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Structuring an artificial intelligence based decision making tool for cyclic steam stimulation processes

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A R T I C L E I N F O

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A B S T R A C T

Cyclic steam stimulation (CSS) is one of the more popular EOR techniques due to the existence of giant heavy oil reserves existing in different parts of the world. Numerical reservoir simulation plays a critical role in investigating the mechanisms and optimizing field development strategies of CSS processes. An artificial neural network (ANN) based model is considered to be a powerful subsidiary tool of high fidelity models for its fast computational speed and reliable prediction capability. This work focuses on the development of a robust surrogate model as a screening/design tool for cyclic steam injection processes using artificial neural network technology.

The major contribution of this work includes training of the ANN model using a network topology optimization workflow to help the ANN better understand the complex data structures that are encountered in such processes. The developed ANN model successfully incorporates rock-fluid properties such as relative permeability and temperature dependent viscosity as input parameters together with the other relevant data. Last but not least, the network model utilizes a hybrid structure to adapt to the automatic cycle switching scheme that can be encountered in cyclic steam injection processes. The paper shows that the ANN model can be employed both as a classification tool and a nonlinear regression tool. The model is validated via extensive blind tests against high fidelity simulation models and can be used as a powerful screening and process design tool in global optimization of the process.

1. Introduction

Thermal EOR plays a significant role in world's energy supply as significantly large heavy oil reserves have been discovered around the world (Briggs et al., 1988 and Manrique et al., 2010). Statistical data shows that over 50% of world oil resources are found in heavy oil and bitumen reservoirs (Bjørnseth, 2013 and Santos et al., 2014). More than 1.3 million barrel of global heavy oil production per day is from steam utilizing EOR projects according to reported journal survey data (Meyer et al., 2007). Cyclic steam stimulation (CSS) is a broadly implemented thermal EOR technique in heavy oil industry for its attractive economic efficacy and fast project response (Alvarez and Han, 2013). Extensive CSS projects have been carried in Midway-Sunset Field in USA, Cold Lake Field in Canada, Bohai Oil field in China, etc (Koottungal, 2014 and Liu et al., 2016). A successfully implemented CSS project could yield a recovery factor of 10–15% of OOIP, which can be improved by co-injecting steam with chemical additives and by implementation of horizontal wells (Srivastava and Castro, 2011; Sun and Zhou, 2011 and Wu et al., 2009). Numerical reservoir simulation implementing high fidelity thermal recovery models plays a significant role in investigating flow mechanisms as well as project design of CSS implementations. Artificial neural networks (ANN) are considered as powerful nonlinear regression and classification models which have been extensively utilized in petroleum and natural gas industry. They can be deployed as a subsidiary tool for high fidelity numerical simulation models for their extremely fast computational speed, especially when a rapid screening or a large volume of simulation runs is required. The fast and accurate analysis capabilities of ANN inspire the main motivation for this work, which aims at structuring a robust ANN model which can be used as an expert system in designing and screening cyclic steam injection projects.

The principal objective of this work is to develop ANN-based proxy models to study CSS process implementation in conventional oil sands. A commercial, high fidelity thermal simulation software, Computer

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Nomenclature

ANN	Artificial neural network
AVISC	Viscosity coefficient A in Andrade's correlation
BVISC	Viscosity coefficient B in Andrade's correlation
CSS	Cyclic steam stimulation
$\boldsymbol{E}$	ANN error function
$\boldsymbol{g}$	Gradient of the error function
$\boldsymbol{H}$	Hessian matrix
k_{rgro}	Gaseous phase relative permeability at residual oil saturation, fraction
k_{roiw}	Oleic phase relative permeability at irreducible water saturation, fraction
k_{rwro}	Aqueous phase relative permeability at residual oil saturation, fraction
m	The number of testing cases
n	The number of output neurons
n_g	Exponential coefficient for gas phase relative permeability curve in gas-liquid table
n_{og}	Exponential coefficient for oil phase relative permeability curve in gas-liquid table
n_{ow}	Exponential coefficient for oil phase relative permeability curve in oil-water table
n_w	Exponential coefficient for water phase relative permeability curve in oil-water table
$\boldsymbol{o}$	ANN prediction in backpropagation training
S_{gc}	Critical gas saturation, fraction
S_{org}	Residual oil saturation in gas-liquid table, fraction
S_{orw}	Residual oil saturation in oil-water table, fraction
$\boldsymbol{t}$	Training target in backpropagation training
T	Temperature, °F
$\boldsymbol{w}$	Weight matrices of the ANN model
μ	Viscosity, cp

Modeling Group® (CMG) STARS, is employed to model the cyclic steam injection procedures and generate synthetic production histories as the knowledgebase to train the proxy models. The reservoir model of this work focuses on a drainage-area-based reservoir with a vertical CSS well as the minimum simulation unit. The model inputs include spatial reservoir properties, initial conditions, rock and fluid properties and engineering design parameters used in the process implementation. In order to include the relative permeability tables and temperature dependent crude oil viscosity tables as variables; Corey's three-phase relative permeability and Andrade's oil viscosity correlations are employed to generate libraries of relative permeability and temperature-viscosity tables, respectively. The model predicts the oil flow rate and cumulative production profiles. An in-house ANN training module is developed employing scaled conjugate gradient algorithm and is implemented to train the ANN models. In order to solve the sophisticated steam injection problems implementing ANN, a workflow is designed to train and test a large number of ANN models with various architectures (number of hidden layers, number of hidden neurons, transfer function, etc.). The ANN architecture yielding the best blind test performance is selected as the optimized ANN model. A parallel computation technique is employed to train and test multiple ANN architectures synchronically to boost the executing speed of the workflow.

In line with the work flow discussed above, this work focuses on exploring the application of ANN to study cyclic steam injection problems. The CSS procedure in this work is designed in such a way that the CSS cycle will automatically switch when the oil flow rate in the

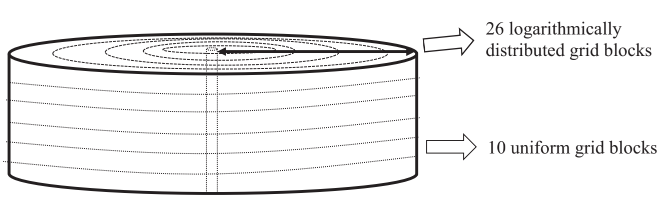

Fig. 1. A three-dimensional view of CSS simulation model.

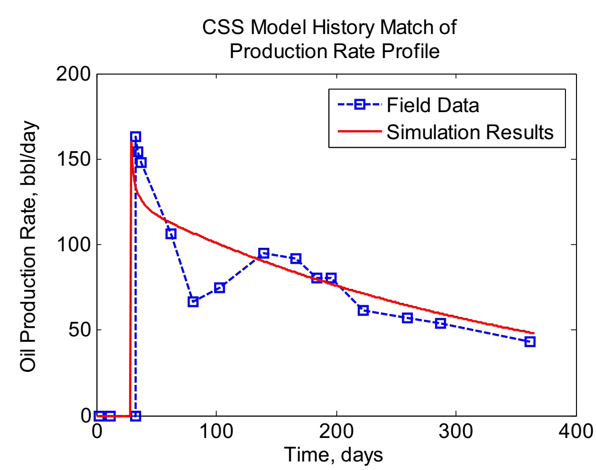

Fig. 3. Production history match of cyclic steam injection numerical model to field data, reservoir properties: porosity ~28%, Horizontal permeability ~500 mD, kv/kh ratio ~0.25, Viscosity @110 F ~500 cp, initial pressure ~1200 psi, initial temperature ~110 F, water saturation ~15%, net pay ~120 feet. Reported cumulative production ~29 MSTB, simulated cumulative production ~27 MSTB (Pascual, 2001).

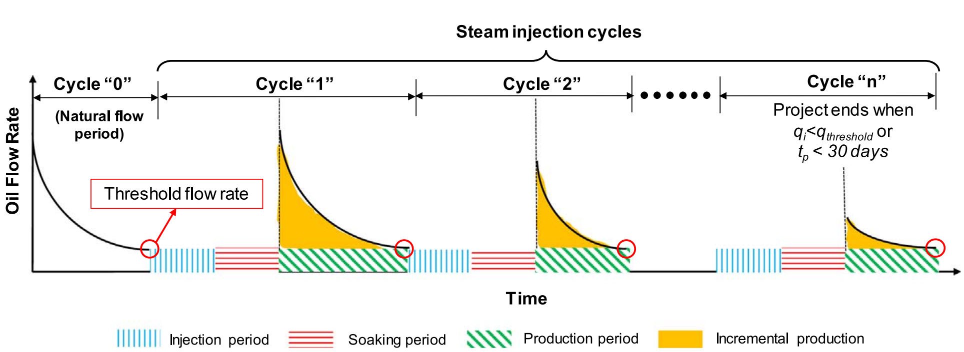

Fig. 2. A schematic illustration of the cyclic steam injection process.