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Development of novel correlation for prediction of hydrate formation temperature based on intelligent optimization algorithms

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ABSTRACT

Since hydrate formation could cause problems such as high pressure drop and clogging in pipelines, estimation of hydrate formation conditions is of vital importance in prevention of such problems. To do this, firstly hydrate formation conditions for methane and pure water system should be studied and then corrections be imposed on the methane–pure water system correlation to predict the formation conditions for natural gas and in the presence of impurities and salts. Many correlations for methane–pure water system have been suggested but they all seems to lack accuracy in hydrate formation conditions prediction. In this paper, on the basis of experimental data from Sloan work, a new correlation was developed using MATLAB curve fitting software and then optimized using optimization methods such as Genetic Algorithm, Particle Swarm Algorithm, and Imperialist Competitive Algorithm to enhance the accuracy of the correlation. The results of the new correlation have been compared to previous works and it shows that the new correlation has the lowest amount of error and the highest accuracy.

1. Introduction

Natural gas hydrates are crystalline solids composed of water and gas. The gas molecules (guests) are trapped in water cavities (host) that are composed of hydrogen-bonded water molecules. Typical natural gas molecules include methane, ethane, propane, and carbon dioxide (Sloan and Koh, 2008). Hydrates can form where hydrocarbons and water are present at low temperatures and high pressures. The formation of gas hydrates during hydrocarbon production and transportation causes serious problem in petroleum industries.

Gas hydrate formation is a concomitant process which requires presence of both host and guest molecular species. Conditions under which hydrates will form are determined largely by the nature of the guest, but the most common compounds of natural gas will crystallize at temperatures above the ice point with pressures nearly 10 atm. Such conditions are also common in oil and gas transmission hence gas hydrate formation is a major possible cause of pipeline occlusion (Khamehchi et al., 2013). Since 1934, when Hummerschmidt concluded that natural gas hydrates were blocking gas transmission lines, the susceptibility of forming solid hydrates in gas transmission under normal operating conditions has led to many investigations aimed at understanding and avoiding hydrate formation, an area of ongoing research (Hammerschmidt, 1934; Sloan and Koh, 2008).

K-Value method (Wilcox et al., 1941) was the first model for predicting hydrate formation conditions which utilizes the vapor–solid equilibrium constants for prediction. The hydrate forming conditions are predicted from empirically estimated vapor–solid equilibrium constants which should satisfy:

$$K_i = \frac{y_i}{x_i} \tag{1}$$

$$\sum_{i=1}^{n} \frac{y_i}{x_i} = 1 \tag{2}$$

Where y_i is the mole fraction of the ith hydrocarbon component in the gas is phase on a water-free basis and x_i is the mole fraction of the same component in the solid phase on a water-free basis. The second model known as the gas gravity method (Katz, 1945) relates the hydrate formation pressure and temperature with gas gravity.

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Few correlations have been developed by Kobayashi et al. (1987), Berge (1986), Motiee (1991), Hammerschmidt (1934) and Towler and Mokhatab correlation (Carroll, 2009) which correlate the hydrate formation temperature (HFT) as a function of pressure and gas gravity. Bahadori and Vuthaluru (2009) formulate a new empirical correlation for estimation of hydrate formation condition for sweet gas. Ameripour and Barrufet (2009) proposed two new correlations that could calculate the hydrate formation temperature or pressure. Khamehchi et al. (2013) developed new correlation to predict the hydrate formation temperature for natural gases with various gravities by utilizing IPS (Intelligent Proxy Simulator) neural network model. The main objective of the present study is to develop a new correlation for predict the hydrate formation temperature (HFT) at presence of pure water and methane. In this article we firstly develop a general form of hydrate formation temperature, using MATLAB software. Then by utilizing optimization algorithms like Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Imperialist Competitive Algorithm (ICA) the constants of new correlation have been adjusted in order to accommodate the new correlation to experimental data and reduce its error. Finally the new correlation has been compared with other correlation represented before to show its accuracy.

2. Methodology

2.1. Data collection

In this research, over 120 data point are gathered at the three-phase equilibrium of water–hydrate–vapor systems. Data are collected from Sloan and Koh (2008). The data covers wide range of pressure and temperature from 2.77 to 1000 bar and 275 to 330 K respectively for pure water–methane system. Review of literatures indicated that temperature and pressure are the common correlation variables. However, according to Ikoku (1980), hydrate-formation process is considered to be a physical rather than a chemical process and therefore, the physical properties of water could aid the gas molecules entering the void space as a guest.

