for selection and design among EOR techniques for these reservoirs.

• Computational Intelligence models, which result the lowest error, based on actual field data, is strongly proposed to solve intricate industrial problems instead of empirical correlations and mechanistic models.

• Oil recovery modeling with Computational Intelligences shows good results.

• For save money and time in obtaining oil recovery percent for MEOR process and according to high accuracy of our modeling that show 0.99 for R value and 0.04 for MSE, it is recommend to compare these results with laboratory or oil fields operations data.

KEYWORDS
Microbial, Enhanced Oil Recovery candidates, Green method, Oil recovery prediction, Adaptive Neuro Fuzzy Inference System, Iranian Southern Oil Fields.

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