Available online at www.sciencedirect.com
ScienceDirect
Information Sciences 177 (2007) 4445–4461
INFORMATION SCIENCES
AN INTERNATIONAL JOURNAL
www.elsevier.com/locate/ins

Predicting injection profiles using ANFIS

Mingzhen Wei [a,*], Baojun Bai [a], Andrew H. Sung [b], Qingzhong Liu [b], Jiachun Wang [c], Martha E. Cather [d]

[a] *University of Missouri-Rolla, 129 mcNutt Hall, 1870 Miner Circle, Rolla, MO 65409, United States*
[b] *New Mexico Institute of Mining and Technology, 801 Leroy Place, Socorro, NM 87801, United States*
[c] *Daqing Petroleum Company Limited, PetroChina, Daqing, Haerbing, PR China*
[d] *New Mexico Petroleum Recovery Research Center/New Mexico Tech, 801 Leroy Place, Socorro, NM 87801, United States*

Received 21 September 2005; received in revised form 16 March 2007; accepted 17 March 2007

Abstract

Decision making pertaining to injection profiles during oilfield development is one of the most important factors that affect the oilfields' performance. Since injection profiles are affected by multiple geological and development factors, it is difficult to model their complicated, non-linear relationships using conventional approaches. In this paper, two adaptive-network-based fuzzy inference systems (ANFIS) based neuro-fuzzy systems are presented. The two neuro-fuzzy systems are: (1) grid partition based fuzzy inference system (FIS), named ANFIS-GRID, and (2) subtractive clustering based FIS, named ANFIS-SUB. We compare the performance of resultant FIS and study the effect of parameters. A real-world injection profile data set from the Daqing Oilfield, China is used. FIS are generated and tested using training and testing data from that data set. The impact of data quality on the performance of FIS is also studied. Experiments demonstrate that although soft computing methods are somewhat of tolerant of inaccurate inputs, cleaned data results in more robust models for practical problems. ANFIS-GRID outperforms ANFIS-SUB due to its simplicity in parameter selection and its fitness in the target problem.

Keywords: ANFIS; Subtractive clustering; Grid partition; Petroleum industry; Data quality problems

1. Introduction

In water flooding oilfields, injected water pushes petroleum fluid (oil, gas or/and water) to move toward to wellbore through the porous media underground. Injection profiles of injection wells present the distribution of injected water in the active or producing strata. Understanding injection profiles significantly aids in analyzing production related problems, such as residual oil distribution, residual reserve estimation, water flooding efficiency, injection and production balance, and so on.

* Corresponding author. Tel.: +1 573 341 4221; fax: +1 505 835 6031.
E-mail address: weim@umr.edu (M. Wei).

0020-0255/$ - see front matter
doi:10.1016/j.ins.2007.03.021

Many methods can be applied to obtain injection profiles in oilfields, such as sealed coring, sidewall coring, interpretation of logging data, C/O spectral logging, numerical simulation and comprehensive analysis of static and dynamic data from the oilfield development. Most of those methods, except for numeric simulation, are for obtaining injection profiles by in-place measurement and interpretation. They are expensive and time-consuming. In addition, it is impossible to obtain injection profiles whenever and wherever they are needed for improving oil recovery (IOR) purposes. Reservoir numeric simulation models the oil/gas production by combining petroleum fluid flow and other models. By properly modeling reservoir and matching the history production data, reservoir simulation generates injection profiles in the production history and predicts injection profiles in the future. However, reservoir simulation has its own inherent problems, including that (1) it is difficult to model multiple parameters and integrate sub-models; (2) history matching is still largely a trial-and-error, and consequently time-consuming process which depends heavily on reservoir simulation expertise; and (3) reservoir simulators sometimes encounter difficulties in modeling actual reservoir features due to their built-in limitations. In addition, time-consuming post-processing is required to obtain injection profile data from reservoir simulation results. Considering that injection profiles are required in many different IOR projects, it is desirable to have handy data available when it is required.