2.2. Genetic algorithm (GA)

A genetic algorithm (GA) is a search investigative that imitates the process of natural evolution. This investigative is routinely used to generate useful solutions to optimization and search problems. Genetic algorithms belong to the larger class of evolutionary algorithms (EA), which generate solutions to optimization problems using techniques motivated by natural evolution, such as inheritance, mutation, selection, and crossover (http://en.wikipedia.org/wiki/Genetic_algorithms Melanie, 1996).

The genetic algorithm process is as follows (Gen and Cheng, 1997):

Step 1. Determine the number of chromosomes, generation, and mutation rate and crossover rate value
Step 2. Generate chromosome–chromosome number of the population, and the initialization value of the genes chromosome–chromosome with a random value
Step 3. Process steps 4–8 until the number of generations is met
Step 4. Evaluation of fitness value of chromosomes by calculating objective function
Step 5. Chromosomes selection
Step 6. Crossover
Step7. Mutation
Step 8. New Chromosomes (Offspring)
Step 9. Solution (Best Chromosomes)

Fig. 1 shows a simple flow chart of Genetic Algorithm.

2.3. Particle Swarm Optimization (PSO)

The Particle Swarm Optimization Algorithm (PSO), at first establish by Kennedy and Eberhart (1995), has proven to be a powerful competitor to other population based evolutionary algorithms for global optimization problems. It is a stochastic optimization technique inspired by social behavior of bird crowd or fish schooling. It is exhibit that PSO gets better results in a faster, cheaper way compared with other stochastic techniques like Genetic Algorithms (GA) (Mohamed et al., 2010). Another reason that PSO is interesting is that there are a small number of parameters to tune. Furthermore PSO has both simple formulation and computer execution.

We can summarize the basic PSO workflow in the following steps:

1. Initialize the swarm by allotting a random position in the parameter space to each particle with rational random velocity.
2. Appraise the fitness function for each particle.
3. For each individual particle, compare the particle's fitness value with its personal best position (*pbest*). If the current value is better than the *pbest* value, then the *pbest* value and the corresponding position are replaced by the current fitness value and position respectively.
4. Update the *global* best fitness value and the corresponding best position.
5. Update the velocities and positions of all the particles.
6. Repeat steps 2–5 until a stopping criterion is encountered (e.g., the maximum number of iterations or a sufficiently good fitness value).

Fig. 2 shows a basic Concept of modification of a searching point by PSO.

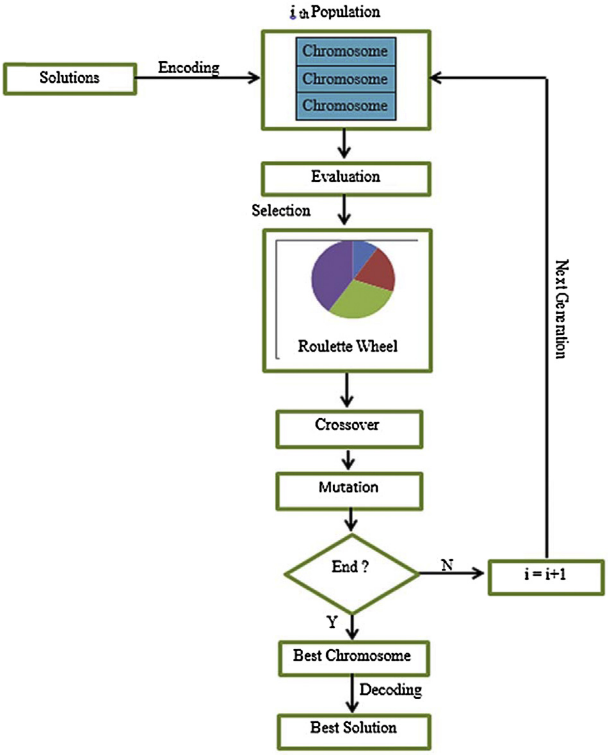

Fig. 1. The flowchart of Genetic Algorithm.