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Novel natural gas molecular weight calculator equation as a functional of only temperature, pressure and sound speed

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ABSTRACT

In city gate stations (CGS) experimental facilities are currently employed to specify natural gas compositions and subsequently calculate its density. Then, natural gas mass flow rate is calculated by employing an Ultrasonic Flow Meter (UFM), and a volume corrector to convert the given value to its equivalent in standard conditions. As online measurement of natural gas compositions is a costly and difficult task, this study presents an innovative method for natural gas mass flow metering in CGSs. In this method, a novel correlation, which is a functional of only three simple measurable variables i.e. temperature, pressure and sound speed, is presented for calculating natural gas molecular weight, and then, employing the authentic equations of state (EOS) of AGA8 for natural gas, its density could be calculated. The correlation was developed based on curve fitting and data mining approaches on a large database associated with four different natural gas fields of Iran and its accuracy was validated with available experimental data for seven other Iran's natural gas fields and two more gases with sample compositions. Each database in correlation development and validation stage (13 databases altogether) consists of 17,000 sound speed values in all possible temperature and pressure ranges in CGSs after expansion process. Mean absolute error (MAE) and mean absolute percentage error (MAPE) methods are used to validate the correlation accuracy and compare its performance with the correlation presented previously for the same objective. The evaluation results prove high prediction accuracy for the presented correlation and its superiority comparing to the previous work.

1. Introduction

Natural gas mass flow metering is a big problem in natural gas distribution systems as its compositions, even in an individual natural gas pipeline, could vary significantly over time. Therefore, sophisticated experimental facilities are required to measure the natural gas compositions and removing these facilities from mass flow metering systems in transmission pipelines (specially CGSs) has been the concern of experts working in this area. Over the last years, many devices such as multiple ultrasonic transient-time meters as alternative devices for conventional orifice plates and turbine meters have been employed for natural gas metering (Froysa and Lunde, 2005). Basically, these devices meter the stream volume flow rate and the natural gas density is also required for calculating its mass flow rate. Natural gas density can be directly measured, independent of pressure and temperature effects, by Coriolis density meters; mass flow controllers; gas chromatographs and etc. However, there are some disadvantages with such devices and their most highlighted disadvantage is that the use of these devices is work demanding and costly. Also, another aspect of importance in these instruments is the ability of detecting drift as a common problem. That's why; reducing the number of such devices in metering stations (specifically CGS) is highly addressed in the corresponding studies (Smalling et al., 1986; Valdes and Cadet, 1991).

For this aim, many studies have already been done and the number of studies in this area is increasing so fast. For example, Ref. (Smalling et al., 1986) refers to an invention that introduces an apparatus for flow metering in tubes. However, this apparatus is only suitable for low concentration gases and in the velocity range of 0–50 ft/s and even in this velocity range, prediction deviations up to 2% is expected for mass flow metering. Therefore, this is clear

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that the device could not be recommended to be used in CGSs as not only natural gas is not a low concentration composition, but also in a CGS, in many cases, the velocity of natural gas stream is higher than 50 ft/s. Also, 2% prediction deviation for mass flow rate seems to be much more than standard levels. Ref. (Hiismaeki, 1993) also points out to another device made for the same objective; however, this instrument is only applicable for such low pressures in which natural gas behaves like an ideal gas while natural gas status through CGSs is far away from an ideal gas. Ref. (Valdes and Cadet, 1991) employs the heavy virial equation (Hirschfelder et al., 1964) to calculate natural gas molecular weight based on the computed sound speed as a functional of pressure, temperature and gas compositions. Although the device accuracy is really high, the compositions of the natural gas mixture are still required in this method. There are other similar works which are worth mentioning in this area (Hammond, 2001; Watson and A White, 1982; Dell'Isola et al., 1997; Buonanno et al., 1998).

