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Model Formulation for the Exact Position of Dew Point along a Gas Pipeline

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Abstract

The natural gas piping network is often laid under the seabed, under or above earth surface through places of various temperature gradients. In such environments, if the temperature of the flowing stream of gas is below the water or hydrocarbons dew points, temperatures condensation occurs. The condensates so formed accumulate at low points in the pipes, thereby obstructing the flow of gas. Flow obstruction leads to pressure drop along the line. Hydrates can also be formed if there is excessive cooling of the gas due to pressure drop. The result of this is obstruction of flow or freeze-up of the valves, a worst-case situation leading to total obstruction of flow. This necessitates the need to find at what point along a pipeline at which condensation will commence after attainment of dew point for natural gas gaseous mixtures. The mathematical models so generated help to determine the dew point of such hydrocarbon's mixtures and the extent of the length from the upstream end of the pipeline at which dew point will be attained. To stop attainment of dew point temperature on a prolongs pipe length, the pipe is covered with a layer of insulating materials of low thermal conductivity.

Keywords: Mass Flowrate; Specific Heat Capacity; Burial Depth; Convective Heat Transfer; Thermal Conductivity; Residual Heat; Dew Point Temperature; Flow Resident Time.

1. Introduction

The natural gas piping network is laid over thousands of kilometres [1]. By several temperature differences of such places, dew point temperature of the hydrocarbon's mixtures might be approached, leading to the formation of condensates. This condition might lead to excessive pressure drops; this governing factor is resulting in extreme cooling and eventual formation of hydrates [2]. The mathematical model so developed is a remedial measure to ascertaining the dew point temperature and the exact point on a pipeline. Drain plugs could be installed at such points for periodical draining out of the condensates that are formed.

Hydrocarbon dew point determination is it the gas chromatography method, Chilled mirror method, or gas equations approach still shows a wide margin of deviation when results are compared. The dew point temperature is highly dependent on the operating steam pressure, environmental effects and gas composition [3, 4, 5]. In general term, the accuracy of these methods is within -5% to 5%. Hence the need to consistently formulate models that could correlate the experimental results and mathematical models results to a close margin of accuracy. By so doing the problem of excessive pressure drop due to flow obstruction can be gotten rid off. This helps in optimizing the cost of design, construction, operation and maintenance of the natural gas piping network.

2 Purposes and Significance

Gas pipelines systems with reference to Natural Gas Pipelines approach due point temperatures because of environmental effects, average flow stream pressure, bulk stream temperature, cooling associated with pressure drops at valves and fittings, the sudden expansion of the fluid stream in the pipeline among others. These effects can lead to condensation or liquid fallout from heavy hydrocarbon components of the gaseous mixture. The liquid fallout if not timely recovered could lead to increased line pressure drop, decreased heating value of gas steam, increased pumping and compression power, reduction inline transmission efficiency, higher cost of investment and operation of gas pipeline assets and facilities and other undesirable effects.

In gas pipeline network system, point of attainment of dew point temperature must be ascertained d to enable installation of drain plugs for periodical removal of the liquid fallout and the condensates so formed. Gas chromatographs, chilled mirror, gas equations of state such as Peng Robinson, Redlich Kwong Soave and PG-SAFT methods had been used at one time or the other for hydrocarbon dew point determination, even the characterization of the gas stream. This paper is to exploit the fundamental heat flux concept for the determination of dew point temperature of the complex hydrocarbon mixture. This approach would generate comparative analysis with other existing methods of dew point calculation of natural gas stream in the pipeline network system.

3 Mathematical Models for Determination of Exact Position of Dew Point along a Pipeline

Referring to Figure 1, consider a cylindrical pipe of certain thickness with a layer of insulating material of a particular thickness around it. The heat flux, q, crossing the system boundary, using the concept of a cylindrical coordinate system can be expressed as:

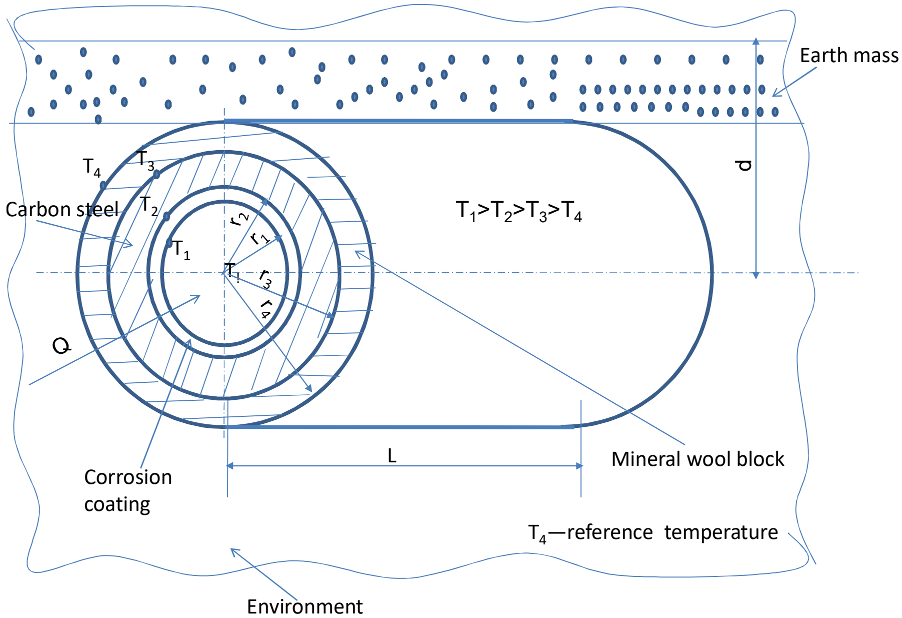

Figure 1: Cylindrical pipe of certain thickness with a layer of insulating material

