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Assessing and optimization of pipeline system performance using intelligent systems

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ABSTRACT

The fuel consumption minimization of a pipeline system including boosting units has been investigated in this paper. Virial equation of state has been used to study steady state non-isothermal flow of natural gas. Due to the complexity of mentioned equations and requirement time to study the different operating states, intelligent systems including Artificial Neural Network (ANN), Adaptive Neuro-Fuzzy inference System (ANFIS), and Fuzzy Inference System (FIS) are applied to predict and optimize the pipeline system. As a case study, IGAT 5 pipeline with four compressor stations is chosen to be explored which transports the natural gas from Asalouyeh (South Pars Energy Zone-IRAN) for oil well injection purposes. The results have shown that ANN is slightly more accurate than the other two predictive methods. Therefore ANN results are introduced to Genetic Algorithm (GA) to determine the optimum speed of each compressor and their compression ratio.

1. Introduction

The chronic dependency of industries on natural gas is due to its low price and environment friendly features compared to other fuels. The distance between natural gas refinery (gas reservoir) and the consumer is significant. In order to overcome the problem of long distances two common ways are widely suggested; the application of pipeline networks and Liquefied Natural Gas (LNG). The first one is more suitable for short distances while the second is more favorable for far distances, but it is worth noting that it has not become predominant in undeveloped countries (Ibrahim et al., 2000). In this work pipeline networks are chosen to study. Pipeline networks consist of two main parts: compressor stations and pipeline. Compressor stations are located on pipelines in order to recover the pressure drop along the pipeline by boosting the gas using turbo-compressors. Turbo-compressors consume 3–5% of the transported gas as fuel (Wu et al., 2000; Borraz-Sánchez and Ríos-Mercado, 2005). The value of consumed gas is so pronounced particularly when the volume of transported gas is high. In this regard the optimization of pipeline network procedure to minimize the fuel consumption must be considered to reduce the fuel costs and increase its efficiency (Wu, 1998).

The optimization of pipeline network has been interesting for many researchers using numerical and analytical calculations based on the type of problem. Tabkhi (2007) classified several types of pipeline network optimization methods. In this relation Oke et al. (2003) have introduced a transient model for the pipeline puncture for high pressure hydrocarbon mixtures.

Uilhoorn (2009) presented a non-isothermal transient model for mixed hydrocarbon natural gas pipelines. In this contribution Chaczykowski (2010) investigated the one dimensional non-isothermal flow to simulate the slow and fast transients. The results of such researches were used to determine the effects of different pipeline thermal models on the gas flow rate. The pipeline optimization includes the determination of the optimum design parameters like pipeline diameter, number of turbo-compressors, the distance between compressor stations (Tabkhi et al., 2009), and and etc., or the optimum independent variables like the compressor and the fan cooler speed (Chaczykowski et al., 2011). In order to attain the best answer several methods can be employed. Borraz-Sánchez and Ríos-Mercado (2009) used the tabu search method to optimize the operation of pipeline system. In another

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study the optimization of pipeline using ant colony was done by Chebouba et al. (2009). All of the optimization methods which are used so far have been about the turbo-compressors in particular centrifugal compressors. These compressors are prevalently used because of their flexibility for different operation conditions. In this regard there are interesting studies about the modeling of turbo-compressor performance which plays a fundamental role in pipeline networks optimization. Odom and Muster (2009) presented the simple approximations to relate the compressor's head and efficiency to the gas volumetric flow and compressor speed.

When the systems are complex to interpret and also the accurate information about the process may not be available or they have a nonlinear time variable behavior, the results of modeling using knowledge based approaches may not be convincing. Due to the lack of information and difficulties in prediction of gas turbine and compressor efficiency, intelligent systems may be used to find the relations between the involved parameters (Acaroglu, 2011; Takassi et al., 2011). The results of modeling works to predict the gas turbine and compressor efficiency cannot be extended to general conditions, since they are based on specific assumptions (Wu, 1998; Wu et al., 2000; Abbaspour et al., 2005; Borraz-Sánchez and Ríos-Mercado, 2005, 2009; Tabkhi, 2007; Uilhoorn, 2009; Chaczykowski, 2010). Therefore the significance of techniques which depend on experimental data such as Artificial Neural Network (ANN), Adaptive Neuro-Fuzzy inference System (ANFIS), and Fuzzy Inference System (FIS) seems to be obvious. The capability of these prediction methods in several processes such as catalyst behavior (Takassi et al., 2011), normal cutting forces (Acaroglu, 2011), water treatment (Rahmanian et al., 2011, 2012), thermosyphon thermal performance (Shanbedi et al., 2013), crude oil viscosity (Abedini et al., 2012), wind generator optimized performance (Meharrar et al., 2011), cavity thermal performance (Aminossadati et al., 2012), membrane processes (Chakraborty et al., 2003), and etc. has been approved before.

