PIPING DESIGN FOR LNG LIQUEFACTION SYSTEMS

A thesis submitted in partial fulfillment of the requirements for the award of degree of

Master of Technology in Marine Engineering and Management

by

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INDIAN MARITIME UNIVERSITY KOLKATA CAMPUS

Department of Marine Engineering

CERTIFICATE

This is to certify that the thesis entitled **"PIPING DESIGN FOR LNG LIQUEFACTION SYSTEMS"** submitted by SATYA VART GUPTA to Indian Maritime University Kolkata Campus for the award of the degree in Master of Technology in Marine Engineering and management, is a bonafide record of the project work carried out by him under our supervision. The contents of this thesis, in full or in parts have not been submitted to any other institute or University for the award of any degree or diploma.

The Project has been carried out at Indian Maritime University Kolkata Campus.

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ABSTRACT

Liquefied Natural gas is the future of the energy sector, as it is a source of clean energy. The liquefaction of natural gas is achieved at 111.67 K temperature, 1 atm; which is a cryogenic temperature. The cryogenic flow needs special attention because fluid, as well as material of the pipe, behave differently at cryogenic temperature. Two-phase flow is another critical point in the liquefaction of natural gas.

The objective of this thesis work is to select the material of the pipe, calculate frictional losses in the pipe, and pressure drop in the pipe through which the cryogenic fluid flows. The frictional loss in the pipe mostly depends on Reynolds number, Roughness factor, and phase of flow. As the Reynolds number increases, the friction factor increases in a greater value. As the time lapses, corrosion and erosion factor plays a key role in frictional pressure drop. As there is an increment in pipe diameter, the pressure drop due to friction or frictional losses decrease but by virtue of that the weight of the piping system increases which is an unfavourable condition from an economic point of view.

The flow in pipe encounters different forms of fluid in the liquefaction cycle of natural gas i.e. liquid phase flow, Gas phase flow and mix flow of liquid and gas. The Liquid flow and gas flow in a pipe are mainly deal with the Colebrook equation. Two-phase flow is a critical phenomenon in the liquefaction cycle.

The pipe sizes mentioned in the result can be used for experimental setup. It is found that the corrosion factor is 0.3 and 3 mm respectively for a period of 30 years. Also, it is found that, there exists two phase flow after the joule Thomson expansion device. While selecting the pipe size, it has been observed that the thickness of the pipe greatly depend on internal pressure of the flowing fluid.

CHAPTER 1

INTRODUCTION

1. Introduction

The energy is the basic element of today life. For every work of day to day life, energy in various form are required. The world today faces an energy crisis. Global population is rising rapidly – projected to reach 9.7 billion people by 2050 as per study of UN DESA [1]. More human being means higher energy demand, but on top of this, we can't forget the 1.2 billion people today who already live without electricity. Using affordable, renewable energy sources in developing countries can help raise their quality of life.

As countries worldwide invest in additional power sources, they all need to think about the world they are creating for these future generations. Power sources that pollute our planet, air and water resources and emit climate change-inducing greenhouse gasses could not be a long-term energy solution on a resource-constrained planet.

Providing a sustainable and clean energy source for more than 9 billion people is a monumental challenge. To meet this challenge, clean energy sources need to be a larger portion of the energy mix.

There are four large-scale shifts in the global energy system set the scene for the World Energy Outlook 2017 [2]:, the growing electrification of energy, the rapid deployment and falling costs of clean energy technologies, the shift to a more services-oriented economy and a cleaner energy mix in China, and the resilience of shale gas and tight oil in the United States.

These shifts come at a time when traditional distinctions between energy producers and consumers are being blurred and a new group of major developing countries, led by India subcontinent, moves towards centre stage. The largest contribution to demand growth – almost 30% – comes from India subcontinent, whose share of global energy use rises to 11% by 2040 (still well below its 18% share in the anticipated global population).

Compared with the past twenty-five years, the way that the world meets its growing clean energy needs changes dramatically in the New Policies Scenario, with the lead now taken by natural gas, by the rapid rise of renewables and by energy efficiency.

Natural gas is a fossil clean energy source that formed deep beneath the earth's surface. Natural gas contains many different organic compounds. The largest component of natural gas is methane, a compound with one atom of carbon atom and four atom of hydrogen atoms (CH_4). Natural gas also contains smaller amounts of natural gas liquids (NGL; which are also hydrocarbon gas liquids), and non-hydrocarbon gases, such as carbon dioxide and water vapour. The use of natural gas is as a fuel and to make materials and chemicals.

Liquefied natural gas (LNG) is natural gas that has been cooled to a liquid state, at about -150°C, for shipping and storage. The volume of natural gas in its liquid state is about 600 times smaller than its volume in its gaseous state. Natural gas has many qualities that make it an efficient, relatively clean burning, and economical energy source.

Burning liquefied natural gas for energy results in fewer emissions of nearly all types of air pollutants and carbon dioxide (CO_2) than burning coal or petroleum products to produce an equal amount of energy.