Soft computing techniques are known for their efficiency in dealing with complicated problems when conventional analytical methods are infeasible or too expensive, with only sets of operational data available. Soft computing methods have been widely applied in many areas in the petroleum industry, such as reservoir description [27], well logging interpretation [16], production prediction [29] and treatment optimization [17]. In this paper, two neuro-fuzzy systems, ANFIS-GRID and ANFIS-SUB, are employed to model the relationships of injection profiles and their influential parameters. A set of data from real injection profiles in the Daqing Oilfield of China is employed to train and test these neuro-fuzzy systems. Average prediction accuracy of about 80% is achieved.

The rest of this paper is organized as follows. Section 2 describes the injection profile modeling problem; Section 3 is a brief introduction to ANFIS, ANFIS-GRID, and ANFIS-SUB; Section 4 studies the effects of parameters for these neuro-fuzzy systems and presents the experimental results on the raw data; Section 5 demonstrates the effect of low quality data on the performance of FIS and presents the improved result using cleaned data; Section 6 concludes the paper.

2. Problem statement

In water flooding oilfields, the injection profile is tightly related to fluid flow in the underground porous media. Therefore, water injectivity of the injection wells is affected by many parameters. For example, the larger the permeability, the larger the water injectivity is. Water always breaks through along the high permeability channels to the producing wells. Formation communication between injection and producing wells, which depends on the depository environment for oil/gas generation and transportation, is another important factor that affects the injectivity. With a nice communication environment, stored oil/gas volume in reservoirs can be produced easily, hence nice injectivity.

In the underground porous media, petroleum fluid flow follows the non-linear Darcy's Law, described by the following equation:

$$u = -\frac{k}{\mu}\frac{\mathrm{d}P}{\mathrm{d}x}, \tag{1}$$

where u is the superficial velocity; k is the permeability; μ is the viscosity of petroleum fluid; and $\mathrm{d}P/\mathrm{d}x$ is the pressure drop in fluid flow direction. Considering the complex interaction of rock and fluid properties, anisotropy of permeability, the fluid flow can be generally described as follows:

$$\begin{cases} \nabla \cdot \left\{ \frac{KK_{\mathrm{rw}}}{\mu_{\mathrm{w}} B_{\mathrm{w}}} (\nabla p_{\mathrm{w}} - \gamma_{\mathrm{w}} \nabla d) \right\} \pm Q_{\mathrm{w}} = \phi \frac{\partial}{\partial t}\left(\frac{S_{\mathrm{w}}}{B_{\mathrm{w}}}\right) & \text{for oil,} \\ \nabla \cdot \left\{ \frac{KK_{\mathrm{ro}}}{\mu_{\mathrm{o}} B_{\mathrm{o}}} (\nabla p_{\mathrm{o}} - \gamma_{\mathrm{o}} \nabla d) \right\} \pm Q_{\mathrm{o}} = \phi \frac{\partial}{\partial t}\left(\frac{S_{\mathrm{o}}}{B_{\mathrm{o}}}\right) & \text{for water,} \\ \nabla \cdot \left\{ \frac{KK_{\mathrm{ro}}R_{\mathrm{s}}}{\mu_{\mathrm{o}} B_{\mathrm{o}}} (\nabla p_{\mathrm{o}} - \gamma_{\mathrm{o}} \nabla d) \right\} + \nabla \cdot \left\{ \frac{KK_{\mathrm{rg}}}{\mu_{\mathrm{g}} B_{\mathrm{g}}} (\nabla p_{\mathrm{g}} - \gamma_{\mathrm{g}} \nabla d) \right\} \pm (R_{\mathrm{s}}Q_{\mathrm{o}} + Q_{\mathrm{g}}) = \phi \frac{\partial}{\partial t}\left(\frac{S_{\mathrm{g}}}{B_{\mathrm{g}}} + \frac{R_{\mathrm{s}}S_{\mathrm{o}}}{B_{\mathrm{o}}}\right) & \text{for gas,} \end{cases} \tag{2}$$