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Prediction of natural gas flow through chokes using support vector machine algorithm

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ABSTRACT

In oil and gas fields, it is a common practice to flow liquid and gas mixtures through choke valves. In general, different types of primary valves are employed to control pressure and flow rate when the producing well directs the natural gas to the processing equipment. In this case, the valve normally is affected by elevated levels of flow (or velocity) as well as solid materials suspended in the gas phase (e.g., fine sand and other debris). Both surface and subsurface chokes may be installed to regulate flow rates and to protect the porous medium and surface facilities from unusual pressure instabilities.

In this study a reliable, novel, computer based predictive model using Least-Squares Support Vector Machine (LSSVM) algorithm is applied to predict choke flow coefficient in both nozzle and orifice type chokes in subsonic natural gas flow conditions. The average absolute relative deviation of the proposed model from reported data for nozzle-type and orifice-type choke are nearly 0.25% and 0.15% and the squared correlation coefficient is around 0.9961 and 0.9982 respectively.

1. Introduction

Wellhead chokes are typically utilized to control oil and gas flow rates from producing wells in the petroleum industry, so chokes ensure stable pressure downstream, offer the required back-pressure to a reservoir and prevent formation damage from overmuch drawdown (Guo et al., 2007). Both surface and subsurface chokes have been installed in flow lines to control flow rates and to provide protection the formation and surface appliances from abnormal fluctuations in pressure.

Furthermore, some atypical choke-like constrictions may shrinkage and limit the flow rate from a blown-out well (Clark and Perkins, 1981). The compressible fluid flow pipeline system designers should presuppose the phenomenon of choked flow toward the mass flow rate eventuate a maximum value (Sachdeva et al., 1986; Morris, 1996). Changing of flow area may consequences the choked flow, For instance, in a process element (e.g., a safety or/and control valve) and at a pipeline extension. Those chokes are nozzles, fixed or adjustable orifices (Morris, 1996). Diversification of factors such as comprehending well potential, prevention of water/gas coning or sand production, controlling reservoir depletion, pressure drop imposed by surface equipment and other parameters may make it advantageous to limit the production rate from a flowing well (Rodriguez et al., 2013). As a choke must be very qualified to tolerate a wide range of flow rates, therefore its design requires careful selection of flow path profiles, valve configuration and ease of maintenance (Keith and Crowl, 2005).

Flow regime in the choke:

The Flow regimes are classified into two main groups; namely critical and sub-critical while the fluid going through a surface choke.

1.1. Critical flow

The critical flow occurs when the fluid velocity of attains the sonic velocity for the two-phase flow condition and the flow rate is not affected by the downstream pressure which is called downstream pressure independency (Al-Attar, 2008). At critical flow condition, the choke experiences a discontinuity in pressure,

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implying that the upstream pressure is not dependent on the downstream pressure.

Literature (Guo and Ghalambor, 2005) mentioned that stabilization of well production rate and separation operation condition have been obtained by applying critical flow rate through choke.

Even though critical flow regime results constant and independent to upstream pressure velocity, but because of dependency of gas density to pressure, mass flux should be altered by changing in upstream pressure (Ling, 2012).

1.2. Subcritical flow

On the other hand, in the sub-critical flow regime, the flow rate pertain to the pressure difference and the effect of changing in downstream pressure on upstream pressure (Al-Attar, 2008).

Because of difficulty with estimation gas and sound velocities in the field, practically the ratio of downstream to upstream pressure is typically applied to characterize critical flow regime from subcritical. The subsonic (subcritical) flow is maintained, if this pressure ratio has a value higher than or the same as the critical pressure ratio (Perry, 1984; Ashford, 1974).

The critical pressure ratio is defined in terms of the gas specific heat ratio, as given below,

$$\left(\frac{P_{\text{outlet}}}{P_{\text{up}}}\right)_{\text{c}} = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} \tag{1}$$

in which, P_{outlet} represents the outlet pressure (or downstream) of the choke, P_{up} introduces the gas inlet pressure (or upstream) of the choke, and k refers to the specific heat ratio of gas (Cp/Cv). The typical values of k are 1.4 and 1.28 for air and natural gas (NG), respectively. Hence, the critical pressure ratio of air is determined to be 0.528, while natural gas holds a value of 0.549 for this ratio (Ashford, 1974).