In the course of current work an inclusive approach is used to model the steady state non-isothermal flow of natural gas pipeline having compressor stations. The real gas model is applied using Virial corresponding state. Each compressor station comprises of three main elements; compressor, gas turbine, and fan cooler. The objective target of this paper is minimizing the fuel consumption in gas turbine which is a function of compressor speed and discharge pressure. Due to the large number of involved equations and their complexity and required long time of calculations to determine the optimum compressor speed of each one, intelligent systems including ANN, ANFIS, and FIS along with the Genetic Algorithm (GA) are used to predict the relationship between the decisive parameters and optimize the objective parameter which is the fuel consumption.

2. Thermodynamic and mathematical model

Gas transmission networks are comprised of compressor stations and connected pipelines to deliver the gas to specific far destinations. In this part, a comprehensive model is presented to model turbo-compressors and fan coolers under non-isothermal steady state conditions in a specific boosting. Initially the physical properties and real gas model are applied, and then the mathematical model for each part of compressor stations and pipeline as is presented which is derived from mass, momentum, and heat conversion laws. Fuel consumption of a turbine is determined using characteristic curves of turbine and compressor which are unique for each one.

2.1. Real gas model and specific heat capacity

It is appropriate to use an equation of states to calculate the gas mixture features confidently, where the parameters have physical significance and are related to each other directly with intermolecular forces so that Virial equation of state is acceptable enough to be applied (Prausnitz et al., 1998). In this regard this equation is used for the gas which is boosted in compressor stations and in pipelines.

The Virial equation of state gives the compressibility factor as function of (T, ρ) (Prausnitz et al., 1998):

$$Z = 1 + B\rho_n + C\rho_n^2 \tag{1}$$

where ρ_n is the molar density (mol/cm^3). It is more suitable to use temperature and pressure (T, P) as an independent variable instead of (T, ρ), therefore compressibility factor will be calculated as follow (Sengers et al., 2000):

$$Z = 1 + B'P + C'P^2 \tag{2}$$

The coefficients in equation (2) are exclusively related to Virial coefficients as below (Sengers et al., 2000):

$$B' = \frac{B}{RT} \tag{3}$$

$$C' = \frac{(C - B^2)}{(RT)^2} \tag{4}$$

For a mixture of m components, the second and the third Virial coefficients will be calculated using mixing rules (Prausnitz et al., 1998):

$$B = \sum_{i=1}^{m}\sum_{j=1}^{m} x_i x_j B_{ij} \tag{5}$$

$$C = \sum_{i=1}\sum_{j=1}\sum_{k=1} x_i x_j x_k C_{ijk} \tag{6}$$

where B and C can be computed for pure components using some other relations which consider the intermolecular effects and are functions of reduced temperature and pressure (Prausnitz et al., 1998; Sengers et al., 2000).

The real specific heat capacity, C_p, can be estimated considering Virial equation of state as follow:

$$C_p = C_p^0 - T\int_p^p \left(\frac{\partial^2 v}{\partial^2 T}\right)_p \mathrm{d}p \tag{7}$$

Ideal specific heat capacity can be obtained from Perry's handbook for the components of natural gas (Seader et al., 1997):

$$C_p^0 = c_1 + c_2\left(\frac{\frac{c_3}{T}}{\sinh\left(\frac{c_3}{T}\right)}\right)^2 + c_4\left(\frac{\frac{c_5}{T}}{\cosh\left(\frac{c_5}{T}\right)}\right)^2 \tag{8}$$

Using mixing rule, the ideal specific heat capacity of natural gas is obtained:

$$C_p^0 = \sum C_{pi}^0 y_i \tag{9}$$

The real specific heat capacity at constant pressure considering the Virial equation of state can be simplified as below: