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Investigation of hydrate formation in natural gas flow through underground transmission pipeline

Mahmood Farzaneh-Gord [a, *], Hamid Reza Rahbari [a], Mahdi Bajelan [b], Lila Pilehvari [b]

[a] *The Faculty of Mechanical Engineering, Shahrood University of Technology, Shahrood, Iran*
[b] *The Lorestan Gas Company, Khoram Abad, Iran*

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ABSTRACT

A natural gas underground transmission pipeline has been simulated by solving governing equations for one-dimensional non-isothermal compressible viscous flow in steady state condition. Temperature and pressure profiles have been calculated and temperature propagation distance has been calculated for various conditions. The natural gas is considered as a real gas and effect of composition has been studied. The possibility of gas hydrate formation as an important parameter in the natural gas pipeline has been investigated. Numerical calculations have been compared with previous studies. Results show that there is less than 3% difference between current and previous studies. Results also show that natural gas composition has no effect on temperature and pressure profiles but has a big effect on natural gas hydrate temperature and temperature propagation distance. For natural gas with low molar mass, the hydrate temperature is very low and consequently, the temperature profile along the pipeline is higher than the hydrate temperature. For natural gas with a higher molar mass and consequently low hydrate formation temperature, the natural gas temperature along pipeline may fall below the hydrate temperature.

1. Introduction

Natural gas is an important fuel and widely used in households and industry. Natural gas is transported through high pressure underground transmission pipelines before reaching its destination at City Gate Stations (CGS). There will be a pressure loss during this flow transportation. Natural gas pressure has to be raised at certain distances along the transmission gas pipeline between 60 and 160 km to overcome pressure loss. The natural gas pressure is increased at compressor stations (CS) by gas turbine, electric motor or internal combustion engine driven compressors.

At certain thermodynamic conditions in natural gas flow, ice-like crystalline compounds are formed which are commonly called gas hydrates. This thermodynamic condition is a function of natural gas pressure, temperature and composition. It is mentioned that the plugging of transmission pipelines is due to hydrates formation (Nasrifar et al., 1998). Other issues with formation of solid hydrate within the transmission pipeline include the fouling of the line heater (for preheating natural gas in CGS) and other utilities downstream of pipelines, internal erosion and corrosion and even blocking pipelines (Nasrifar et al., 1998). Consequently, it is recommended that the gas temperature within pipelines be higher than hydrate temperature.

As natural gas flows in pipeline, its temperatures and pressure varies. The natural gas temperature within pipeline should be always higher than local hydrate temperature to prevent hydrate forming. To be able to predict the temperature profile within a pipeline, the heat transfer and fluid flow between the natural gas and environment should be considered simultaneously.

In most previous studies, natural gas temperature in underground pipeline has been considered isothermal. Also the natural gas has been considered as an ideal gas. Here, natural gas flow within an underground transmission pipeline between a CS and CGS has been studied. A non-isothermal model has been considered for natural gas flow. Natural gas has been treated as real gas and the effect of natural gas composition have been also studied on temperature and pressure profiles. The natural gas hydrate temperature has been calculated along the pipeline based on gas composition and local pressure. The difference between local gas temperature and hydrate temperature has been compared and possibility of falling behind hydrate temperature is investigated. A correlation has been developed for predicting the length at which

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[*] Corresponding author. Tel.: +98 273 3330040x3353; fax: +98 273 3330258.

E-mail addresses: mahmood.farzaneh@yahoo.co.uk, mgord@shahroodut.ac.ir (M. Farzaneh-Gord), rahbarihamidreza@yahoo.com (H.R. Rahbari), Mahdibajelan@yahoo.com (M. Bajelan), pilehvari@nigc-lorestan.ir (L. Pilehvari).

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the gas temperature reaches to 99% of soil (underground) temperature.

2. Summary of recent work on this subject

There are many published articles about thermodynamic and heat transfer simulation of natural gas transmission pipelines (Churchill, 1980; Crowl and Louvar, 2002; Levenspeil, 1984; Crane, 1988). In the most studies, isothermal flow conditions have been considered. One-dimensional compressible flow with friction and heat transfer has been the focus of most research (Farina, 1997; Cochran, 1996). Gersten et al. (2001) have simulated natural gas flow in both onshore and offshore pipelines based on a steady-state non-isothermal gas flow. They showed that uncertainties in planned transport capacities and pressure losses reduce by considering heat-transfer. Osiadacz and Chaczykowski (2001) present a comparison of isothermal and non-isothermal pipeline ideal gas flow models. The steady-state heat-transfer term for calculating heat exchange between the gas and the surrounding soil has been considered. Nevertheless, it has been shown that there is a significant difference between pressure profile along the pipeline between isothermal and non-isothermal flow models. The work of Modisette (2002) concluded that the accuracy of the heat-transfer model affects both line-pack and pressure loss in gas pipelines. Duan et al. (2012) have been working on a derivate energy equation for the oil-gas flow in pipelines. They have produced the Explicit Temperature Drop Formula (ETDF) for oil-gas steady state temperature calculation. This new energy equation has considered many factors, such as Joule–Thomson effect, pressure work, friction work and impact of terrain undulation and heat transfer with the surroundings along the line. Their work concluded that elimination of the temperature iteration loop and integration of the explicit temperature equation, instead of the enthalpy energy equation used in the ETDF is a valid approach. Dorao and Fernandino (2011) have simulated natural gas flow in pipelines under transient conditions. Their results show that the development of transient simulators of pipeline systems presents several applications such as providing tools for training operation personnel, support tools for on-line systems, and during the design phase of a gas pipeline. Najibi and Taghavi (2011) have studied the effect of important parameters on optimum design for high pressure natural gas transmission pipeline. They have investigated technical and economical points of view for optimal transmission pipeline design and operation.

