Sizing of Gas Pipelines

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***Abstract*-In this study, an effective approach for calculating the size of a gas pipeline is presented. The method is simple and does not need any complicated calculations. The proposed approach uses a simple flow formula to derive the diameter, length, flow rate, inlet and outlet pressures. In general, the method tends to give better results of pipe size prediction. The subject of this paper is to present mathematical relationships, based on which Gas pipe size is calculated.**

Keywords- Flow Rate; Gas Flow Equation; Pipe Diameter; Sizing of Pipeline; Gas Pipeline

I. INTRODUCTION

In this paper very practical information concerning sizing of gas pipelines are given. All equations which are used and their modifications are very well known (for example: Gas Pipeline Hydraulics by E. Shashi Menon).

Problem is that in the case of computer simulation or optimization of the gas network we need an accurate mathematical model for the real conditions. In practice, several equations are available that relate the gas flow rate with gas properties, pipe diameter and length, upstream and downstream pressures.

The methodology presented in this document for sizing a gas pipeline guarantees uninterrupted operation at all stages. The general flow equation, Modified Panhandle equation (Panhandle B), AGA flow equation, etc. may be used for this purpose. The flow rate, length and internal diameter of a pipeline can be simply found by re-arranging any of the flow equations.

II. THEORETICAL PIPELINE EQUATIONS

For basic sizing purposes, the steady state general flow equation can be used. Consideration should always be given to unsteady state, to test the ability of the pipeline to overcome emergency conditions.

Software is available for accurately sizing short pipelines [1]. Pipelines over 50 km long require greater accuracy and the uses of Panhandle “A”, Panhandle “B” (modified panhandle equation) or AGA flow formulae are recommended (refer to Clause 6.3 of IGE/TD/1 edition 4).

A. *General Flow Equation*

The equation can be used for flow conditions at all pressure ranges and are the basis for many of the flow equations used in the analysis of pipelines (i.e. transmission and distribution network). The smooth pipe law must be corrected using efficiency factor to perfectly model the flow in a pipe system, due to the presence of pipe joints, fittings, flanges, etc.

The flow rate, length, pressure, and diameter of a pipeline can be simply found by re-arranging the General flow equation.

Assumptions:

- the flow process is Isothermal
- the pipeline is horizontal
- Changes in kinetic energy of the gas are negligible
- No mechanical work is done by or on the gas
- the flow is steady-state
- the energy loss due to friction is given by the Darcy-Weisbach equation

The general flow equation is simplified as [2]

$$Q = \frac{7.574}{10^4}\left[\frac{T_s}{P_s}\right]\frac{1}{\sqrt{f}}\left[\frac{(P_1^2 - P_2^2)D^5}{S.L.Z.T}\right]^{0.5} \tag{1}$$

From Equation (1), the pipe diameter, inlet and outlet pressures, and length can be calculated as follows:

Pipe diameter

$$D = \left[\frac{10^4}{7.574} Q\sqrt{f}\right]^{0.4} \left[\frac{P_S}{T_S}\right]^{0.4} \left[\frac{S.L.Z.T}{P_1^2 - P_2^2}\right]^{0.2} \tag{2}$$

Inlet and outlet pressures

$$P_1 = p_2^2 + \left[\left(\frac{10^4}{7.574} Q\sqrt{f}\right)\left(\frac{P_S}{T_S}\right)\left(\frac{S.L.Z.T}{D^5}\right)^{0.5}\right] \tag{3}$$

$$P_2 = p_1^2 - \left[\left(\frac{10^4}{7.574} Q\sqrt{f}\right)\left(\frac{P_S}{T_S}\right)\left(\frac{S.L.Z.T}{D^5}\right)^{0.5}\right] \tag{4}$$

Length

$$L = \left[\left(\frac{10^4}{7.574}\frac{Q\sqrt{f}}{D^{2.5}}\right)^2 \left(\frac{P_S}{T_S}\right)^2 \left(\frac{S.Z.T}{P_1^2 - P_2^2}\right)\right]^{-1} \tag{5}$$

The general flow equation is simplified for medium pressure systems to the following [2]:

$$Q = \frac{1.269}{10^2}\frac{1}{\sqrt{f}}\left[\frac{(P_1^2 - P_2^2)D^5}{S.L.}\right]^{0.5} \tag{6}$$

The equation (6) is applicable to pipeline systems with pressures up to seven bar (gauge).