On the other hand, EOSs are widely used for computing natural gas density. Most broadly employed standard EOSs for natural gas are AGA8 and GERG2008 (AGA8 and Compressibility and, 1992; Farzaneh-Gord and Rahbari, 2011). However, even these EOSs, in addition to temperature and pressure, need either the natural gas compositions or molecular weight, for calculating its density. In fact, knowing the compositions, these EOSs calculate the natural gas molecular weight and subsequently, this value is used for density measurement (Farzaneh-Gord and Rahbari, 2011). Therefore, what is the main essential information of these EOSs for density metering is the mixture molecular weight. It is worth mentioning that AGA8 and GERG2008 are not the only equations that could be used for density measurement of natural gas mixtures and several more correlations have been developed for this objective. Dranchuk and Abou-Kassem developed a gas density calculator correlation utilizing 1500 data points, including pure gases and gas mixtures from different sources (Dranchuk and Abou-Kassem, 1975). Londono et al. reported simplified correlations for calculating the density of hydrocarbon gases like natural gas (Londono et al., 2002). Al-Quraishia and Shokirb employed Alternating Conditional Expectations (ACE) algorithm and presented a new equation for computing the density of hydrocarbon gases and pure and impure gas mixtures (AlQuraishi and Shokir, 2009). There are also other authentic references in this field (Gysling, 2007; Hall and Holste, 1995; Farzaneh-Gord et al., 2015c; Standing and Katz, 1942; Weberg, 1990). In another work, Farzaneh-Gord and Rahbari developed novel correlations for calculating most thermodynamic and thermal properties of natural gas such as density based on AGA8 EOS (Farzaneh-Gord and Rahbari, 2011). In the mentioned study, each thermodynamic property is a functional of natural gas pressure, temperature and specific gravity. These methods were developed by Farzaneh-Gord and Rahbari (Farzaneh-Gord and Rahbari, 2011) and were previously presented in Farzaneh-Gord et al. (Farzaneh-Gord et al., 2010; Farzaneh-Gord and Rahbari, 2012) and Marić (Marić, 2005, 2006; Marić et al., 2004).

Also, in one of the last studies in this area, Farzaneh-Gord et al. (Farzaneh-Gord et al., 2015a) developed a correlation to calculate natural gas molecular weight as a functional of temperature, pressure and Joule–Thomson coefficient of natural gas in CGSs. In an almost similar manner, this works presents a novel correlation for calculating the molecular weight of natural gas stream just as a functional of its pressure, temperature and sound speed while there is no information about its compositions. Having the value of molecular weight calculated by the presented correlation, one could then calculate the natural gas density by employing AGA8 EOS. Finally, using the value of density given by AGA8 EOS and the data given by the UFM and volume corrector existent at the CGS, natural gas mass flow rate passing through the CGS is easily calculated. The main advantage of the current study relative to Ref. (Farzaneh-Gord et al., 2015a) is that the accuracy of the correlation presented in this work almost doubles. Also, in contrast with the previous study in which CGS configuration needed to be revised by adding some facilities to measure natural gas Joule–-Thomson coefficient, the CGS conventional configuration is not supposed to be amended in this method. Detailed information related to the proposed approach is presented in sections 3 and 4. It should be mentioned that the correlation development and its validation has been done by accurate curve fitting and data mining method on a large database associated with 11 major natural gas fields of Iran and two more sample gases.

2. Current flow metering method

The first question may arise here is that what a CGS is. In fact, a CGS is a station close to natural gas consumption points in which natural gas pressure is reduced significantly, from almost 1000 psi to 250 psi (Farzaneh-Gord et al., 2011; Farzaneh-Gord et al., 2012; Arabkoohsar et al., 2015; Farzaneh-Gord et al., 2015; Arabkoohsar et al., 2014). As it was mentioned before, CGS is one of main places in natural gas transmission system in which mass flow metering is carried out. Fig. 1 illustrates how natural gas mass flow rate is currently measured in CGSs of Iran (and probably other countries as well). According to the figure, experimental facilities are employed to measure natural gas compositions, and subsequently its density. Also, in addition to temperature and pressure gauges, there is a UFM to calculate the natural gas stream velocity. Finally, a volume corrector receives all these four measured values (i.e. natural gas stream velocity, its temperature, pressure and density) to calculate the natural gas mass flow rate based on standard condition ($P = 0.1$ MPa and $T = 25$ °C).

The main problem of this method is the high deviation of gas density relative to the actual value as it is measured once or at most twice a year because natural gas composition measurement process by the experimental facilities is really costly. Therefore, as long as the experimental instruments or online density meter instruments are available, natural gas density could be calculated accurately; otherwise, mass flow rate measurement would not be accurate enough. That's why presenting novel, simple and accurate real time methods of natural gas mass flow metering seems to be very beneficial.

3. The proposed idea

Based on the presented information in introduction section, the main goal of this work is to facilitate natural gas mass flow metering in CGSs as one main places of natural gas industry. For this objective, a novel correlation for molecular weight calculation of natural gas mixtures just as a functional of three easy measurable parameters, i.e. natural gas temperature, pressure and sound speed, is developed. Then, using the calculated value of molecular weight by this correlation along with the natural gas temperature and pressure as the essential input information of AGA8 EOS (as one of

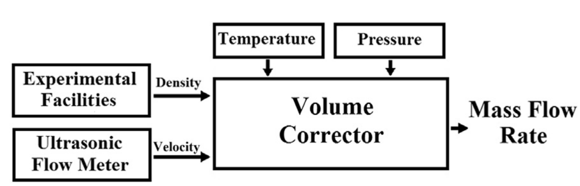

Fig. 1. Natural gas mass flow rate metering process diagram.