GAS FLOW NETWORK ANALYSIS IN PUTRAJAYA RESIDENTIAL AREA USING COX METHOD

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ABSTRACT

This paper presents a gas flow network analysis in Putrajaya residential area which focusing on natural gas pipeline due to its economical advantages. Increasing demand of natural gas makes the distribution pipeline network becomes more and more complex. Pressure drop occurs in pipeline during the transportation especially for the existing pipeline when the capacity of pipeline increases. Various formula of gas flow equation is used for sizing and designing a proper distribution system to avoid the reduced delivery pressure or pressure drop that may not acceptable to the customer receiving the gas. The objectives of this research are to validate Cox Equation as well as to compare the actual pressure drop with the current pressure drop which is calculated using Cox method. The actual pressure drop data from GMSB which based on Pole Equation is compared and results show less pressure drop for Cox Equation. This Cox method can be applied for supply pressure above 29.4kPa was implemented using a loop method as a gas network analysis in designing a natural gas distribution system. Loop method is applied to determine the gas flow rate for the interconnected gas pipeline network. Hardy Cross method was used for solving looped network. Final gas flow rate was determined after the convergence of absolute value of looped correction is decreased and gets stable value. Finally, Cox method is used for sizing the gas pipeline by referring the API 5L Scheduled 40 Table. In conclusion, Cox Method is applied for the existing natural gas pipeline in Putrajaya residential area and shows the reduction of pressure drop as well as looped gas distribution network is able to ensure the security, continuity and reliability of supply pressure to the various customers.

ABSTRAK

Kertas kerja ini membentangkan analisis rangkaian aliran gas di kawasan Putrajaya kediaman yang memberi tumpuan pada paip gas asli yang disebabkan oleh kelebihan menjimatkan. Peningkatan permintaan gas asli yang menjadikan rangkaian pengagihan talian paip menjadi lebih dan lebih kompleks. Kejatuhan tekanan telah berlaku dalam perancangan semasa pengangkutan terutama bagi saluran paip yang sedia ada apabila meningkatkan keupayaan saluran paip. Pelbagai formula aliran gas digunakan untuk menyesuaikan saiz dan bentuk satu sistem pengagihan yang teratur untuk mengelakkan pengurangan tekanan atau kejatuhan tekanan yang tidak boleh diterima oleh pelanggan menerima gas. Objektif penyelidikan ini adalah untuk mengesahkan dan menggalakkan Kaedah Cox serta membandingkan susutan tekanan sebenar dengan kejatuhan tekanan semasa yang dikira menggunakan Persamaan Cox. Penurunan tekanan data sebenar telah diambil dari GMSB berdasarkan Persamaan Paul dibandingkan dan keputusan menunjukkan kejatuhan tekanan yang kurang untuk Persamaan Cox. Persamaan Cox ini boleh digunakan untuk tekanan bekalan di atas 29.4kPa telah dilaksanakan dengan menggunakan kaedah gelung sebagai analisis rangkaian gas dalam mereka bentuk sistem pengagihan gas asli. Kaedah gelung digunakan untuk menentukan kadar aliran gas untuk rangkaian saluran paip gas yang saling berkaitan. Kaedah Hardy Cross telah digunakan untuk menyelesaikan rangkaian bergelung. Kadar aliran gas akhir adalah ditentukan selepas penumpuan nilai mutlak pembetulan bergelung menurun dan nilai yang stabil. Akhirnya, Persamaan Cox digunakan untuk menetukan saiz saluran paip gas dengan merujuk API 5L Berjadual 40 Jadual. Kesimpulannya, kaedah Cox digunakan untuk saluran paip gas asli yang sedia ada di kawasan kediaman Putrajaya dan menunjukkan pengurangan kejatuhan tekanan serta rangkaian pengedaran gas bergelung mampu untuk memastikan keselamatan, kesinambungan dan kebolehpercayaan tekanan bekalan kepada pelbagai pelanggan.

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LIST OF ABBREVIATIONS

AGA	American Gas Association
API	American Petroleum Institute
GMSB	Gas Malaysia Sdn Bhd.
IGT	Institute Gas Technology
LNG	Liquefied natural gas
NG	Natural gas
OGJ	Oil and Gas Journal

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CHAPTER 1

INTRODUCTION

1.1 Background of Research

Natural gas is one of the major fossil fuel besides oil that widely used in residential, commercial and industrial. Now, it becomes a great attention which our worldwide is focusing on due to its economical and environmental friendly advantages. Therefore natural gas demand is increasing year by year not only for the world market which lead to LNG trade but also local market demand where domestic natural gas consumption has been increasing steadily by 0.1Tcf from 2010 (OGJ 2012). For Malaysia country, domestic natural gas is subsidized by Malaysia Government and they will have to ensure the adequate supplies to meet the current demand. This growth of demand has been seen in our development of Malaysia new federal administrative capital which is Putrajaya. Therefore, Putrajaya is being focused to study for the gas network analysis which according to City Planning Department Putrajaya Corporation, natural gas has been used as a utility to generate chilled water (Siong, H.C., 2006) for air-conditioning for buildings as well for residential gas appliances due to the reason of elimination excessive energy use.

In order to supply the natural gas to customer, pipeline is one of the main transportation in gas distribution system which has to be designed properly which to optimize the expenditure. By considering the existing pipeline, this increasing of pipeline capacity will create greater changes of delivery pressure without changing the originating pressure of compressor station. But the reduced delivery pressure or pressure drop may or may not be acceptable to the customer receiving the gas. As we know, compressor station shall be installed to maintain the delivery pressure and this delivery pressure always operate at high turbulence flow region. Even though the compressor is installed to maintain the delivery pressure, but installing the intermediate compressors along the pipeline will reduce the operating pressure.

Moreover, by installing additional compressor station also will increase the capital and operating cost. Therefore, capital cost for pipeline distribution system is considerable important to optimize its expenditure. Thus, this point needs gas distribution network analysis which to determine need for system reinforcement and supply requirement for interconnected network.

Generally, the development of gas network is the purpose of the natural gas transportation and distribution in high capacity, which usually local storage tanks unable to supply the consumer needed flow rate. Gas network analysis is used to determine the amount of gas, flow rate of the gas and the pressure used in a pipeline system. Besides that, it also can used to determine the usage of gas by consumers especially during the peak times. By making the network analysis, time of maintenance and failure of pipeline can be measured. The effect of new load on the pipeline also can be predicted, (Puah, 2002).

1.2 Problem Statement

According to Oil and Gas Journal early in 2011, in Malaysia, natural gas consumption is increasing steadily by reaching 1.1 Tcf in 2010 for domestic users which counted 42% of gas production. It shows that natural gas, as one of the most important sources of energy for many commercial and residential users throughout the world. However, increasing demands of natural gas throughout the domestic users makes the gas distribution pipeline system becomes more complex (Chapman, et.al.,2005 and Hamedi, et.al., 2008).This growth of demand has been seen in development of Malaysia new federal administrative capital, Putrajaya. In order to supply the natural gas to customer, pipeline is one of the main transportation in gas distribution system which has to be designed properly which to optimize the expenditure. But during transportation the impact of pressure drop due to friction occurs especially in existing pipeline system while increasing the loads demands of customer.

Therefore, proper sizing of supply pipelines is important so that each gas appliance receives enough gas to perform properly. Inadequate sizing of supply pipelines not only will cause inefficient appliance operation but also supply interruptions which can adversely affect the safety of the system. Even though the compressors station is installed to maintain the delivery pressure, but there is a limit number of compressors station that can be installed in existing pipeline system since high pressure required continues to increase with flow rate. An additional factor must be taken into consideration as the flow rate is increased, is the resulting higher velocity in pipeline system. The gas velocity must be well below the erosional velocity for the pipe which is does not exceed 20 meter over second as stated in gas domestic pipeline by Energy Commission. By adding compressor stations will also increase the capital and operating cost. Therefore, in order to distribute the natural gas to the customer chain, a proper distribution planning in the natural gas network is discussed in this research.

1.3 Research Objective

The objective of this research is to validate the Cox Equation and to compare the actual pressure drop with the current pressure drop. The actual data using Pole Equation from GMSB is compared using Cox Equation. Lastly, to suggest the new gas distribution network using loop analysis that ensures the reliability, security and continuity of supply to the customer.

1.4 Scope of Research

This research of gas flow network analysis is carried out by studying a distribution gas pipeline of Putrajaya residential area. This research is focusing on natural gas pipeline which increasing of natural gas demand for residential area where it dominates as 23.8 % of city area according to Putrajaya Master Plan, Putajaya Corporation. Besides that, natural gas is chosen as a reason for economical advantages and environmental friendly which in line with a vision of planning and development of Putrajaya based on concept ‘city in a garden’. Lastly, Cox equation is employed in this research for designing a natural gas network system which more focuses on sizing gas distribution pipeline as well as for calculating pressure drop.

1.5 Significance of Research

This research is done to promote the Cox equation which is one of the gas flow equation for gas pipeline sizing distribution. Pressure drop is one of the important things that have to be focused when designing a gas distribution network which will affect the supply distribution to customer. Therefore, Cox equation helps to reduce a pressure drop which ensuring the safety delivery of gas supply and cost effective as well as to fulfill the customer requirements. Cox Equation is much simpler than the other gas flow equation that be used in gas pipeline sizing for distribution system. Lastly, this research performs a loop analysis using Hardy Cross method which gives advantage of reliability, continuity and security supply to the various customers.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Transmission and distribution companies around the world are looking to maximize their network operating capabilities and system developments in a cost effective manner while continuing to operate in a safe and efficient manner. The business of delivering gas to the consumer is a complex process that can involve different departments, companies or organizations. From exploration and production, through processing, transmission and storage to distribution, management of transportation capability is vital to maximizing profitability.

The multifaceted networks of pipes that consist of gas distribution system present redoubtable flow analysis problem. Initially the flowing gas in feed into a system from several transmissions pipeline city-gate stations, from one or more peak-load gas production plants or from storage facilities scattered through the system. In addition, many distribution systems consist of several superimposed networks of piping operated at different pressure levels. Networks of 200-300 loops and 500- 600 pipe section are very common. Many networks contain over 1000 pipe sections and some larger cities have interconnected piping networks containing tens of thousands of pipe section. At one time the only method of solving network flow problem was a manual trial-and-error procedure. The most common software used locally is GDNAP developed by CONGAS (Canada Oil and Gas Company) and NASS developed by Tokyo Gas. Both of the software uses the Hardy Cross technique in solving network analysis problem, however not all station are practically used those methods, and now we revile the networking method using COX method. In local residential area, will caused lot of problems encourage by public people, building and construction, geological factor and etc.

2.2 Gas Flow Network

Generally, the development of gas network is the purpose of the natural gas transportation and distribution in high capacity, which usually local storage tanks unable to supply the consumer needed flow rate. Natural gas network analysis is used to determine the amount of gas, flow rate of the gas and the pressure used in a pipeline system. Besides that, it also can used to determine the usage of gas by consumers especially during the peak times. By making the network analysis, time of maintenance and failure of pipeline can be measured. The effect of new load on the pipeline also can be predicted. Generally, network analysis can be divided into three type, that are Network tracing, Network routing and Network Allocation (Puah, 2002). Network tracing is done in order to trace the location of the particular pipeline in the system. Network routing is done in order to find out the optimum path or the shortest path, which costs less for the system. Network allocation is done in order to relocate all the pipelines into the main support.

The optimization of the piping network has been increased time to time to ensure the safety and cost effective for distribution piping system especially growing demands for natural gas. It also even becomes more complex as the use of this energy source increases which is according to Chapman,. *et .al.,* (2005). According to Arai.N and Ando.H, (2010) better understanding of available capacity of network as well as actual demand growth in a questioned area will enable us to spare unnecessary network capacity increase investment.

Operational optimization using rigorous mathematical techniques is a viable tool for enhancing the efficiency of pipeline operations. Currently available commercial packages do not provide the capability for fully automated optimization of operational parameters; but rather provide computational support for human decision making. Thus, the solutions are generally not truly optimal, and require considerable user involvement. This work advances the current state of pipeline simulations by using detailed equipment modeling and rigorous mathematical optimization that will automatically generate truly optimal solutions with practically no user involvement (Chapman, *et. al*., 2005).

Natural gas systems are becoming more and more complex as the use of this energy source increases. The behavior of the gases is affected by three factors: the temperature of the gas, the pressure of the gas, and the volume of the gas. Temperature significantly affects the pressure and volume of a gas; it is therefore essential to have a method of including this effect in calculations of pressure and volume. To a diver, knowing the effect of temperature is essential, because the temperature of the water deep in the oceans or in lakes is often significantly different from the temperature of the air at the surface.

Osiadacz and Chaczykowski (1998, 2009) compared isothermal and non-isothermal transient models for gas pipelines which adiabatic flow is associated with fast dynamic changes in the gas. In this case, heat conduction effects cannot be neglected. Isothermal flow is associated with slow dynamic changes. Changes of temperature within the gas due to heat conduction between the pipe and the soil are sufficiently slow to be neglected.

A typical gas network consists of one or more gas sources (gas producers or storages), one or more gas loads (electrical generators, other networks, or storages), pipelines, compressors, and other devices, such as valves and regulators. The compressors are installed in the network in order to increase the gas pressure so that the gas can flow through the pipeline to the locations where it is consumed. Valves and regulators are devices that allow selected sections of the gas networks to be cut off (at break-down, for overhaul etc.), and they also provide control of the gas flow rate, prevent excessive growth of pressure in the network, and prevent the flow of gas in an undesirable direction.

Three basic types of components of a gas network are considered for network modeling purposes:

(i) pipelines,

(ii) compressors, valves, regulators and other devices, and

(iii) Interconnection points (nodes or busses).

For an example it is anticipated that an average household has the following gas-consuming devices (J. Krope *et. al*., 2000):

(i) gas cooker with consumption of 1.25 m^3/h;

(ii) gas kettle for preparing hot water with consumption of 1.25 m^3/h;

(iii) gas boiler for the production of consumable hot water and for floor heating with the consumption of 3 m^3/h;

Since consumers of gas are usually remote, gas has to be supplied to consumers by pipelines. The most important quantities to be considered when sizing the pipeline are its:

(i) Maximum operating pressure; and

(ii) Flow volume.

With respect to their operating pressure gas networks can be divided into:

(i) high-pressure gas networks (working pressure is higher than 1 bar);

(ii) medium-pressure gas networks (working pressure from 0.1 to 1 bar);

(iii) Low-pressure gas networks (working pressure up to 0.1 bar).

When planning a gas network, the following must be carried out and observed:

(i) priority pipe network analysis;

(ii) Planning of optimal construction rules based on envisaged gas demand.

To determine the most important physical quantities and flow-pressure characteristics of the gas used in the network we use computer software. For the purposes of flow-pressure analysis, we specify (J. Krope *et. al*., 2000):

(i) types of gas consumers;
(ii) pressure load;
(iii) the capacity of the network;
(iv) friction coefficient;
(v) nominal pipe diameters;
(vi) pipe connections;
(vii) Allowed speed, etc.

Gas network analysis is done in order to enhance the performance of gas flow in pipeline and need to optimize the problems regarding natural gas distribution system. Basically, there are two types of optimization problems are of interest in pipeline networks: design optimization and operation optimization. According to Firooz Tabkhi (2007), in design optimization, the goal is to optimize the pipeline design by selecting appropriate layouts, equipment, etc. while in operation optimization, the network and station configuration is given and the goal is to operate the pipeline network in an optimal manner**.**

By considering the existing pipeline system, to meet increased demand will requires adequate gas pressure to customers at all the time. Gas pressure need to be maintained because pressure drop of delivery pressure may not be acceptable to the customers. While increase the capacity of pipeline, capital cost for distribution system need to be considered as well as the gas velocity in which increasing too when gas flow rate or loads demands increases. Therefore network analysis is needed in order to design a network system. Analysis of gas network is to determine the need for system reinforcement. Gas network also used to determine the supply requirement for interconnected network and economic of fringe areas as well as to determine the effect of new loads whether the existing pipeline system is capable of taking the new loads. In terms of maintenance, gas network is done to determine the effects of equipment or line failure of the pipeline system.

There are several techniques to solve a gas network problem which are nodal method, loop method, loop-node method and Hardy Cross method. Hardy cross method is widely used in practical gas practical industry. This method was developed by

Professor Hardy Cross in 1936. This method supposes to be used to solve non linear equations. This method has been improved in solving non linear equation on loop spatial natural gas network in Serbia. This is done by Dejan Brkic, (2008) by introduction of influence of adjacent contours Yacobian matrix which is used in calculation and also in this way it necessary to reduce the number of iteration in calculations. But in this paper will be using loop method as a gas network analysis which is also involves iteration in calculation. This loop method will be discussed detail in Chapter 3 which is also using Hardy Cross method.

2.3 Selection of Flow Equation

Flow equations are required to calculate the pressure drop in the gas network system. There are many flow equations that can be used in gas industry. Majority of them are developed based on the results of gas flow experiments. Thus, they are only capable to a limited range of flow and pipe surface conditions Table 2.1 shows the guidelines to the selection of a flow equation for the distribution system calculation. Six flow equations are mainly used in this research and applied into the computer simulator. They are Lacey's equation, Pole's equation, Cox's equation, Polyflo equation, Panhandle 'A' equation and Weymouth equation (Abdel-Alim Hashem. *et. al*., 2000).

There are few assumptions applied to eliminate the problems in calculation using those equations which includes; there is no fraction factor for Cox's and Weymouth, because the value is already inserted into the flow equations. In this research, the specific of gas is assumed to be 0.589 and the compressibility factor, Z is assumed 0.95. These two values are subjected to change, depend on the type of natural gas (natural gas properties) and the type of pipe used. The temperature and pressure is assumed as standard temperature and standard pressure, normally used by international gas users in solving network analysis. The efficiency factor normally varies between 0.8 and 1 for most gas pipes (Aylmer, 1980). The actual flow in a pipe will be 80% of the flow predicted (Osiadacz, 1987).

Table 2.1: Guidelines to Selection of a flow equation for Distribution System Calculation (Poh, 2007)

Type of Piping	Predominant Type	Equation Used	Range capacity
High pressure utility supply mains	Partially turbulent	Panhandle A	Relatively good, slightly optimistic approximation for Smooth pipe Flow Law at Reynolds number >30000
High pressure utility supply main	Fully turbulent	Weymouth	Good approximation to Fully Turbulent Flow law for clears rough commercial pipe of 10 to 30 inch diameter
Medium and high pressure distribution	Partially turbulent	Panhandle A	Relatively good, slightly optimistic approximation for Smooth Flow Law at Reynolds number > 30000
Medium and high pressure distribution	Partially turbulent	Weymouth	Very conservative for pipe of less than 20 inch diameter.
Medium and high pressure distribution	Partially turbulent	Cox's	Pressure range > 5psi. Velocity < 20 m/s in all pipes.
Low pressure distribution	Partially turbulent	Pole's	Good approximation to Smooth pipe Flow Law for pipe of 4 inch diameter or smaller

Table 2.2: Flow Equations (Poh, 2007)

Flow Equations	Equation	K value Calculation
Lacey's / Pole's	$Q = 7.1 \times 10^{-3} \sqrt{\frac{(p_1 - p_2)D^5}{SL}}$	$K = 11.7 \times 10^3 \frac{L}{D^5}$
Cox's	$Q = 1.69 \times 10^{-3} \sqrt{\frac{(p_1{}^2 - p_2{}^2)D^5}{SL}}$	$K = 206.22527 \times 10^3 \frac{L}{D^5}$
Polyflo	$Q = 7.57 \times 10^{-4} \frac{T_n}{P_n} \sqrt{\frac{(p_1{}^2 - p_2{}^2)D^5}{fSLT}}$	$K = 27.24 \frac{L}{E^2 D^{4.848}}$
Panhandle 'A'	$Q = 7.57 \times 10^{-4} \frac{T_n}{P_n} \sqrt{\frac{(p_1{}^2 - p_2{}^2)D^5}{fSLTZ}}$	$K = 18.43 \frac{L}{E^2 D^{4.854}}$
Weymouth	$Q = 11854124.6 \frac{T_n}{P_n} D^{8/3} \sqrt{\frac{(p_1{}^2 - p_2{}^2)}{SLT}}$	$K = 2590000 \frac{L}{D^{16/3}}$

Table 2.2 shows the flow equation while table 2.3 shows the limitation of the equations.

Table 2.3: Limitation of Equation (Poh, 2007)

Flow Equations	Pressure Range (bar gauge)	Assumption Made
		Fraction factor, f Specific gravity of gas, S Temperature, T and Normal Temperature, T_n Normal Pressure, P_n Compressibility factor, Z Efficiency factor, E
Lacey's/Pole's	0-0.075	$f = 0.0044(1 + \frac{12}{0.276D}$ S=0.589
Cox's	0.75-7	S=0.589
Polyflo	0.75-7	$\sqrt{\frac{1}{f}} = 11.98 \times E \left(\frac{SQ^{0.076}}{D}\right)$ S=0.589

		T=288K
Panhandle A	>7	$\sqrt{\frac{1}{f}} = 11.98 \times E\left(\frac{SQ^{0.076}}{D}\right)$ S=0.589 T_n=T=288K, P_n=1.01325 bar Z=0.95, E=0.8
Weymouth	>7	S=0.589 T_n=T=288K, P_n=101.32kPa

2.4 Fundamental of Gas Flow Equation

Many gas flow equations have been developed and widely used in the practical of gas industry. Gas flow also depends on gas properties, pipe diameter, length, initial gas pressure, temperature and pressure drop due to friction. But in this paper will focus on calculating pressure drops due to the common problem that always occurred during gas transportation in pipeline system. Gonzales, A.H.,*et.al.,* (2008) stated that the demanded gas has to be supplied to delivery points with a specified pressure and the undesired pressure drops along the network must be periodically restored. Therefore, pressure drops must be avoided to maintain the delivery pressure to the customer. Formula which is derived from equation 2.1 is commonly used to calculate the pressure drop. As a gas flow through a pipeline, the total energy of the gas flow at various points consists of energy due to pressure, due to velocity and energy due to the elevation or position. Bernoulli's equation simply connects these components of the energy of the flowing fluid to form energy conservation. This Bernoulli's equation is shown as below and denote as equation 2.1

$$Z_A + \frac{P_A}{\gamma} + \frac{{V_A}^2}{2g} + H_p = Z_B + \frac{P_B}{\gamma} + \frac{{V_B}^2}{2g} + h_f \qquad (2.1)$$

Where H_p is the equivalent head added to the fluid by compressor at A and h_f represents the total frictional pressure loss between points A and B which is shown in

Figure 2.1. Starting this basic energy equation, applying gas laws and after some simplification, various formulas were developed over years to predict the performance of a pipeline transporting gas. These formulas intended to show the relationship between the gas properties, compressibility factor with the gas flow rates, pipe diameter, length and the pressure along the pipeline.