For a low pressure pipe system with maximum operating pressure of 0.075 bar (gauge) or an absolute pressure of 1.08825 bar, the general flow equation is simplified as follows [2]:

$$Q = \frac{5.712}{10^4}\frac{1}{\sqrt{f}}\left[\frac{(P_1 - P_2)D^5}{S.L}\right]^{0.5} \tag{7}$$

Equation (7) is specific to low pressure pipeline systems.

In a real system, gas flow does not follow the smooth pipe law; because real systems are not perfectly smooth [2]. Factors that contribute to the deviation from smooth pipe conditions are:

- Actual pipe roughness
- Pipe joints, welds, etc
- Valves
- Bends, tees and other fittings
- Presence of dust and debris

The US Bureau of Mines' tests indicate that the deviation from smooth pipe law could be represented by a fixed percentage of the smooth pipe flow. This leads to the idea of efficiency factor that correct the smooth pipe law to actual conditions.

$$E = Q_{actual}/Q_{smooth\ pipe} \tag{8}$$

Where, E is the efficiency factor which converts the smooth pipe transmission factor into an actual transmission factor.

Therefore, the general flow equation can be written as [2]

$$Q = \frac{7.574}{10^4}\left[\frac{T_s}{P_s}\right]\frac{E}{\sqrt{f}}\left[\frac{(P_1^2 - P_2^2)D^5}{S.L.Z.T}\right]^{0.5} \tag{9}$$

A usual value of E is 0.95 for a new pipeline and is constant for a wide range of Reynolds number (Re).

From Equation (9), the pipe diameter, inlet and outlet pressures, and length can be calculated as follows:

Pipe diameter

$$D = \left[\frac{10^4}{7.574}\frac{Q\sqrt{f}}{E}\right]^{0.4}\left[\frac{P_S}{T_S}\right]^{0.4}\left[\frac{S.L.Z.T}{P_1^2 - P_2^2}\right]^{0.2} \tag{10}$$

Inlet and outlet pressures

$$P_1 = p_2^2 + \left[\left(\frac{10^4}{7.574}\frac{Q\sqrt{f}}{E}\right)\left(\frac{P_S}{T_S}\right)\left(\frac{S.L.Z.T}{D^5}\right)^{0.5}\right] \tag{11}$$

$$P_2 = p_1^2 - \left[\left(\frac{10^4}{7.574}\frac{Q\sqrt{f}}{E}\right)\left(\frac{P_S}{T_S}\right)\left(\frac{S.L.Z.T}{D^5}\right)^{0.5}\right] \tag{12}$$

Length

$$L = \left[\left(\frac{10^4}{7.574}\frac{Q\sqrt{f}}{\times D^{2.5} \times E}\right)^2\left(\frac{P_S}{T_S}\right)^2\left(\frac{S.Z.T}{P_1^2 - P_2^2}\right)\right]^{-1} \tag{13}$$

For a low pressure distribution system we have [2].

$$Q = \frac{5.712}{10^4}\frac{E}{\sqrt{f}}\left[\frac{(P_1 - P_2)D^5}{S.L}\right]^{0.5} \tag{14}$$

E is the efficiency factor that varies with velocity.

In these equations all units are self-consistent, but for general use it’s more convenient to express it in terms of the units which are normally used:

Where,

L = pipe length, m

D = Pipe diameter, mm

T = Gas temperature, K

P = Gas pressure, bar

Q = gas flow rate, standard m^3/h

Z = Gas compressibility factor at the flowing temperature, dimensionless

f = friction factor (can be obtained from the moody chart)

S = Gas gravity

T_s= Standard temperature, K

P_s = Standard pressure, (1.01325 bar)

P_1 = inlet pressure, bar

P_2 = outlet pressure, bar

B. Modified Panhandle Equation

The modified panhandle equation (Panhandle B equation) is used in large diameter, high pressure transmission lines.

In fully turbulent flow, it is found to be accurate for values of Reynolds number in the range of 4 to 40 million [3].

Gas Flow Rate

$$Q = 1.002 \times 10^{-2} E\left(\frac{T^\circ}{P^\circ}\right)^{1.02}\left[\frac{P_1^2 - P_2^2}{T.L.Z}\right]^{0.51}\frac{(D)^{2.53}}{S^{0.490}} \tag{15}$$

Based on Equation (15), the pipe inside diameter, inlet and outlet pressure, and length can be calculated as follows:

Inlet and Outlet Pressures

$$P_1 = \left[P_2^2 + \left(8.315 \times 10^3 \left(\frac{Q}{E}\right)^{1.961} \left(\frac{P^\circ}{T^\circ}\right)^2 \frac{S^{0.961}}{(D)^{4.961}} T.L.Z\right)\right]^{\frac{1}{2}} \tag{16}$$

$$P_2 = \left[P_1^2 - \left(8.315 \times 10^3 \left(\frac{Q}{E}\right)^{1.961} \left(\frac{P^\circ}{T^\circ}\right)^2 \frac{S^{0.961}}{(D)^{4.961}} T.L.Z\right)\right]^{\frac{1}{2}} \tag{17}$$

Length

$$L = (P_1^2 - P_2^2)\frac{1}{8315}\left(\frac{E}{Q}\right)^{1.961}\left(\frac{T^\circ}{P^\circ}\right)^{2.0}\frac{(D)^{4.961}}{S^{0.961}T.Z} \tag{18}$$

Pipe inside Diameter

$$D = 6.168\left(\frac{Q}{E}\right)^{0.395}\left(\frac{P^\circ}{T^\circ}\right)^{0.403}\left(\frac{T.L.Z}{P_1^2 - P_2^2}\right)^{0.202} S^{0.194} \tag{19}$$

Where,

Q = gas flow rate, standard m^3/day

E = pipeline efficiency, a decimal value less than 1.0

D = pipe inside diameter, mm

T^0 = base temperature, K (273+ ℃)

P^0 = base pressure, kPa

P_1 = upstream pressure, kPa (absolute)

P_2 = downstream pressure, kPa (absolute)

Z = gas compressibility factor

L =length of pipe segment, km

T = average gas flow temperature, K (273+ ℃)

C. American Gas Association Equation

Using the American gas association (AGA) equation, the transmission factor, F, is calculated by using two different equations [3].

First, *F*, is calculated for the rough pipe law (referred to as the fully turbulent zone).

For fully turbulent flow,

$$F = 4\log\left(\frac{3.74D}{\varepsilon}\right) \tag{20}$$

Next, F_t is calculated based on the smooth pipe law (referred to as the partially turbulent zone).

For partially turbulent flow,

$$F = 4\log\left(\frac{Re}{\sqrt{1/f}}\right) - 0.6 \tag{21}$$

Finally, the smaller one of the two values of the transmission factor is used in the General Flow Equation for pressure drop calculation [3].

Even though the AGA method uses the transmission factor instead of the friction factor, we can still calculate the friction factor by using the relationship shown in Equation (22).

$$F_t = \frac{1}{\sqrt{f}} \tag{22}$$

Equation (22) can be substituted into the general flow equation to determine the gas flow rate.

Where,

F_t = Von Karman smooth pipe transmission factor

ε = internal pipe roughness

Re = Reynolds number

V = velocity at average conditions, m/s

ρ = gas density at average conditions, kg/m^3

All other parameters are as previously defined.

D. Panhandle A Equation

The Panhandle A flow equation used for the analysis of the transmission system with Reynolds numbers between 5 and 11 million. Panhandle A equation is derived by substituting

$$\frac{1}{\sqrt{f}} = 6.87{R_e}^{0.07305}$$

into the general flow equation (Equation (9) above) to give an explicit equation below [2]:

$$Q = \frac{7.952}{10^3} E \left[\frac{T_s}{P_s}\right]^{1.07881} \left[\frac{1}{S}\right]^{0.4606} \left[\frac{P_1^2 - P_2^2}{T.Z.L}\right]^{0.5394} d^{2.6182} \tag{23}$$

An efficiency factor, E, is usually incorporated in a similar manner to the smooth pipe law. The pipe length, inlet pressure, outlet pressure and internal diameter are simply found by re-arranging Equation (23).

III. CONCLUSION

This paper on sizing of gas pipelines has provided a summary of the following:

- Standardized equations used in sizing gas pipelines in order to ensure pipeline integrity and meet industry needs.
- How to re-arrange the various flow equations in order to calculate the gas flow rate, pipe length, inside diameter, inlet and outlet pressure.
- Sizing of gas pipelines has been in existence for centuries and are documented in codes, client standards, handbooks, research papers, and so on. Based on research, there is regular improvement on the mathematical relations for sizing gas pipelines.

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REFERENCE

[1] IGE/TD/1, “Steel pipelines for high pressure gas transmission”, 4th ed., London-United Kingdom: Institution of Gas Engineers, 2001.

[2] G.G. Nasr, “Gas Flow and Network Analysis”, Salford: Salford University, 2011.

[3] E. Shashi Menon, “Gas Pipeline Hydraulics - Pressure Drop Due to Friction”, London – United Kingdom: CRC Press - Taylor & Francis Group. Chapter 2, 2005.