In the field of underground natural gas pipelines, a few studies have been conducted. The Schorre equation (Schorre, 1954) is a well-known relationship for predicting temperature variation within the pipeline. Forrest (1978) interpreted and modified the Schorre equation to implement the Joule–Thomson variation effect. Coulter (1979) solved the energy equation by using the compression factor and assuming constant heat capacity at constant pressure, to derive the temperature profile along the pipelines. Edalat and Mansoori (1988) predicted the temperature profile of underground pipeline flow based on the corresponding states principle. They introduced an analytical technique through considering that the Joule–Thomson coefficient and heat capacity at constant pressure are functions of both temperature and pressure. Chung et al. (1999) have presented a semi-analytical solution for heat transfer from an underground gas pipeline with convection on the exposed surface. In their study, the effects of finite convective heat loss from the exposed ground surface were investigated for an underground gas pipeline. Nouri-BorujerdiZiaei-Rad (2009) analyzed the gas flow in high-pressure buried gas pipelines subjected to wall friction and heat transfer. Their study was performed for two compressor stations and assumed that the natural gas is an ideal gas. Sanaye and Mahmoudimehr (2012) have modeled isothermal and non-isothermal natural gas pipelines including equipment in a gas pipeline by deriving a new form of conservation equation set for compressible flow. Their results show that higher ground temperatures increased the gas flow temperature, volumetric flow rate and pressure loss. These factors increased the required compressor power and fuel consumption.

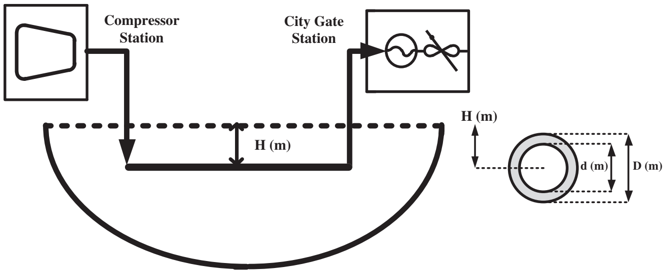

Fig. 1. Underground transmission natural gas pipeline between a CS and a CGS.

There are also studies on aboveground pipeline flow. Farzaneh-Gord et al. (2010a) have investigated the effects of exterior surface paint color on temperature profile for above ground pipelines. Their results show emissivity and absorptivity of surface are the predominant parameters in temperature profile flow which can increase or decrease pipe surface and fluid temperature especially for low Reynolds number flow. Farzaneh-Gord et al. (2011a) have studied reducing uncertainty in crude oil measurement by selecting an optimized envelope color of a pipeline. They have developed an analytical model for predicting oil temperature at the pipeline exit (the metering point) based on climate and geographical conditions. They have studied the effects of envelope color and the uncertainty in the measurement system due to temperature rise. Farzaneh-Gord et al. (2011b) have studied uncertainty reduction for the metering system by adjusting pipeline volume flow rate. Their results show that outlet oil temperature from the pipeline increases either by lowering volume flow rate or using darker painting (higher absorptivity and lower emissivity) for the pipeline exterior surface. Also they show that uncertainty in measurement could be reduced by painting the exterior surface with the lightest color (lower absorptivity and higher emissivity; e.g. white) which seems a practical approach.

3. Modeling problem

Fig. 1 shows an underground natural gas pipeline between a CS and a CGS for transporting natural gas between two positions.

Governing equations for compressible one-dimensional steady-state real gas flow through a circular pipe are as follows:

Conversion of mass in one-dimensional pipeline has been defined by following equation

$$\frac{\partial(\rho u)}{\partial x} = 0 \tag{1}$$

In Equation (1), ρ is density, u is velocity.

Density of natural gas in pipeline could be calculated by the following equation

$$\rho = \frac{P}{ZRT} \tag{2}$$

In Equation (2) Z is compressibility factor. Compressibility is a function of temperature and pressure as well as composition ($Z = Z(T,P)$). There are various types of equations of state (EOS) for predicting natural gas compressibility. The sensitivity of the