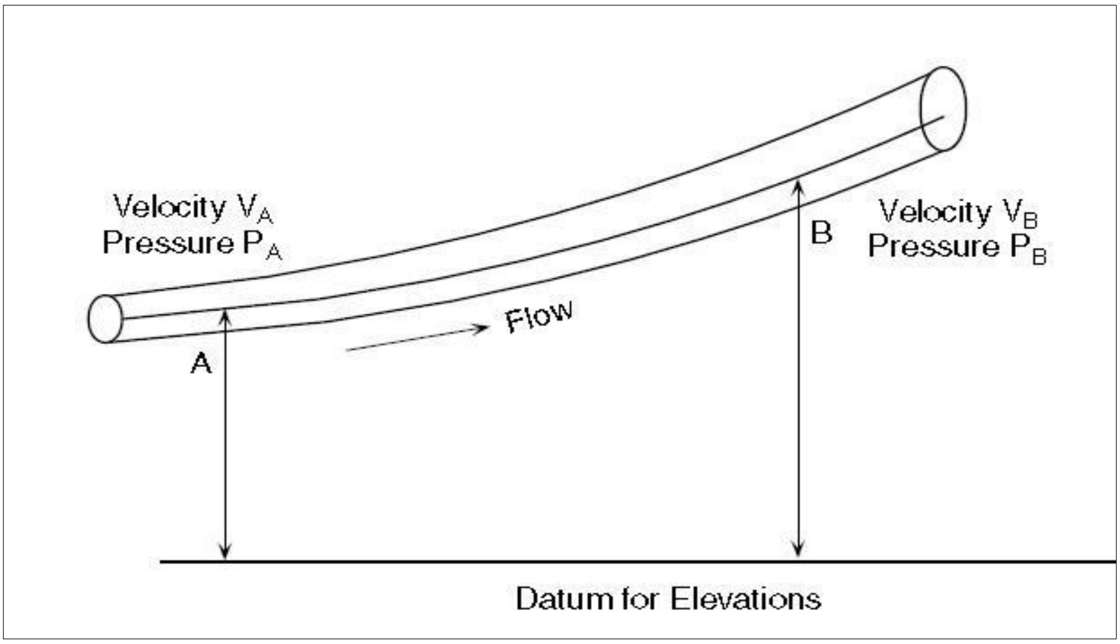

Figure 2.1 Energy of Flow of Fluid *(Menon, E.S..(2005).*

Thus with the certain assumptions, the basic energy equation is simplified and came out with various formula such as General Flow equation. Then through derivation and simplification of General Flow equation came out with Weymouth equation, Panhandle A, Panhandle B, Mueller equation, AGA equation, Spitzglass equation, IGT equation, Colebrook-White equation, Modified Colebrook-White equation and Fritzsche equation which has been practiced in gas industry. Most of these equations are applied for steady state.

These analytical equations will considerably enhance gas pipeline design in terms of both ease of usage and accuracy and this was proved by Adeosun, T.*A et. al.*, (2009). In their research also proved that the compressible gas flow through pipelines in natural gas industry has been solved by using the development of unsteady-state

Weymouth equation which is applied for gas volumetric flow rate in horizontal and inclined pipes without neglecting any of terms of fundamental differential equations. Therefore this gas flow network analysis is considerably enhancing gas pipeline design.

The General flow equation is called fundamental flow equation for steady state isothermal flow in gas pipeline which according to Menon, E.S. (2005) in his book entitled, Gas Pipeline Hydraulics. Equation 2.2 shows the General Flow equation which is also basic equation for relating pressure drop with flow rate.

$$Q = 77.54 \left(\frac{T_b}{P_b}\right) \sqrt{\left(\frac{{P_1}^2 - {P_2}^2}{G T_f L Z f}\right)} D^{2.5} \qquad (2.2)$$

Where;

Q = gas flow rate, SCFD

f = friction factor, dimensionless

T_b = base temperature, °R (460 + °F)

P_b = base pressure, psia

P_1 = upstream pressure, psia

P_2 = downstream pressure, psia

G = gas gravity (air = 1.0)

T_f = average gas flowing temperature, °R (460 + °R)

L = pipe segment length, mi

Z = gas compressibility factor at the flowing temperature, dimensionless

D = pipe inside diameter, in.

In SI unit, the General Flow equation is stated as below and denoted as equation (2.3)

$$Q = 1.1494 \times 10^{-3} \left(\frac{T_b}{P_b}\right) \sqrt{\left(\frac{{P_1}^2 - {P_2}^2}{G T_f L Z f}\right)} D^{2.5} \qquad (2.3)$$

Where;

Q = gas flow rate, SCMD

f = friction factor, dimensionless

T_b = base temperature, K (273 + ºF)

P_b = base pressure, kPa

P_1 = upstream pressure, kPa

P_2 = downstream pressure, kPa

G = gas gravity (air = 1.0)

T_f = average gas flowing temperature, K (273 + ºC)

L = pipe segment length, km

Z = gas compressibility factor at the flowing temperature, dimensionless

D = pipe inside diameter, mm

The derivation of General Flow equation which involves of simplifying assumptions which are:

(i) Steady flow
(ii) Isothermal flow due to heat transfer with the surroundings through the pipe wall
(iii) Negligible kinetic energy change in the pipe
(iv) Constant compressibility of the gas over the length of the pipe
(v) Validity of Darcy friction loss relationship across the pipe
(vi) Constant friction coefficient along the pipe length.

Then, the simpler of this General Flow equation has been derived and modified to introduce low, middle and high pressure distribution system which applicable in gas industry. However the difference between them is the assumed value for friction factor f or the transmission factor ($1/\sqrt{f}$). Further modification is made to the above general