$$q = \frac{2\pi L(T_1 - T_4)}{\frac{1}{h_{in}} + \ln\left(\frac{r_2}{r_1}\right)/K_{As} + \ln\left(\frac{r_3}{r_2}\right)/K_{cs} + \ln\left(\frac{r_4}{r_3}\right)/K_{mw} + \ln\left[\left(\frac{d}{r_4}\right) + \sqrt{\left(\frac{d}{r_4}\right)^2 - 1}\right]/K_S} \tag{1}$$

$$h_{in} = 0.0225\frac{K_f}{2r_1}\left[\frac{2Vr_1}{\nu_f}\right]^{0.8}\left[\frac{C_{Pf}\nu_f\rho_f}{K_f}\right]^{0.4} \tag{2}$$

The first term in the denominator of equation 1 gives the contribution to heat loss by the convective circulation of the fluid stream. The second term is the heat loss contribution due to the conductivity of the corrosion coating; the third term is the loss contribution due to the thermal conductivity of the pipe. The fourth and fifth terms are respectively, the contributions resulting from the thermal conductivities of the insulation materials and the mass of the overlying soil [7, 8].

If R_L and R_G are the liquid and gas hold up in the pipeline, and Q, the flow capacity in m^3/s. The Volumetric flow rate, Q_L, of liquid in the pipeline is [5]:

$$Q_L = R_L Q \tag{3}$$

The volumetric flow rate of the gas in the pipeline is:

$$Q_G = R_G Q = (1 - R_L)Q \tag{4}$$

The mass flowrate, $\dot{m}_L$, of liquid and condensate in the line is given as:

$$\dot{m}_L = \rho_L Q_L \tag{5}$$

The mass flowrate, $\dot{m}_G$, of gas in the pipeline is expressed as:

$$\dot{m}_G = \rho_G Q_G \tag{6}$$

The area of cross-section, A, of the pipe is:

$$A = \pi r_1^2 \tag{7}$$

The mean velocity, V_L, of the liquid in the line is:

$$V_L = \frac{Q_L}{A} \tag{8}$$

The mean velocity, V_G, of gas in the line is:

$$V_G = \frac{Q_G}{A} \tag{9}$$

The average mixture velocity, V, is:

$$V=Q/A \tag{10}$$

For a given pipe length, L, the resident time, t, of the gas in the pipe is given as:

$$t = \frac{L}{V} \tag{11}$$

$$L=Vt \tag{12}$$

Substituting equation 11 in equation 1:

$$q = \frac{2\pi Vt\left(T_1 - T_4\right)}{\frac{1}{h_{in}} + \ln\left(\frac{r_2}{r_1}\right)/K_{As} + \ln\left(\frac{r_3}{r_2}\right)/K_{cs} + \ln\left(\frac{r_4}{r_3}\right)/K_{mw} + \ln\left[\left(\frac{d}{r_4}\right) + \sqrt{\left(\frac{d}{r_4}\right)^2 - 1}\right]/K_S} \tag{13}$$

If T_R is the reference temperature, the amount of heat per unit time, q_G, stored by the gas in the line is:

$$q_G = \dot{m}_G C_{pG}\left(T_1 - T_R\right) \tag{14}$$

The amount of heat per unit time, q_L, stored by the liquid in the line is:

$$q_L = \dot{m}_L C_{pL}\left(T_1 - T_R\right) \tag{15}$$

The amount of heat per unit time, q_M, stored by the mixture is:

$$q_M = q_L + q_G \tag{16}$$

The residual heat per unit time, q_R, in the fluid mixture is:

$$q_R=q_M-q \tag{17}$$

If, T_d, is the dew point temperature of the mixture, therefore,

$$q_R = \dot{m}_L C_{PL}(T_d - T_R) + \dot{m}_G C_{PG}(T_d - T_R)$$

$$T_d = T_R + \frac{q_R}{\dot{m}_L C_{PL} + \dot{m}_G C_{PG}} \tag{18}$$

4 Model Applications

The generated set of mathematical models is invaluable in determining the dew point temperature of complex hydrocarbons mixtures. The models can also be applied to get the exact point on a pipeline where dew point temperature will set in.

5 Recommendations for Future Research

Computer simulation of the mathematical models should be developed, and the Input data to the simulation should be obtained from reputable oil/gas producing companies. Different types of insulating materials should be considered as pipe coating and their effectiveness in the attainment of dew point temperature for complex hydrocarbons mixture. For buried pipes, the effect of burial depth on the attainment of dew point temperature of complex hydrocarbons mixtures should be explored.

6 Conclusions

Mathematical models for determining the dew point of complex hydrocarbons mixtures have been formulated. The models could be employed to compute the exact position on a gas pipeline from the upstream end at which dew point will set in. This approach to calculating and optimizing flow variables in natural gas pipelines will be more comprehensive.

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