1.3. Pressure equation for choke: sonic and subsonic

Prognostication of pressure drop across the chokes has not a general equation for different kinds of production fluids. To choose a choke flow model, the necessity of consideration of some factors like gas fraction in the fluid and flow conditions or regimes (It means sonic or subsonic) have been accentuated in literature (Nøkleberg and Søntvedt, 1995).

The time limitation for heat transfer (referring to adiabatic condition) and minority of friction loss at chokes (implying process reversibility) direct to isentropic-based pressure equations that should be applied to fluid flow across chokes (Guo and Ghalambor, 2005).

Pressure drop across chokes results gas temperature reduction. So if the gas has considerable water content and gas temperature is below hydrate formation temperature, gas hydrate formation will observe (Stewart and Arnold, 2011).

1.4. Subsonic flow equation

Gas flux through a choke at subsonic condition is shown by following equation:

$$Q_{\text{sc}} = 1248CAP_{\text{up}}\sqrt{\frac{k}{(k-1)\gamma_{\text{g}}T_{\text{up}}}\left[\left(\frac{P_{\text{dn}}}{P_{\text{up}}}\right)^{\frac{2}{k}} - \left(\frac{P_{\text{dn}}}{P_{\text{up}}}\right)^{\frac{k+1}{k}}\right]} \tag{2}$$

In Eq. (2), Q_{sc}(Mscf/d) is the flow rate of gas, P_{up} (psia) stands for the upstream pressure at choke, A (in^2) represents the choke cross-sectional area, T_{up} (°R) is the upstream temperature, g (32.2 ft/s^2) is the symbol for the gravitational acceleration, γ_{g} refers to the specific gravity of gas with respect to air, and C introduces the choke flow coefficient.

Table 1
Statistical description of applied data base for developing nuzzle-type choke predictive model.

Parameter	Min	Max	Average
Reynolds number	4000	2,000,000	346,689
d/D (ratio of choke diameter to pipe diameter)	0.4	0.725	0.587043
Choke flow coefficient	0.9425	1.2	1.056067

Sound velocity in the gas is greater than gas velocity at the in situ conditions when the flow regime is subsonic. The velocity is written as follows (Guo and Ghalambor, 2005):

$$v = \sqrt{v_{\text{up}}^2 + 2g_{\text{c}}C_pT_{\text{up}}\left[1 - \frac{z_{\text{up}}}{z_{\text{dn}}}\left(\frac{p_{\text{down}}}{p_{\text{up}}}\right)^{\frac{k-1}{k}}\right]} \tag{3}$$

where C_p is the gas specific heat at a constant pressure. This parameter for air equals 187.7 lbf-ft/lbm-R.

1.5. Sonic flow equation

Maximum gas rate through choke is observed during sonic flow condition. For an ideal gas, passaging rate would be expressed as following equation:

$$Q_{\text{sc}} = 879CAP_{\text{up}}\sqrt{\left(\frac{k}{\gamma_{\text{g}}T_{\text{up}}}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \tag{4}$$

Sensitivity of the choke flow coefficient “C” to Reynolds number is negligible when the Reynolds number is higher than 10^6. For this reason, the “C” value corresponding to the Reynolds number of 10^6 is utilized for “C” parameter at greater values of the Reynolds numbers.

It has been perceived that most of wells in the field operate at subcritical condition (Fortunati, 1972).

2. Data collection and statistics

The sufficiency and accuracy of each collected data set play an important role to propose any acceptable model.

171 data point are related to orifice type choke and 164 data point are relevant to nozzle type choke that all were collected from Guo and Ghalambor (2005).

Recent researches (Bahadori, 2012a,b; Guo and Ghalambor, 2005) proposed that choke flow coefficient for two mentioned type of chokes is depended to Reynolds number and the ratio of choke diameter to pipe diameter.

A statistical analysis of the datasets for nozzle and orifice type choke is shown in Tables 1 and 2 respectively. As it can be seen, the data points cover applicable range of independent variables.

Table 2
Statistical description of applied data base for developing orifice-type choke predictive model.

Parameter	Min	Max	Average
Reynolds number	4000	3,000,000	402,070.2
d/D	0.2	0.75	0.5262
Choke flow coefficient	0.585	0.792	0.6598