Optimization Applications Seeking to Improve Performance of Natural Gas Reservoirs, Production, Processing and Utilization: A Selection of Case Studies

Journal of Natural Gas Science & Engineering Virtual Special Issue 2014

Editorial / Introduction to the Virtual Special Issue by David A. Wood. JNGSE, 2014 (November) vol. 21, p. A1-A3.

Optimization is an essential performance-improving tool for diverse practical applications across many sectors of the natural gas industry and its supply chains. Optimization algorithms have developed and evolved rapidly in recent years leading to reduced computation times and the improved accuracy of desired results. Their increased application is due partly to expanded computer memories, data storage capacities and processing speeds and capabilities. It is also partly due to the valuable insight to systems, processes and equipment functionality that can be gained by applying such algorithms, regardless of the industry sector under consideration.

This special issue has the objective of highlighting some of the key benefits optimization analysis currently brings to various sectors of the natural gas industry, and to stimulate readers to apply and further develop these and other optimization approaches. It does this by compiling a set of articles published during 2014 in the *Journal of Natural Gas Science and Engineering*. These articles are purposefully selected from different sectors of the industry. They are also selected because they document the application of various optimization methodologies and algorithms to achieve performance-enhancing objectives and improve insight to the systems studied.

The eleven published research articles compiled in this special edition (see contents list for details) cover optimization issues from the following sectors of the industry: sub-surface reservoir conditions, reservoir fluid properties, drilling trajectories for deviated well bores, production performance, processing and treatment of produced gas, transmission pipeline operating conditions, novel power generation system efficiencies, compressed natural gas (CNG) vehicle refuelling systems, and dual fuel diesel-CNG engine emissions and performance. Collectively these articles provide a set of case studies highlighting some of the current optimization problems commanding the attention of researchers from across the natural gas industry, and algorithms and methodologies that can provide meaningful solutions to those problems. Several of the articles include computer-code listings for the algorithms they present providing readers with greater insight to the details of the implementation of their respective methodologies.

The following paragraphs introduce each of the articles included in this special issue and provide brief overviews of their content.

Applying a Robust Solution Based on Expert Systems and GA Evolutionary Algorithm for Prognosticating Residual Gas Saturation in Water Drive Gas Reservoirs (Tatar et al., 2014), presents techniques to improve the prediction of residual gas saturation. Such prediction is important as it influences the potential gas recovery factors related to certain production and injection well patterns. The study applies Committee Machine Intelligent System (CMIS) to assess the performance of well-established empirical correlations based on a large database of published experimental data. CMIS constructs its combined optimization network using three independent optimization networks, viz. multilayer perceptron neural network (MLP), radial basis function neural network (RBF), and least square support vector machine (LSSVM) to predict the residual gas saturation in water drive gas reservoirs using four petrophysical input metrics (e.g. porosity, permeability, initial gas saturation, residual gas saturation). These three networks involve a machine learning approach being trained with four parameters as input followed with a back propagation algorithm to minimize the mean squared error (MSE). A genetic algorithm (GA) was then applied to generate combined optimization network. The CMIS generated models outperformed alternatives for the correlations and database studied.

Evaluating Gas Production Performances in Marcellus Using Data Mining Technologies (Zhou et al., 2014) proposes post-hoc analysis of large databases of well data to identify those geological factors which are most important in predicting gas recovery from a specific geographic region of a much larger petroleum province, i.e. in this case the Marcellus Shale extending across vast areas of the Northeast United States. This work started with a database of 631 wells from Northern West Virginia. The data base was screened/ filtered using Mahalanobis distance analysis to provide coherent subset of 187 wells that was and statistically analysed for the variables the one-year cumulative gas production, fracture fluid volume, proppant mass, vertical depth, lateral length, treatment rate, and number of fracture stimulation stages. Regression analysis established the relationship between two or more variables. Cluster analysis was used to identify subgroups of the dataset with similar multivariate characteristics. Principal component analysis (PCA) was used to establish data patterns and explain the major variances of the data set. The analysis identifies the number of hydraulic fracture stages is found to be the most significant parameter among all factors studied for the horizontal wells in West Virginia. It also identifies that the fracture fluid volume and proppant mass are relatively important compared to other parameters.

Prediction of permeability in a tight gas reservoir by using three soft computing approaches: A comparative study (Baziar et al., 2014) considers the performance of different optimization algorithms in determining reservoir permeability from well log data. Multilayer perceptron neural network (MPNN), co-active neuro-fuzzy inference system (CANFIS) and support vector machine (SVM) algorithms are employed to predict permeability based on data from three wells drilled in the Mesaverde tight gas sandstones (Washakie Basin, U.S.A.). Two different dataset patterns are constructed to evaluate and compare the performance of each algorithm. These predict permeability by using either previously seen data or unseen data. The study shows that all three methods are capable of predicting permeability to acceptable levels once trained for specific reservoir formations, but the CANFIS and SVM algorithms are more effective than the MPNN algorithm in delivering more accurate results. The SVM algorithm performs slightly better and significantly more rapidly in solving this task for the Mesaverde reservoir than the CANFIS algorithm.

Application of Soft Computing Approaches for Modeling Saturation Pressure of Reservoir Oils (Talebi et al., 2014) describes a predictive model for calculating the bubble point pressure of an oil reservoir, i.e. the pressure at which gas first comes out of solution. The bubble point pressure varies depending on the composition of the oil and gas and the reservoir temperature. Being able to predict bubble point pressure, rather than determine it experimentally for each sample, can save time and cost in reservoir development decisions impacting oil and gas recovery. The study builds artificial neural networks (ANN) using MLP and RBF algorithms for a dataset of 750 crude oil samples from various geographic locations and tests them against sixteen empirical correlations of gas saturation pressure as a function of the variables: solubility of gas measured as gas to oil ratio (GOR), oil gravity, gas gravity and reservoir temperature. Analysis of variance (ANOVA) is then applied to the ANN correlations to test their sensitivity to specific dependant variables. That sensitivity analysis identifies that GOR and gas gravity are the key dependant variables impacting the bubble point pressure of oils. The MLP and RBF models developed using the technique on the database studied display higher correlation coefficients between predictive and published experimental data than previously published relationships implying improved accuracy.

Designing and Optimizing Deviated Wellbore Trajectories Using Novel Particle Swarm Algorithms (Atashnezhad et al., 2014) suggests improved methodologies for establishing the optimum drilling measured depth of directional and horizontal wells in 3-D space to reach desired sub-surface targets while complying with a number of linear and non-linear constraints. It establishes that meta-optimized particle swarm optimization (PSO) algorithms lead to faster convergences and more reliable results than stand-alone PSO algorithms. Meta-optimization involves an initial step to tune the behavioral parameters to be applied in the subsequent PSO step. The study uses the tuned PSO algorithms to successfully optimize measured depth for complex horizontal wellbore designs with multiple constraints. The results confirm that behavioral-parameter tuning has significant positive effects on the convergence and computation times achieved by the particle swarm optimization algorithm in providing optimum solutions to the specified wellbore designs.

Simulation, Optimization, and Sensitivity Analysis of a Natural Gas Dehydration Unit: A Case Study in Sarkhun Qeshm Gas Processing Plant; Iran (Roozbahani et al., 2014) screened thermodynamic simulation models for reliability in determining dehydration process efficiency. This led to the selection of the RSMHV2 (i.e. Redlich-Kwong-Soave equation of state with Modified-Huron-Vidal mixing rule) simulation model and a series of sensitivity analysis where performed with that model for independent variables (i.e. wet gas molar flow rate, diethylene glycol (DEG) molar flow rate, DEG purity and associated water molar flow rate) based upon the operational dependent variables (i.e., volatile organic compound (VOC) emissions, dry gas dew point, solvent loss and total process duty). The results of the sensitivity analysis are then combined to optimize (i.e. minimize) dry gas dew point, the key variable with respect to improving pipeline transportation performance. At the prevailing operating conditions of the plant the analysis revealed that a 10% increase in solvent molar flow rate could reduce the dry gas dew point by up to 6%.

Design of an Ensemble Neural Network to Improve the Identification Performance of a Gas Sweetening Plant using the Negative Correlation Learning and Genetic Algorithm (Azizkhani et al., 2014) describes the construction and application of a methodology to optimize performance of the Alkanoamine regeneration tower of the gas treatment plant associated with the Ahwaz field onshore Iran. This involves the combination of negative correlation learning and genetic algorithms to create an Ensemble Neural Network (ENN) with component neural networks being trained simultaneously. The genetic algorithm participates in the training of the component neural networks and selects the weights allocated to each trained network in the ensemble. Production of lean amine with the minimum H2S content is a key performance objective of gas sweetening plants. The steam load entering the re-boilers and the temperatures of the inlet rich amine at times (t) and (t-1) are employed as inputs of the dynamic model, together with the H_2S content of lean amine outlet from the bottom of the regeneration tower at time (t-1). The H_2S content of the lean amine at time (t) is the key monitored output of the dynamic model. The results suggest that the model proposed outperforms single and bagging neural network techniques in optimizing the plant.

Optimal Operation of Trunk Natural Gas Pipelines via an Inertia-Adaptive Particle Swarm Optimization (IAPSO) Algorithm (Wu et al., 2014) provides a method for balancing commercial operating benefits (i.e. profitability) and maximum gas throughput for a major transmission line between producing gas fields and gas customers. The optimization variables evaluated to solve this non-linear model are: the pressure, temperature, inflow rate and outflow rate at every node (i.e. point of input and offtake), the flow rate through every element (i.e. each pipeline section and compressor), and the status (i.e. on or off) and power consumed by each compressor in the pipeline network. In order to overcome premature convergence of the model and to decrease computation time, a particle swarm optimization algorithm utilizing an adaptive inertia weight strategy is applied to solve this optimization problem. The IAPSO algorithm developed is applied to the 922-km Sebei-Ningxia-Lanzhou gas transmission pipeline in China, demonstrating faster conversion speed and more consistent solutions than other particle swarm algorithms.

Simulation of a solid oxide fuel cell (SOFC) power plant based on the combination of adaptive particle swarm optimization with Levenberg-Marquardt ensemble neural network (Shirkhani et al., 2014) develops dynamic models, constructed as artificial neural networks (ANN), to evaluate power system performance, i.e. output voltage as a function fuel gas flow rates. SOFC's typically consume hydrogen derived from natural gas as the fuel. The ANN model is optimized using a hybrid adaptive particle swarm optimization (PSO) algorithm linked with a Negative Correlation Learning (NCL) method. PSO pre-trains the components of the neural network followed by training with the Levenberg-Marquardt (LM) algorithm. Whereas PSO algorithms provide a global vision of they cannot reliably or quickly find a global minimum precisely, the LM algorithm is able to find the global minimum rapidly, but require good starting points near global minimum to do so. The combined model developed therefore exploits the benefits of each algorithm overcoming their respective weaknesses. A 40-step-ahead-voltage-prediction test confirms that model developed is suitable for predicting the dynamic performance of SOFC.

Compressed natural gas (CNG) behavior in a natural gas vehicle (NGV) fuel tank during fast filling process (FFP): Mathematical modeling, thermodynamic analysis, and optimization (Khamforoush et al., 2014) focuses on improving the performance of CNG vehicle-refuelling stations by reducing the filling time of the NGV fuel tank, compressor work load, energy consumption by the post-compression coolers and increasing the mass of CNG accumulated in the NGV's fuel tank. A mathematical model is developed taking into account the multistage compression requirements of a FFP system and using thermodynamic relationships to calculate the pressure and temperature of the CNG delivered into a vehicle's fuel tank. The model is validated using simulation and measurements taken in a real operating system. The model is then optimized, using a Particle Swarm Optimization (PSO) algorithm, to minimize energy consumption in the compressors and coolers or to maximize the mass of CNG delivered to a vehicle fuel tank.

Application of Grey-Taguchi based multi-objective optimization strategy to calibrate the PM-NHC-BSFC trade-off characteristics of a CRDI assisted CNG dual-fuel engine (Roy et al., 2014) applies grey relation analysis (GRA) in conjunction with the Taguchi's L16 orthogonal array to solve the multi-objective optimization problem of load, fuel injection pressure (FIP) and CNG energy share (CES) for the simultaneous reduction of Brake Specific Fuel Consumption Equivalent (BSFCeq), oxides of nitrogen (NOx), hydrocarbon (HC) and particulate matter (PM) emissions in Common Rail Direct Fuel Injection (CRDI) assisted CNG dual fuel engines. This method reduces the number of experimental trials needed to establish optimal combinations of the multiple objectives. The method successfully optimizes the specified input parameters and identifies which factors have the greatest influence on engine emissions.

The *Journal of Natural Gas Science & Engineering* has an ongoing interest in optimization applications as applied across the natural gas industry, and is pleased to have the opportunity to review manuscripts addressing original research and case studies of such applications, ideally with computer code of the optimization algorithms proposed. I hope the articles presented here will not only provide you with ideas to develop your own ongoing research applications, but also inspire you to submit manuscripts of your current and future original research work to this journal.

Dr David A. Wood
Editor-in-Chief
Journal of Natural Gas Science & Engineering