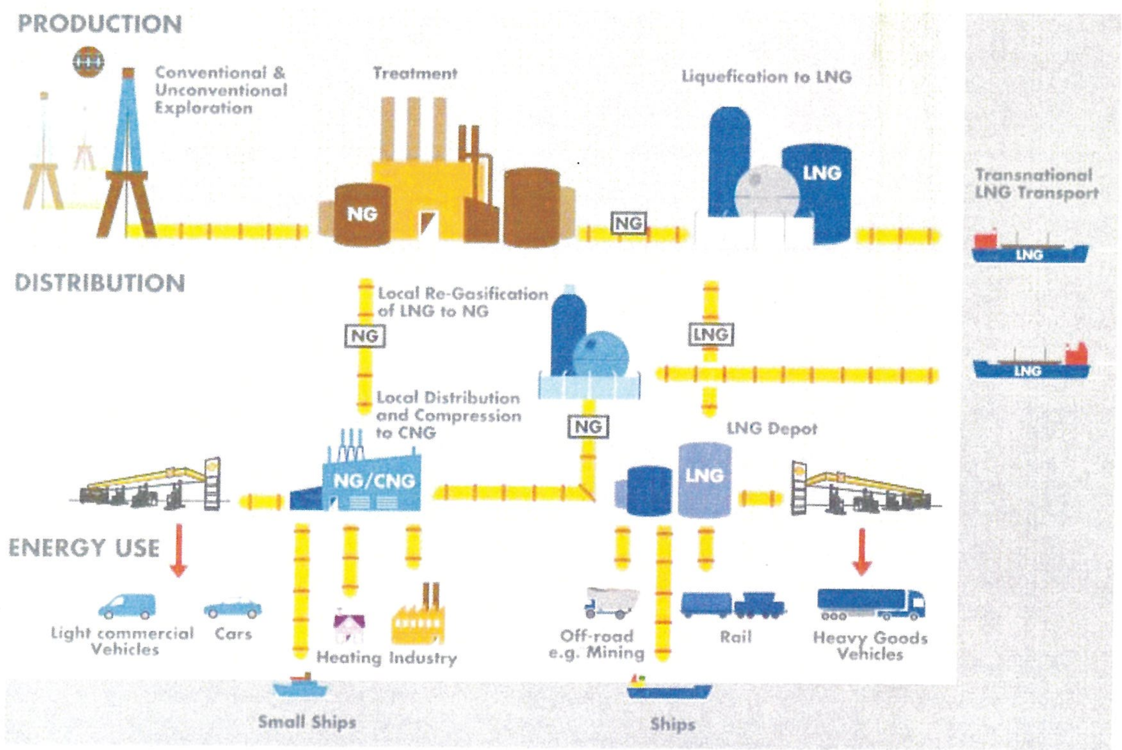

Figure 1- Natural Gas in different stage (articles.maritimepropulsion.com)

Globally natural gas demand that had been rising since 2014 accelerated in 2017, spurred by Asia, which accounted for 1/3 of the additional demand. Economic growth also helped gas demand increase in India, Japan and South Korea (low nuclear availability for these two countries) [4].

The industrial sector uses natural gas as a fuel for process heating, in combined heat and power systems, and as a raw material (feedstock) to produce chemicals, fertilizer, and hydrogen. The electric power sector uses natural gas to generate electricity. The other consuming sectors also use natural gas to generate electricity, and nearly all of this electricity is used by the sectors themselves. The residential sector uses natural gas to heat buildings and water, to cook, and to dry clothes. The commercial sector uses natural gas to heat buildings and water, to operate refrigeration and cooling equipment, to cook, to dry clothes, and to provide outdoor lighting. Some consumers in the commercial sector also use natural gas as a fuel in combined heat and power systems. The transportation sector uses natural gas as a fuel to operate compressors that move natural gas through pipelines and as a vehicle fuel in the form of compressed natural gas and liquefied natural gas. Nearly all vehicles that use natural gas as a fuel are in government and private vehicle fleets.

Natural gas is liquefied by lowering the temperature of the hydrocarbon to approximately -260 degrees Fahrenheit (-160 degrees Celsius). This temperature drop liquefies the methane present in the natural gas, making transportation at atmospheric pressure in the form of LNG possible. LNG is mainly constituted of methane and generally contains ethane, as well. Liquefied Petroleum Gas (LPG) may also be present in the LNG.

The process for the liquefaction of natural gas is essentially the same as that used in modern domestic refrigerators, but on a massive scale. A refrigerant gas is compressed, cooled, condensed, and let down in pressure through a valve that reduces its temperature by the Joule-Thomson effect. The refrigerant gas is then used to cool the feed gas. The temperature of the feed gas is eventually reduced to −161°C, the temperature at which methane, the main constituent of natural gas, liquefies. The temperature below -150°C is called cryogenic temperature. The fluid at cryogenic temperature, the fluid behave differently compared to fluid at normal condition.

1.2. Objective of the study

The objectives of the present study are as follows

1. Section of a Natural Gas liquefaction cycle for study.
2. Structural Design of the Pipe with selection of proper material for the pipe at cryogenic temperature.
3. Calculation of friction factor and frictional losses in Pipe for
    a. Liquid Flow
    b. Gas Flow
    c. Two phase flow
4. Selection of Proper size of Pipe basis on structural and optimum frictional pressure drop.

CHAPTER 2

LITERATURE SURVEY

2.1. Introduction

Liquefied natural gas (LNG), is natural gas that is super-cooled to minus 162 degrees Celsius. At that temperature, natural gas transforms from a gaseous state into a liquid. When in liquid form, natural gas takes up to 600 times less space than in its gaseous state, making it feasible and more economical for transport over long distances.

LNG is very safe to transport, and the industry's safety record is exemplary. For over 50 years, tankers have safely transported LNG around the world.

LNG is an odourless, non-toxic, non-corrosive liquid and leaves no residue after it evaporates. LNG will not ignite until it becomes a vapour, and even then, the vapour will not ignite until it mixes with air and becomes extremely diluted (5-15% vaporized gas-to-air ratio). Below 5%, there is too little gas in the air to burn; above 15%, there is not enough oxygen.

The word cryogenics is defined as the study of low-temperature phenomena. The temperature separating cryogenics from conventional refrigeration that is suggested by the workers at the National Institute for Standards and Technology in Boulder, Colorado, is −150°C (123 K) [5].

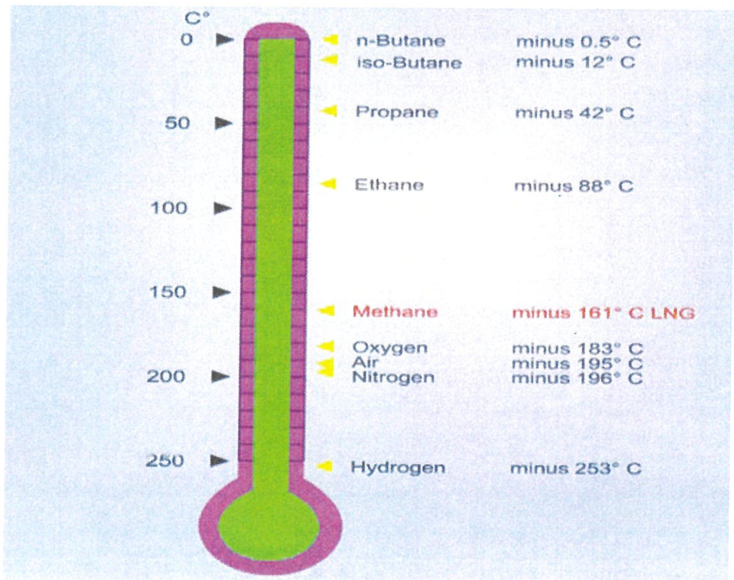

Figure 2- Schematic of a Simple Refrigeration Cycle(whatispiping.com)

2.2. Type of flow in cryogenic flow.

In Natural Gas liquefaction plant the flow encountered with three different type of flow. There are following:-

- Liquid flow
- Gas flow
- Two Phase flow

2.2.1. Liquid Flow

By the principle of conservation of the mass, the mass flow rate at the pipe inlet will equal that at the pipeline outlet since the mass of liquid does not change with temperature or pressure.

