FLOW EQUATIONS IN COMMERCIAL GAS PIPING SYSTEM

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ABSTRACT

There are various types of flow equations in commercial gas piping system and this thesis will covered about the comparison of Cox and Pole's method. FORTRAN 90 software was used to validate the manual calculation of both equations and a comparative study was made. The analytical solutions of the resulting differential equations are obtained in the form of Cox and Pole's equations. The equations give functional relationship between flow rate, inlet pressure and outlet pressure, as well as pressure drop at any given length. The effect of pressure drop per segment on gas flow rate is presented. Both of the equation was calculated manually from the commercial area gas piping route and the syntax generated from the equations were compiled and executed in F90 with no errors. The Cox's method was found more economically with smaller pipe size but allowable pressure drop in each section, compared to Pole's method. The equations considerably enhance gas pipeline design in terms of both ease of usage and accuracy. A simple computer program in FORTRAN 90 is developed to handle these calculations.

ABSTRAK

Terdapat pelbagai jenis rumus aliran di dalam system perpaipan gas komersial dan thesis ini meliputi perbandingan rumus aliran antara jenis kaedah Cox dan Pole. Pengaturcaraan FORTRAN 90 digunakan untuk memvalidasi pengiraan secara manual kedua-dua rumus kaedah Cox dan Pole dan analisis perbedaan dikaji. Solusi secara analitikal yang memberikan hasil perbezaan kedua-dua rumus Cox dan Pole. Rumus-rumus tersebut member fungsi berhubung laju alir, tekanan masuk dan keluar serta penurunan tekanan pada panjang yang telah diberi. Kesan penurunan tekanan pada setiap segmen dalam laju alir gas turut di paparkan. Kedua-dua rumus dikira secara manual daripada system perpaipan di kawasan komersial dan sintaks di hasilkan, disusun dan dilaksanakan di dalam F90 tanpa sebarang kesalahan. Didapati rumus kaedah Cox lebih ekonomik dengan saiz paip yang lebih kecil, namun penurunan tekanan didalam paip masih berada didalam tahap dibenarkan pada setiap seksyen, berbanding dengan rumus kaedah Pole. Dengan menggunakan FORTRAN 90, penurunan tekanan dalam sistem perpaipan komersial dapat di tentukan bersama-sama saiz paip laluan gas tersebut. Rumus-rumus tersebut didapati membantu rekaan paip saluran gas dari segi kemudahan dan ketepatan. Sebuah pengaturcaan FORTRAN 90 telah dibina untuk mengendalikan rumus-rumus tersebut.

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LIST OF SYMBOLS

ΔP	-	Pressure different / Pressure drop
P_{in}	-	Inlet pressure
P_{losses}	-	Pressure loss due to friction
$\Delta P_{elevation}$	-	Pressure elevation differences
v	-	Velocity
Q	-	Flow rate
A	-	Pipe diameter
d	-	Pipe inside diameter
T	-	temperature of flowing gas
°R	-	Rankine unit of temperature
P	-	Pressure of gas
psia	-	Pressure unit in absolute
Q_b	-	Flow rate
MMSCFD	-	Million standard cubic feet per day
P_b	-	Base pressure
T_b	-	Base temperature
Re	-	Reynolds number of flow
μ	-	Gas density
ft^3	-	Cubic feet

F	-	Transmission factor
G	-	Gas gravity
T_f	-	Average gas flow temperature
L	-	Pipe segment length
Z	-	Gas compressibility factor
f	-	Darcy friction factor
e	-	Absolute pipe roughness
h	-	Frictional head loss
Q_s	-	Volume flow rate at standard condition
K_x	-	A parameter that is a function of pipe diameter *d*
K	-	Cox's Coefficient number
K_2	-	Pole's Coefficient number

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Pipelines play a vital role in our daily lives. Cooking and cleaning, the daily commute, air travel and the heating of homes and businesses are all made possible by the readily available fuels delivered through pipelines. The study of flow behavior and pressure drop from two phase liquid in horizontal pipeline was always be the most complicated part in piping network system. The formulation of equations for steady-state gas piping network analysis in gas flow rate in a pipe can be described by many formulae but none are universal. The effect of friction is difficult to quantify and are the main reason for variations in the flow formulae. Recently, many gas flow equations have been developed and a number have been used by the gas-liquid industry. Majorities of those are based on the result of gas-liquid flow experiments. The formula normally varies due to their condition of experiments, which were conducted on varying internal surface roughness and over different range of flow conditions. The second thing that needs to be carefully analyzed is the flow pattern and behavior in gas-liquid flow system. Two-phase flows are commonly found in many industrial processes. The expression of ‘two phase flow’ is used to describe the simultaneous flow of a gas and a liquid, a gas and a solid, two different liquids, or a liquid and a solid. Among these types of two-phase flow, gas–liquid flow has the most complexity due to the deformability and the compressibility of the phases. In this thesis, it is desired to study the flow pattern together with the pressure drop in gas liquid pipe flow system. A design of gas distribution system network in commercial gas piping system is going to be design and the pressure drop will be calculated according to Cox’s and Pole’s rule. The design pressure would be at 1 psig in horizontal pipe flow and the natural gas (NG) was used as the main feed to the customer as a fuel. (Gonzales A. H., 2005).

1.2 Objective

The aims of this research are to make a comparison between different general flow equation with Cox, and Pole’s method in natural gas piping system in commercialized horizontal gas system pipeline and its flow behavior.

1.3 Scope of Study

The scope of this research includes the natural gas supply to commercial area by using horizontal carbon steel pipe which are exposed pipe in targeted building. It will be more focused on Liquefied Petroleum Gas (LPG) in vapor phase and the design pressure for first regulator is 15 psig (High Pressure) and the second regulator is 1 psig at low pressure.

In order to compare the Cox’s and Pole’s method along with other general flow equation, the general flow equation will be considered as well. Also, the piping design, which is the length, pipe diameter, friction factor, pressure drop and allowable pressure drop, was taking into account in this thesis.

1.4 Problem Statement

Gathering lines received natural gas at well sites, often moving it to gas plants for further processing. Sometimes, depending on gas quality and contaminants, the natural gas is injected directly into gas transmission lines without processing. The contents of the natural gas, particularly contaminants, determine whether the natural gas stream needs extensive processing at gas plants.

Facilities at gas plants usually remove acid gasses and the natural gas liquids (NGLs). The acid gasses include hydrogen sulfide and carbon dioxide, gasses having potential to corrode the facilities of both the pipeline and the consumer. Hydrogen sulfide is also toxic and is a pollutant. The NGL could include natural gasoline, butanes, propane, and sometimes ethane.

If a natural gas stream is heavy content of NGLs, at least the natural gasoline and some of the butane has to be removed to avoid condensation in the gas transmission lines. Upon removal, the NGLs have various markets and moves from gas plant in tank cars, trucks, or their own pipelines.

Compressor stations at gas plants or gathering systems boosts the pressure of the natural gas to move or inject the gas into the main line. Sometimes compression is not needed because the natural gas is already at high enough pressure coming out of the ground to force it into the main line or transmission line. Natural gas is always injected into transmission lines as other gas goes by. Since the gas is more or less fungible (interchangeable), batching is not required. As natural gas enters the main line, commercial adjustments can be made for energy content of the injected natural gas. This might be done if it is higher or lower than the typical 1,000 – 1,500 British Thermal Unit (BTUs) per standard cubic foot (scf).

Natural gas transmission lines transport natural gas to the local distribution companies (LDCs) for further movement to homes and businesses. Increasingly, natural gas transmission lines deliver directly to large end users like industrial plants, businesses, commercial sites, and power generation plants, bypassing LDCs. Sometimes, instead of going directly to consumers, natural gas is stored for future use. The storage can consists of aboveground steel tanks, underground caverns, aquifers, or old, depleted oil or gas fields. The management of daily and seasonal storage is an essential service provided by the main lines to the producers, the shippers, and the LDCs.

Natural gas piping systems in multifamily buildings typically operate at standard delivery pressure. Standard delivery pressure according to Southern California Gas Company is 8 inches water column (WC) or 1/4 pound per square inch gauge (psig).

Generally, multifamily units equipped with natural gas water heating, comfort heating, cooking and clothes drying have an operating cost much lower than electric alternatives. By delivering higher operating pressure, both the size and cost of the gas piping system can be reduced. Smaller pipe is easier to handle and install. It is not the “pressure” that counts but it’s the “pressure drop” that moves the gas inside the pipe. Piping systems in apartments are traditionally operated at 8 in. water column (WC) or 1/4 psi. By determining the pressure to 1 psi, several benefits become available when constructing multi-family units.

The pipe size is determined by the amount of energy that can be lost (also called the pressure drop) to move the gas, while leaving enough pressure to meet the minimum requirements of the appliance controls (usually 4 to 6 in. WC). As the pressure goes up, so too does the allowable pressure drop can be accommodated. The greater the pressure drop, the greater the amount of gas that can be “pushed” through the pipe for a given size. For a given amount of gas, the pipe size can be decreased as the allowable pressure drop is increased.

1.5 Benefit and Significant of Research

The significant of the research can be best described as, by using a FORTRAN 90, the pressure drop in natural commercial gas pipeline system can be determine the together with its types of flow on the natural gas itself either as laminar or turbulent. Most of the gas flow equation will be coded and execute in one software and the result will be printed out and then the analysis will come out. These will ease most of the pipeline engineer in order to design a correct pipeline route by determining its suitable pressure drop.

CHAPTER 2

LITERATURE REVIEW

A fluid seems to be slippery by its nature, and yet friction must still be considered. Friction between the inside wall of the pipe and the moving fluid, as well as internal friction between the molecules of the fluid, resist flow and must be overcome with energy. Gravity adds or subtracts pressure depending on elevation differences. Friction generates heat, which is another way of saying it converts pressure energy to heat energy. This heat energy is transferred to the fluid or the surrounding environment. The compressor station at the origin adds pressure that is then consumed by friction and lost as a motive force (Shashi M.E., 2005). In this chapter, it is desired to discuss the general flow equations, together with the commercial gas flow calculations as well as the FORTRAN 90 as the simulation medium.

The equation for the pressure at any point along this level line is:

$$\Delta P = P_{in} - P_{losses}$$

By add in the element of elevation and the equation becomes:

$$\Delta P = P_{in} - P_{losses} \pm \Delta P_{elevation}$$

2.1 Pressure Drop Due to Friction

As gas flows through a pipeline, energy is lost due to friction between the gas molecules and the pipe wall. This is evident in the form of a pressure gradient along the pipeline. In order to calculate the amount of pressure drop due to friction, a couple of important parameters related to the flow of gas in a pipeline need to be considered which is the velocity of flow and the Reynolds number itself. (Shashi M.E., 2005)

2.1.1 Velocity

As gas flows at a particular volume flow rate Q, through a pipeline of diameter D, the velocity of the gas can be calculated using the cross-sectional area of pipe as follows:

$$v = \frac{Q}{A} \tag{2.1}$$

Since the flow rate Q is a function of gas pressure and temperature, we must relate the velocity to volume flow at standard conditions. If the density of gas at flowing temperature is ρ and the density at standard conditions is ρ_b from the law of conservation of mass, the mass flow rate at standards conditions must equal the mass flow rate at flowing conditions. Therefore,

$$\rho_b Q_b = \rho Q \tag{2.2}$$

Using the real gas equation, the above equation can be simplified as

$$\rho_b = \frac{P_b M}{Z_b R T_b}$$

$$\frac{\rho_b}{\rho} = \frac{P_b}{P}\frac{Z}{Z_b}\frac{T}{T_b}$$

$$Q = Q_b \frac{P_b}{P}\frac{T}{T_b}\frac{Z}{Z_b} = Q_b \frac{T}{P}\frac{P_b}{T_b}\frac{Z}{Z_b}$$

$$v = \frac{4}{86{,}400\pi(D/12)^2} Q_b \frac{T}{P}\frac{P_b}{T_b}\frac{Z}{Z_b}$$

$$v = (2.653 \times 10^{-3}) \frac{Q_b}{D^2}\frac{T}{P}\frac{P_b}{T_b}\frac{Z}{Z_b} \tag{2.3}$$

Where v = velocity of flowing gas, ft/s

d = pipe inside diameter, in

T = temperature of flowing gas, °R

P = pressure of gas, psia

Q_b = flow rate, million standard ft^3/day (MMSCFD)

P_b = base pressure, psia

T_b= base temperature, °R

2.1.2 Reynolds Number

The Reynolds number of flow is a dimensionless parameter that depends on the flow rate, pipe diameter, and gas properties such as density and viscosity. The Reynolds number is used to characterize the flow type such as laminar flow or turbulent flow. The Reynolds number is calculated as follows:

$$\text{Re} = \frac{vD\rho}{\mu} \tag{2.4}$$

Where Re = Reynolds number of flow, dimensionless

v =velocity of flowing gas, ft/s

D = pipe inside diameter, ft

μ = gas density, slug/ft^3

In gas flow, the following equation for the Reynolds number is more appropriate:

$$Re = 0.0004778 \frac{P_b}{T_b} \frac{GQ}{\mu D} \tag{2.5}$$

Where P_b = base pressure, psia

T_b = base temperature, °R

G = gas gravity

Q = gas flow rate, standard ft3/day (SCFD)

D = pipe internal diameter, in

μ = gas viscosity, lb/(ft.s)

Laminar flow is defined as flow that causes the Reynolds number to be below threshold value such as 2000 to 2100. Turbulent flow is defined as flow that causes the Reynolds number to be greater than 4000. The range of Reynolds number between 2000 and 4000 characterizes an unstable flow regime known as *critical flow*.

2.2 General Pressure Drop Equation

The general flow equation, also referred to as the fundamental flow equation, relates flow rate, gas properties, pipe size, and flowing temperature to the upstream and the downstream pressures in a pipeline segment. The internal roughness of the pipe is used to calculate a friction factor using the Colebrook-White, modified Colebrook-White AGA equation. The friction factor is then used in the general flow equation.

In a steady-state flow of a gas in a pipeline, pressure loss occurs due to friction between the pipe wall and the flowing gas. The general flow equation can be used to calculate pressure drop due to friction between two points along the pipeline. Since gas properties change with pressure and temperature, the general flow equation must be applied for short segments of the pipeline at a time. The total pressure drop will be the same of the individual pressure drops. The general flow equation for the steady-state isothermal flow in a gas pipeline is as follows:

$$Q = 38.77F \left(\frac{T_b}{P_b}\right) \left(\frac{P_1^2 - P_2^2}{GT_f LZ}\right)^{0.5} D^{2.5} \quad (2.6)$$

Where Q = volume flow rate, SCFD

F = transmission factor, dimensionless

P_b = base pressure, psia

T_b = base temperature, °R

P_1 = upstream pressure, psia

P_2 = downstream pressure, psia

G = gas gravity (air = 1.00)

T_f = average gas flow temperature, °R

L = pipe segment length, mi

Z = gas compressibility factor, dimensionless

D = pipe inside diameter, in

The transmission factor F is related to the friction factor in an inverse way. Since the pressure at the inlet of the pipe segment is P_1, and the outlet is P_2, an average pressure must be used to calculate the gas compressibility factor Z at the average flowing temperature T_f. Instead of an arithmetic average $(P_1 + P_2)/2$, the following formula is used to calculate the average gas pressure in the pipe segment.

$$P_{avg} = \frac{2}{3}\left(P_1 + P_2 - \frac{P_1 P_2}{P_1 + P_2}\right) \quad (2.7)$$

It is noted that Eq. (2.11) does not include any elevation effects due to the main objective for this research which only include for horizontal pipeline.

2.2.1 Reynolds number and friction factor.

The friction factor *f*, introduced earlier, depends on the type of flow (such as laminar or turbulent) and on the pipe diameter and internal roughness. For laminar flow, for Re ≤ 2000, the friction factor is calculated from

$$f = \frac{64}{Re} \tag{2.8}$$

Depending on the value of Re, flow is laminar or turbulent.

For laminar flow:	Re ≤ 2000
For turbulent flow:	Re > 4000

The region for (Re) between these two values is termed the critical flow regime. The turbulent flow region is further subdivided into three separate regions which are turbulent flow in smooth pipes, fully rough pipes and between smooth and rough pipes. This is shown in the moody diagram (App. 1).

In the smooth pipe zone of turbulent flow, the pipe friction factor is not affected significantly by the pipe internal roughness. The friction factor *f* in this region depends only on the Reynolds number Re according to the following equation

$$\frac{1}{\sqrt{f}} = -2log_{10}\left(\frac{2.51}{Re\sqrt{f}}\right) \tag{2.9}$$

For laminar flow the friction factor *f* is calculated from equation (2.13). It can be seen from Eq. (2.13) that the friction factor for laminar flow depends only on the Reynolds number and is independent of pipe diameter roughness. It must be noted that the Reynolds number does depends on the pipe diameter and gas properties. The typical values of pipe roughness are available at Table 1. The friction factor is calculated using either the Colebrook-White equation or the AGA equation and then is used in the general flow equation to calculate the pressure drop. In this research, only the Colebrook-White equation will be used for obtaining the friction factor to apply it in general flow equation.

2.2.2 Transmission Factor and Friction Factor.

The transmission factor F is a measure of how much gas can be transported through the pipeline. Hence it has an inverse relationship to the friction factor *f*. As the friction factor increases, the transmission factor decreases and the flow rate reduces. Conversely, the higher the transmission factor, the lower the friction factor and hence the higher the flow rate achieved. The transmission factor F and the friction factor *f* are related by the following equations:

$$f = \frac{4}{F^2} \tag{2.10}$$

$$F = \frac{2}{\sqrt{f}} \tag{2.11}$$

The friction factor *f* is actually the Darcy friction factor discussed in classical books on fluid mechanics. A similar friction factor called the Fanning factor is also used in industry. The Darcy friction factor and the Fanning friction factor are related as follows

Darcy friction factor = 4 x Fanning friction factor

2.2.3 Colebrook-White Equation

The Colebrook-White equation for obtaining the friction factor is applicable for a wide range of flow in gas pipelines. Friction factor *f* is given for turbulent flow as:

$$\frac{1}{\sqrt{f}} = -2log_{10}\left(\frac{e}{3.7D} + \frac{2.51}{Re\sqrt{f}}\right) \qquad (2.12)$$

Where *f* = Darcy friction factor

D = pipe inside diameter, in

e = absolute pipe roughness, in

Re = Reynolds number of flow

In terms of the transmission factor F, may be written as

$$F = -4log_{10}\left(\frac{e}{3.7D} + \frac{1.255F}{Re}\right) \qquad (2.13)$$

For turbulent flow Re > 4000

It can be seen from both equation that the solutions of friction factor *f* and the transmission factor F are not straightforward. These equations are implicit and therefore have to be solved by successive iteration.

2.2.4 Spitzglass Formula

Spitzglass introduced this formula in 1912 based on tests conducted for the Peoples Gas Light and Coke Company in Chicago. This formula uses a friction factor as follows:

$$f = 0.0112 \left(1 + \frac{3.6}{d} + 0.03d\right) \tag{2.14}$$

There are two version of the pressure drop equation using the Spitzglass method. For low pressure up to 1 psig,

$$h = \frac{LQ_s^2}{1.26 \times 10^7 K^2} \tag{2.15}$$

$$Q_s = 3550\, K \sqrt{\frac{h}{L}} \tag{2.16}$$

$$K = \sqrt{\frac{d^5}{\left(1 + \frac{3.6}{d} + 0.03d\right)}} \tag{2.17}$$

Where h = frictionl head loss, inH_2O

L = pipe length, ft

Q_s = volume flow rate at standard conditions, ft^3/h (SCFD)

K = A parameter that is a function of pipe diameter *d*

d = pipe inside diameter, in

For pressure greater than 1 psig,

$$\Delta P = \frac{LQ_s^2}{2.333 \times 10^7 P K^2} \tag{2.18}$$

$$Q_s = 4830\, K \sqrt{\frac{P\, \Delta P}{L}} \tag{2.19}$$

(2.20)

$$Q_s = 3415K\sqrt{\frac{(P_1{}^2 \; - \; P_2{}^2)}{L}}$$

Where P_1 = upstream pressure, psia

P_2 = downstream pressure, psia

P = average pressure, psia

All other symbols are as defined earlier. It has been found that the Spitzglass formula gives a lower value of flow rate for a given pressure drop and pipe size compared to the Weymouth formula. Hence the Spitzglass formula is used in situations where a more conservative result is desired such as in pipes that are rough or rusty.

2.2.5 Weymouth Formula

Thomas R. Weymouth presented this formula in 1912 for calculating gas flow through high-pressure pipelines. This formula is also used with the flow of compressed air. The Weymouth friction factor is as follows:

$$f = \frac{0.032}{d^{0.3333}} \tag{2.21}$$

The Weymouth formula for airflow at standard condition is:

$$\Delta P = \frac{(1.0457 \times 10^{-3})TL}{Pd^{5.3333}}\left(\frac{P_s Q_s}{T_s}\right)^2 \tag{2.22}$$

Also

$$Q_s = 21.8742\frac{T_s}{P_s}\sqrt{\frac{(P_1^2 - P_2^2)d^{5.3333}}{TL}} \tag{2.23}$$