It must be noted that since the volume of a fluid varies with temperature, but for liquid, which is incompressible fluid, the volume don't vary much with temperature or pressure. The inlet flow rate and the outlet volume flow rate of fluid may be different in a long-distance pipeline, even if there are no intermediate injections or deliveries.

The temperature difference is due to heat loss or gain between the pipeline liquid and the surrounding or ambient conditions. Generally, significant variation in temperature is observed when pumping crude oils or other products that are heated at the pipeline inlet. In refined petroleum products and other pipelines that are not heated, temperature variations along the pipeline are insignificant.

Flow in a liquid pipeline may be smooth, laminar flow (also known as viscous streamline flow). In this type of flow, the liquid flows in layers or laminations without causing eddies or turbulence. As the liquid flow rate is increased, the velocity increases and the flow will change from laminar flow to turbulent flow with eddies and disturbances.

An important dimensionless parameter called the Reynolds number is used in classifying the type of flow in pipelines. The Reynolds number of flow, R [6], is calculated as follows:

$$R = \frac{\rho V D}{\mu}$$

Where,

R = Reynolds number

ρ = Density (Kg/m^3)

V = Velocity of flow (m/s)

D = Diameter of pipe (m)

μ = Dynamic Viscosity (Pa-s)

Flow through pipes is classified into three main flow regimes:

I. Laminar flow: R<2000
II. Critical flow: R>2000 and R<4000
III. Turbulent flow: R>4000

As fluid flows through a pipeline, energy is lost due to friction between the pipe surface and the fluid and due to the interaction between fluid molecules. This energy lost is at the expense of fluid pressure. Hence here the frictional energy lost refers as the pressure drop due to friction.

The pressure drop due to friction in a pipeline depends on the flow rate in pipe, pipe diameter, pipe roughness, liquid specific gravity, and viscosity. In addition, the frictional pressure drop depends mainly on the Reynolds number (and hence the flow regime).

The pressure drop due to friction in a given length of pipeline, expressed in meter of liquid head (h), can be calculated using the Darcy-Weisbach equation [7] as follows:

$$h = \frac{fLV^2}{2gD}$$

Where,

f= Darcy friction factor (dimensionless)

L= Length of pipe (m)

D= Internal diameter of pipe (m)

V= Velocity of flow (m/s)

g=Acceleration due to gravity,9.81 (m/s^2)

In laminar flow, the friction factor f depends only on the Reynolds number. In turbulent flow f depends on pipe diameter, internal pipe roughness, and Reynolds number.

2.2.1.1. *Friction factor for laminar flow*

For laminar flow, with Reynolds number R<2000, the Darcy friction factor f [8]is calculated from the simple relationship.

$$f = \frac{64}{R}$$

Where,

R = Reynolds number

f= Darcy friction factor (dimensionless)

It can be seen from above equation that for laminar flow the friction factor depends only on the Reynolds number and is independent of the internal condition of the pipe. Thus, regardless of whether the pipe is smooth or rough, the friction factor for laminar flow is a number that varies inversely with the Reynolds number.

2.2.1.2. *Friction factor for critical flow*

In the critical zone, where the Reynolds number lies between 2000 and 4000, there is no generally accepted formula for determining the friction factor. This is because the flow is unstable in this region and therefore the friction factor is indeterminate. Most users calculate the value of f based upon turbulent flow.

2.2.1.3. *Friction factor for turbulent flow*

For turbulent flow, when the Reynolds number R>4000, the friction factor f depends not only on Reynolds number but also on the internal roughness of the pipe. As the pipe roughness increases, so does the friction factor. Therefore, smooth pipes have a smaller friction factor compared with rough pipes. More correctly, friction factor depends on the relative roughness (e/D) rather than the absolute pipe roughness e.

A good all-purpose equation for calculation of the friction factor f in the turbulent region (i.e., where R>4000) is the Colebrook-White equation [9]:

$$\frac{1}{\sqrt{f}} = -2\ \log_{10}\left[\left(\frac{e}{3.7D}\right) + \frac{2.51}{(R\sqrt{f})}\right]$$

Where,

f = Friction factor (dimensionless)

e = Absolute pipe roughness (mm)

D = Internal diameter of pipe (mm)

R = Reynolds number (dimensionless)

During the last two or three decades several formulas for friction factor for turbulent flow have been put forth by various researchers. All these equations attempt to simplify calculation of the friction factor compared with the Colebrook-White equation discussed above. Two such equations that are explicit equations in f, afford easy solution of friction factor compared with the implicit equation that requires trial-and-error solution. These are called the Churchill equation and the Swamee-Jain equation

To make matters more complicated, the turbulent flow region (R>4000) actually consists of three separate regions:

Turbulent flow in smooth pipes

Turbulent flow in fully rough pipes

Transition flow between smooth and rough pipes

For turbulent flow in smooth pipes, pipe roughness has a negligible effect on the friction factor. Therefore, the friction factor in this region depends only on the Reynolds number as follows:

$$\frac{1}{\sqrt{f}} = -2\ \log_{10}\left[\frac{2.51}{(R\sqrt{f})}\right]$$

Where,

f = Friction factor (dimensionless)

R = Reynolds number (dimensionless)

For turbulent flow in fully rough pipes, the friction factor f appears to be less dependent on the Reynolds number as the latter increases in magnitude. It depends only on the pipe roughness and diameter. It can be calculated from the following equation:

$$\frac{1}{\sqrt{f}} = -2\ \log_{10}\left[\left(\frac{e}{3.7D}\right)\right]$$

Where,

f = Friction factor (dimensionless)

e = Absolute pipe roughness (mm)

D = Internal diameter of pipe (mm)

For the transition region between turbulent flow in smooth pipes and turbulent flow in fully rough pipes, the friction factor f is calculated using the Colebrook-White equation given previously:

$$\frac{1}{\sqrt{f}} = -2\ \log_{10}\left[\left(\frac{e}{3.7D}\right) + \frac{2.51}{(R\sqrt{f})}\right]$$

Where,

f = Friction factor (dimensionless)

e = Absolute pipe roughness (mm)

D = Internal diameter of pipe (mm)

R = Reynolds number (dimensionless)

2.2.2. Gas Flow

The pipeline flow rate will depend upon the gas properties, pipe diameter and length, initial gas pressure and temperature, and the pressure drop due to friction.

By the principle of conservation of mass, the mass flow rate at the inlet will equal that at the pipeline outlet since the mass of liquid does not change with temperature or pressure. For a given pipe size and length, There it can predict the flow rate possible through a pipeline based upon an inlet pressure and an outlet pressure of a pipe segment.

For most practical purposes, the assumption of isothermal flow is good enough, since in long gas transmission lines the gas temperature reaches constant values, anyway.

An important parameter in flow of gas in a pipe is the non-dimensional term Reynolds number. The Reynolds number is used to characterize the type of flow in a pipe, such as laminar flow, turbulent flow, or critical flow. It is also used to calculate the friction factor in pipe flow.

The Reynolds number is a function of the gas flow rate, pipe inside diameter, and the gas density and viscosity and is calculated from the following equation:

$$R = \frac{\rho V D}{\mu}$$

Where,

R = Reynolds number

ρ = Density (Kg/m^3)

V = Velocity of flow (m/s)

D = Diameter of pipe (m)

μ = Dynamic Viscosity (Pa-s)

In gas pipeline hydraulics [10], using customary units, In SI units, the Reynolds number is

$$R = 0.5134 \left(\frac{P_b}{T_b}\right)\left(\frac{GQ}{\mu D}\right)$$

Where

P_b = Base pressure, kPa

T_b = Base temperature, °K

G = Specific gravity of Gas

Q = Gas flow rate, m^3/day

D = Pipe inside diameter, mm

μ = Dynamic Viscosity, Poise

Flow through pipes is classified into three main flow regimes:

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III. Turbulent flow: R>4000

As liquid flows through a pipeline, energy is lost due to friction between the pipe surface and the liquid and due to the interaction between liquid molecules. This energy lost is at the expense of liquid pressure. Hence we refer to the frictional energy lost as the pressure drop due to friction.

The pressure drop due to friction in a given length of pipe, expressed in meter of liquid head (h), can be calculated using the Darcy-Weisbach equation as follows:

$$h = \frac{fLV^2}{2gD}$$

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In laminar flow, the friction factor f depends only on the Reynolds number. In turbulent flow f depends on pipe diameter, internal pipe roughness, and Reynolds number.

2.2.2.1. Friction factor for laminar flow

For laminar flow, the friction factor is inversely proportional to the Reynolds number, as indicated below.

$$f = \frac{64}{R}$$

Where,

R = Reynolds number

f= Darcy friction factor (dimensionless)

For turbulent flow, the friction factor is a function of the Reynolds number, pipe inside diameter, and internal roughness of the pipe.

2.2.2.2. Friction factor for critical flow

In the critical zone, where the Reynolds number is between 2000 and 4000, there is no generally accepted formula for determining the friction factor. This is because the flow is unstable in this region and therefore the friction factor is indeterminate. Most users calculate the value of f based upon turbulent flow.

2.2.2.3. Friction factor for turbulent flow

For turbulent flow, when the Reynolds number R>4000, the friction factor f depends not only on R but also on the internal roughness of the pipe. As the pipe roughness increases, so does the friction factor. Therefore, smooth pipes have a smaller friction factor compared with rough pipes. More correctly, friction factor depends on the relative roughness (e/D) rather than the absolute pipe roughness e.

The Colebrook-White equation, referred as the Colebrook equation, is a relationship between the friction factor and the Reynolds number, pipe roughness, and inside diameter of pipe. The following form of the Colebrook equation is used to calculate the friction factor in gas pipelines in turbulent flow.

$$\frac{1}{\sqrt{f}} = -2\ \log_{10}\left[\left(\frac{e}{3.7D}\right) + \frac{2.51}{(R\sqrt{f})}\right]$$

Where,

f = Friction factor (dimensionless)

e = Absolute pipe roughness (mm)

D = Internal diameter of pipe (mm)

R = Reynolds number (dimensionless)

To make matters more complicated, the turbulent flow region (R>4000) actually consists of three separate regions:

Turbulent flow in smooth pipes

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Transition flow between smooth and rough pipes

For turbulent flow in smooth pipes, pipe roughness has a negligible effect on the friction factor. Therefore, the friction factor in this region depends only on the Reynolds number as follows:

$$\frac{1}{\sqrt{f}} = -2\ \log_{10}\left[\frac{2.51}{(R\sqrt{f})}\right]$$

Where,

f = Friction factor (dimensionless)

R = Reynolds number (dimensionless)

For turbulent flow in fully rough pipes, with Re being a large number, f depends mostly on the roughness e and, therefore, the friction factor equation reduces to

$$\frac{1}{\sqrt{f}} = -2\ \log_{10}\left[\left(\frac{e}{3.7D}\right)\right]$$

Where,

f = Friction factor (dimensionless)

e = Absolute pipe roughness (mm)

D = Internal diameter of pipe (mm)

For the transition region between turbulent flow in smooth pipes and turbulent flow in fully rough pipes, the friction factor f is calculated using the Colebrook-White equation given previously:

$$\frac{1}{\sqrt{f}} = -2\ \log_{10}\left[\left(\frac{e}{3.7D}\right) + \frac{2.51}{(R\sqrt{f})}\right]$$

Where,

f = Friction factor (dimensionless)

e = Absolute pipe roughness (mm)

D = Internal diameter of pipe (mm)

R = Reynolds number (dimensionless)

2.2.3. Two Phase flow

One of the problem of cryogenic piping systems is heat leakage due to the absorption of heat from environment to pipe. A portion of the cryogenic liquid may evaporate resulting in both liquid and vapour present coexist in the piping system. Also, the throttling of the cryogenic liquid through a valve (joule-Thomson valve) can cause flashing or formation of vapour. In both cases two-phase flow would result. The calculation of pressure drop in two-phase flow is more complex than calculation of pressure drop in single-phase liquid flow.

It is found that the pressure drop in two-phase flow is larger than pressure drop in single-phase liquid flow. Larger pressure drop result in larger pipe size and hence more cost. Because of these reasons, there should as far as possible maintain single phase flow of cryogenic fluids. Sub-cooling of the liquid before a throttle valve can prevent flashing. Use of the proper insulation around the cryogenic piping can minimize heat leaks into the system, thereby preventing vaporization of the liquid.

When two-phase flow is present, we must calculate the pressure drop due to friction using one of the many correlations and empirical formulas such as

Lockhart-Martinelli [11]. These correlations are only approximate, and the calculated results may be off by 20 to 30 percent compared to actual pressure drops measured in the pipe. In this section we will discuss the approach to calculating the pressure drop using the Lockhart-Martinelli method [12]

The frictional component is calculated from the individual pressure drops considering each phase (liquid or gas) flowing separately and alone in the pipe.

The frictional component is calculated, as indicated earlier, by treating the liquid flow separately from the gas flow. We calculate the Reynolds number for the liquid and gas phase separately using the following equations:

$$Re_L \frac{M_L D}{A_L \mu_L}$$

$$Re_g \frac{M_g D}{A_g \mu_g}$$

Where, subscripts L and g refer to the liquid and gas phases, respectively, and where

Re = Reynolds number, dimensionless

M = mass flow rate

D = pipe inside diameter

A = pipe cross-sectional area

μ = dynamic viscosity

Laminar flow for fluid is said to occur for Reynolds numbers less than 1000 and turbulent flow for fluid for Reynolds numbers larger than 2000. This is slightly different from the Reynolds number boundaries for single-phase fluid flow.

Table I - Turbulence parameter for the Two phase flow [12]

Liquid	**Vapour**	R_L	R_g	k_L	k_g	n	m
Turbulent	Turbulent	>2000	>2000	0.046	0.046	0.2	0.2
Laminar	Turbulent	<1000	>2000	16.0	0.046	1.0	0.2
Turbulent	Laminar	>2000	<1000	0.046	16.0	0.2	1.0

Laminar	Laminar	<1000	<1000	16.0	16.0	1.0	1.0

The individual pressure drop due to friction for each phase is then calculated using the following equations:

$$\left(\frac{\Delta P_f}{\Delta z}\right)_L = \frac{2k_L(Re_L)^{-n}\rho_L}{D}\left(\frac{M_L}{A\rho_L}\right)^2$$

$$\left(\frac{\Delta P_f}{\Delta z}\right)_g = \frac{2k_g(Re_g)^{-m}\rho_g}{D}\left(\frac{M_g}{A\rho_g}\right)^2$$

Where subscripts Land g refer to the liquid and gas phases, respectively; $\Delta P_f/\Delta z$ is the frictional pressure drop per unit length of pipe.

Once we calculate the frictional pressure drop for the liquid phase and gas phase separately, the Lockhart-Martinelli parameter [13] X is found by the following empirical equation:

$$X^2 = \frac{(\Delta P_f/\Delta z)_L}{(\Delta P_f/\Delta z)_g}$$

$$\emptyset_L = \left(1 + \frac{c}{X} + \frac{1}{X^2}\right)^{0.5}$$

The frictional pressure drop for two-phase flow is then calculated from one of the following equations:

$$\left(\frac{\Delta P}{\Delta z}\right)_F = \emptyset_L{}^2\left(\frac{\Delta P_f}{\Delta z}\right)_L$$

$$\left(\frac{\Delta P}{\Delta z}\right)_F = \emptyset_g{}^2\left(\frac{\Delta P_f}{\Delta z}\right)_g$$

2.3. Thickness calculation of pipe

Minimum wall thickness gives the absolute minimal thickness of a pipe or structure to contain its contents. Thinner pipe walls mean lighter pipe or structures, which are lighter and cheaper to manufacture. Thinner pipes also allow more fluid flow for the same pipe size. Minimum wall thickness in design is based on the pressure of the vessel or pipe's contents, the material's allowable stress and the outer diameter of the pipe.

Input Variables are as follows [14]:

Design Pressure - Maximum pressure at expected conditions. Generally, the maximum flange pressure at design pressure is used.

Design Temperature - Maximum temperature at expected conditions.

Nominal Pipe Diameter - Pipe Size

Pipe Schedule - Thickness of pipe

Mechanical Allowances - This includes material removed from threading and corrosion allowances

Mill Tolerance - Allowable thickness variation from the mill that produced the pipe. This is defined by the governing specification. For A-53/ A-106 pipe, the mill tolerance is 12.5% [15]

Type of Pipe - This is how the pipe is constructed. The pipe could be ERW or Seamless pipe. A less common type of pipe is furnace butt welded pipe.

ANSI/ASME Standard B31.3 is a very stringent code with a high safety margin. The B31.3 wall-thickness calculation formula is stated as

$$t = t_e + t_{th} + \frac{PD}{2(SE + PY)}\left(\frac{100}{100 - T_{ol}}\right)$$

Where,

t = Minimum design wall thickness (mm)

t_e = Corrosion allowance (mm)

t_{th} = Thread or groove depth (mm)

D = Diameter of pipe (mm)

S = Allowable stress for Pipe (MPa)

E = Longitudinal Weld-joint factor

1.00.	Seamless
0.95	Electric fusion Weld, Double butt, Straight and spiral seam
0.85	Electric resistance weld (ERW)
0.60	Furnace butt weld

Y = Derating factor (0.4 for ferrous materials operating below 540°C)

T_{ol} = manufacturers allowable tolerance (mill tolerance)

12.5%	Pipe diameter up to 500 mm
10%	Pipe diameter above 500 mm

Table II - Values of Coefficient Y for $t < D/6$

Materials	**<482**	**510**	**538**	**566**	**593**	**>621**
Ferritic steels	0.4	0.5	0.7	0.7	0.7	0.7
Austenitic steels	0.4	0.4	0.4	0.4	0.5	0.7
Other ductile metals	0.4	0.4	0.4	0.4	0.4	0.4
Cast iron	0.0					

Corrosion Allowance

As far as I know, there is no corrosion allowance exactly specified in ASME B31.3. Corrosion allowances are normally established by the end user and are somewhat based on personal preferences and industry tradition. 1.5 mm for piping is a common standard, but you are free to set a corrosion allowances you wish, unless a state or local agency has adopted and superceded B31.3. To specify the pipe, add the corrosion allowance to the minimum design thickness and select a pipe schedule that is equal to or greater than the minimum + corrosion allowance.

Below are tables with guidelines for corrosion allowance

Table III - Corrosion Allowance For different fluid in Pipe

Corrosion Allowance	**mm**
Compressed Oil	1.0
Fuel Oil	1.0
Fresh Water	0.8
Sea Water	3.0
Cargo system for oil tankers	2.0
Cargo system for ships carrying liquefied gases	0.3

Thread or groove depth

Thread allowance are provided to compensate the strength reduction due to metal removal due to treading process. Threading Process are done to connect pipe.

Table IV - Thread or grove allownace for Pipe according to diameter

Pipe nominal Diameter (mm)	Thread or grove thickness (mm)
<200	1.52
200-500	2.032
>500	2.8

2.4. Minor Losses

Above study are used to calculate the pressure drop per unit length in straight pipe. Minor losses in a liquefied natural gas (LNG) pipeline are classified as those pressure drops that are associated with piping components such as valves and fittings. Fittings include elbows and tees. All these pressure drops are called minor losses, as they are relatively small compared to friction loss in a straight length of pipe[16].

Generally, minor losses are included in calculations by using the equivalent length of the valve or fitting or using a resistance factor or K factor multiplied by the velocity head $V^2/2g$. The term minor losses can be applied only where the pipeline lengths and hence the friction losses are relatively large compared to the pressure drops in the fittings and valves. In a situation such as plant piping and tank farm piping the pressure drop in the straight length of pipe may be of the same order of magnitude as that due to valves and fittings. In such cases the term minor losses is really a misnomer.

Table V - L/D factor for different type of Valave [17]

Type of Valve	L/D factor
Gate Valve	8
Globe Valve	340
Angle Valve	55
Ball Valve	3

Pluge Valve straight way	18
Pluge valve 3 way through flow	30
Pluge Valve branch Flow	90
Swing check Valve	100
Lift Check Valve	600
Standard Elbow, 90 degree	30
Standard Elbow, 45 degree	16
Standard Elbow, 90 degree long radius	16
Standard tee through flow	20
Standard tee through branch	60
Miter bends, 0 degree	2
Miter bends, 30 degree	8
Miter bends, 60 degree	25
Miter bends, 90 degree	60

In any case, the pressure losses through valves, fittings, etc., can be accounted for approximately using the equivalent length or K times the velocity head method. It must be noted that this way of calculating the minor losses is valid only in turbulent flow. No data are available for laminar flow. Accounting for minor losses is using the resistance coefficient or K factor. The K factor and the velocity head approach to calculating pressure drop through valves and fittings can be analysed as follows using the Darcy equation. From the Darcy equation , the pressure drop in a straight length of pipe is given by

$$h = K\frac{V^2}{2g}$$

Where

h	=	head loss (m)
K	=	L/D factor
V	=	Velocity of fluid (m/s)
g	=	Gravity Factor

2.5. Code – ASME 31.3

The B31.3 Code [15] contains requirements for piping typically found in petroleum refineries; chemical, pharmaceutical, textile, paper, semiconductor, and cryogenic plants; and related processing plants and terminals. This code prescribes requirements for materials and components, design, fabrication, assembly, erection, examination, inspection, and testing of piping. This Code applies to piping for all fluids including: (1) raw, intermediate, and finished chemicals; (2) petroleum products; (3) gas, steam, air and water; (4) fluidized solids; (5) refrigerants; and (6) cryogenic fluids. Also included is piping which interconnects pieces or stages within a packaged equipment assembly.

CHAPTER 3

METHODOLOGY

3.1. Assumption

The following assumption have be made in the following study.

I. The composition of the Natural Gas is made up of methane (CH_4) only. i.e. methane is 100% as constitute.

II. The Pressure drop is for calculation only. This effect is not applied on the Pipe line or or cycle calculation.

3.2. Natural Gas Liquefaction Cycle

The natural gas is condensed into a liquid form at close to atmospheric pressure by cooling it to approximately −162 °C; maximum transport pressure is set at around 25 kPa. Natural gas cooles down to liquid form for ease and safety of non-pressurized storage or transport.

The process for the liquefaction of natural gas is essentially the same as that used in any modern domestic refrigerators, but it works on a massive scale. A refrigerant gas is compressed, cooled, condensed, and let down in pressure through a valve that reduces its temperature by the Joule-Thomson (JT) effect. The refrigerant gas is then used to cool the feed gas. The temperature of the feed gas is eventually reduced to −161°C, the temperature at which methane, the main constituent of natural gas, liquefies. In the LNG process, constituents of the natural gas (propane, ethane, and methane) are typically used as refrigerants either individually or as a mixture.

There are large number of cycle for Liquefaction of the natural Gas. Most commercially available liquefaction processes are based on these cycles or a combination of these cycles. These processes include the pure-component cascade cycle, propane-precooled mixed-refrigerant cycle, dual mixed-refrigerant cycle, single mixed-refrigerant cycle, mixed-fluid cascade process, compact LNG technology, and integral incorporated cascade (CII™) process.

For the simplification of the study, here we are considering the simple precooled linde-hampson cycle. The layout of the precooled Linde hampson cycle is shown in figure 3. There different major component used in this Process are shown in diagram.

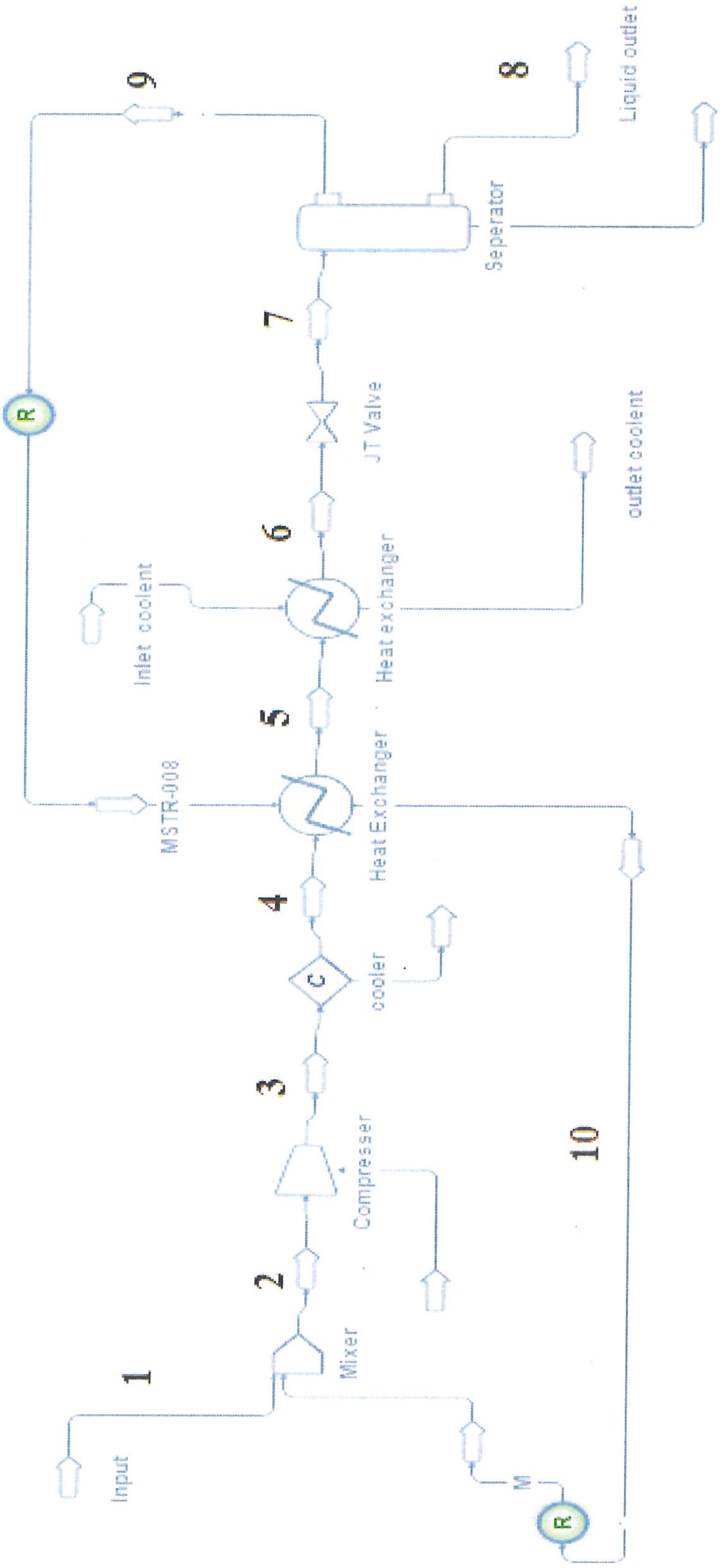

Figure 3- Layout of Pre-cooled linde hampson Natural Gas Liquifaction cycle modeled in DWSIM Software

3.2.1. Specification for Precooled Linde – Hampson Natural Gas Liquefaction cycle

Cycle	:	Precooled linde hampson
Cycle Capacity	:	1000 Kg/day
Working Fluid	:	Methane
Maximum Pressure	:	4 MPa
Minimum Pressure	:	0.101325 MPa (1 atm)
Cooling Fluid	:	Propane

3.2.2. Inlet Condition of gas

Methane

Pressure : 101325 Pa (1 atm)

Temperature : 300 K

Propane

Pressure : 101325 Pa (1 atm)

Temperature : 90 K

3.2.3. Methane Properties

The standard properties of the working fluid i.e. methane are shown in table VI.

Table VI - Properties of the methane

Molecular weight	16.042	
Normal Boiling Point	111.7	K
Critical Temperature	190.7	K
Critical Pressure	4.63	Mpa
Temperature at Triple Point	88.7	K
Pressure at tripple point	10.1	Mpa

3.3. Pipe specification

The Pipe is subjected to cryogenic temperature in this Process and the material pipe behave differently at cryogenic temperature as compared at normal temperature. So ASME B 31.3: 2006: Process Piping: ASME Code for Pressure Piping is used for designing of the pipe.

Nominal composition - 18Cr-10Ni-Ti

Specification	-	A376
Type/Grade	-	TP321
UNS No.	-	S32100
Min Temp (°C)	-	-255
Mim. Tensile Strength (MPa)	-	483
Min Yield Strength (MPa)	-	172
Max. Use Temperature (°C)	-	816

Table VII - Basic Allowable Stress, S, MPa, at Metal Temperature oC

Temp up to	40	225	250	275	325	350	375	400	450
Allowable stress	115	115	112	109	104	102	100	98.8	96.3

For this particular study, the following values has been taken.

Corrosion Allowance	:	0.3 mm
Longitudinal Weld Factor	:	1

As per International standard, there are specified size of pipe are available in the market. For LNG plant installation ASME standard pipe specification has been taken into consideration. Table VIII shows the standard specification of pipe as Pipe Nominal Diameter and Pipe outer diameter.

Table VIII - Pipe Nominal diameter and Outer diameter as per ASME standard

Nominal Diameter (mm)	Pipe outer diameter (mm)
15	21.3
20	26.7
25	33.4
32	42.2
40	48.3
50	60.3
65	73
80	88.9

90	101.6
100	114.3
125	141.3
150	168.3
200	219.1
250	273.1
300	323.9

3.4. Calculation

3.4.1. Calculation of Pipe thickness

For calculation of thickness of pipe, the Code ASME B31.3 has been taken into consideration. For calculation the code is developed using MATLAB software. The MATLAB code is shone in Appendix I.

3.4.2. Calculation of Frictional Losses

As discussed earlier, there three phase are possible in liquefaction cycle as: Liquid phase, Gas Phase and two phase. For these condition, three different type of condition are used for these calculation.

For calculation of friction losses in liquid phase, the code is developed using MATLAB software. The MATLAB code is shown in Appendix II for frictional loss in pipe.

For calculation of friction losses in gas phase, the code is developed using MATLAB software. The MATLAB code is shown in Appendix III for frictional loss in pipe.

For calculation of friction losses in two phase, the code is developed using MATLAB software. The calculation for two phase friction losses are more complicated as compared to single phase friction losses. The MATLAB code is shown in Appendix IV.

CHAPTER 4

RESULT AND DISCUSSION

4.1. Pipe between Inlet & mixer

Pipeline Number	:	1
Location	:	Inlet to mixer
Pressure	:	1 atm (101.325 kPa)
Temperature	:	300 K
State	:	Gas

Properties at specified temp and pressure as per NIST data

Mass Flow rate	:	0.011574 Kg/s
Density	:	0.6528 Kg/m^3
Viscosity	:	1.12e-5 Pa-s

Table IX - Minimum required thickness of pipe according to nominal diameter for Pipeline number 1

Pipe Nominal Diameter	Minimum required thickness (mm)
15	1.830
20	1.833
25	1.836
32	1.841
40	1.844
50	1.850
65	1.856
80	1.864
90	1.871
100	1.877
125	1.891
150	1.904
200	1.930
250	1.957
300	1.983

Table IX shows the minimum thickness required for pipe as per operating pressure in pipeline 1. Table X and Figure 4 shows the Reynolds Number, friction factor and total Pressure drop in Pipeline 1. Considering 5% of maximum pressure drop for working pressure of 1 atm. So from table X, pipe specification of 20 X 40 is selected. The minimum thickness of pipe is 2.87 mm which is more than minimum thickness required as per table IX, which has required minimum pipe thickness of 1.833 mm.

Table X - Friction factor and total pressure drop in pipeline 1 due to flow with pipe specification

Pipe Specification	Pipe outer diameter (mm)	Thickness (mm)	Reynolds Number	Friction factor	Total Pressure Drop (Pa)
15 x 40	21.3	2.77	83530.38	0.009002	18186.65149
20 x 40	26.7	2.87	62807.19	0.008102	4131.426267
25 x 40	33.4	3.38	49415.87	0.007445	1204.483816
32 x 40	42.2	3.56	37526.76	0.006785	297.7111129
40 x 40	48.3	3.68	32155.32	0.006453	137.015777
50 x 40	60.3	3.91	25084.58	0.005967	39.89018996
65 x 40	73	5.16	21002.53	0.005653	16.67928939
80 x 40	88.9	5.49	16894.75	0.0053	5.801295575
90 x 40	101.6	5.74	14607.62	0.005082	2.886184647
100 x 40	114.3	6.02	12873.45	0.004904	1.581494626
125 x 40	141.3	6.55	10268.63	0.004608	0.545337613
150 x 40	168.3	7.11	8543.865	0.004386	0.23180393
200 x 20	219.1	6.35	6378.095	0.004065	0.060586146
250 x 20	273.1	6.35	5055.448	0.003834	0.021161902
300 x 20	323.9	6.35	4230.202	0.003671	0.009522611

So Selected pipe specification are as

Pipe Specification : 20 x 40

Pipe outer diameter : 26.7 mm

Pipe thickness : 2.87 mm

4.2. Pipe between Mixer & compressor

Pipeline Number : 2

Location : Mixer to Compressor

Pressure : 1 atm (101.325 kPa)

Temperature : 319 K

State : Gas

Properties at specified temp and pressure as per NIST data

Mass Flow rate	:	0.11574 Kg/s
Density	:	0.6137 Kg/m^3
Viscosity	:	1.18 e-5 Pa-s

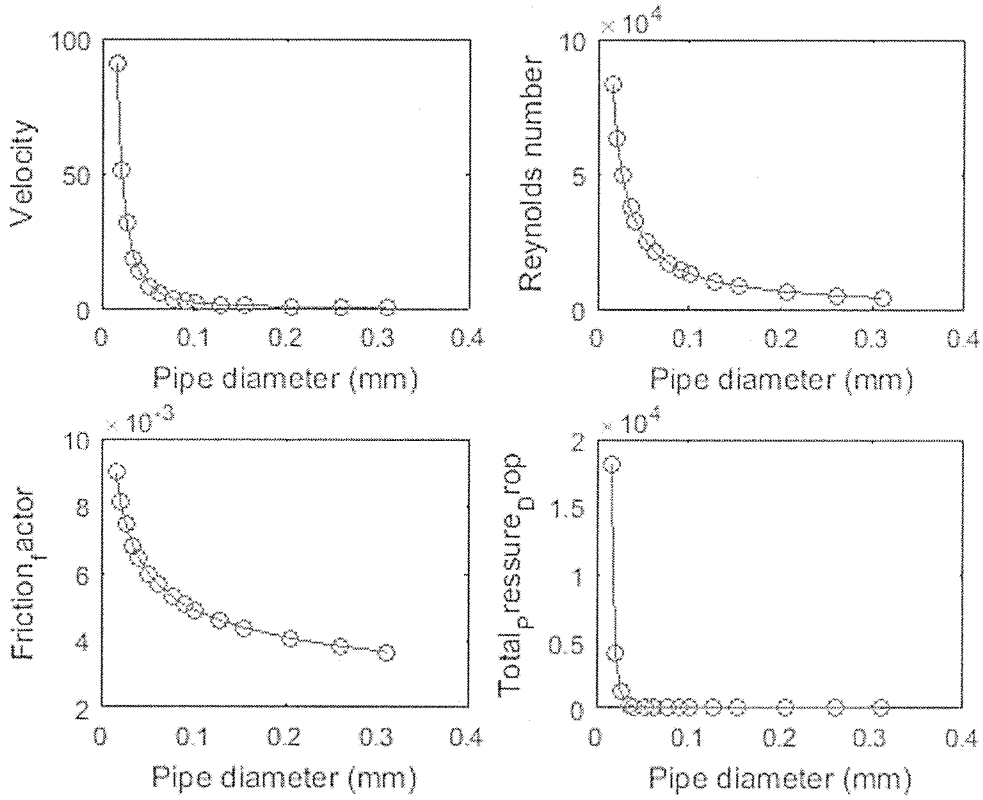

Figure 4 – Velocity, Reynolds number, friction factor and total pressure drop behaviour with respect to different pipe diameter for pipeline 1

Table XI - Minimum required thickness of pipe according to nominal diameter for Pipeline number 2

Pipe Nominal Diameter	Minimum required thickness (mm)
15	1.830
20	1.833
25	1.836
32	1.841
40	1.844
50	1.850
65	1.856
80	1.864
90	1.871
100	1.877

125	1.891
150	1.904
200	1.930
250	1.957
300	1.983

Table XII - Friction factor and total pressure drop in pipeline 2 due to flow with pipe specification

Pipe Specification	Pipe outer diameter (mm)	Thickness (mm)	Reynolds Number	Friction factor	Total Pressure Drop (Pa)
15 x 40	21.3	2.77	792830.6982	0.00900233	1934565.416
20 x 40	26.7	2.87	596136.0593	0.008101849	439471.4651
25 x 40	33.4	3.38	469031.9746	0.00744518	128124.3409
32 x 40	42.2	3.56	356186.1974	0.006785341	31668.3708
40 x 40	48.3	3.68	305203.024	0.006452725	14574.75467
50 x 40	60.3	3.91	238090.9261	0.005967109	4243.23202
65 x 40	73	5.16	199346.0722	0.005652639	1774.223058
80 x 40	88.9	5.49	160356.9277	0.005300062	617.1001734
90 x 40	101.6	5.74	138648.5997	0.005082494	307.0116017
100 x 40	114.3	6.02	122188.6544	0.004904164	168.2280441
125 x 40	141.3	6.55	97464.99067	0.004607748	58.00910007
150 x 40	168.3	7.11	81094.31337	0.004386031	24.6576379
200 x 20	219.1	6.35	60537.84788	0.004065115	6.444719245
250 x 20	273.1	6.35	47983.9163	0.003834477	2.251051236
300 x 20	323.9	6.35	40151.06621	0.003670655	1.01294701

Table XI shows the minimum thickness required for pipe as per operating pressure in pipeline 2. Table XII and Figure 5 shows the Reynolds Number, friction factor and total Pressure drop in Pipeline 2. Considering 5% of maximum pressure drop for working pressure of 1 atm. So from table XII, pipe specification of 50 X 40 is selected. The minimum thickness of pipe is 3.91 mm which is more than minimum thickness required as per table IX, which has required minimum pipe thickness of 1.850 mm. So Selected pipe specification are as

Pipe Specification : 50 x 40

Pipe outer diameter : 60.3 mm

Pipe thickness : 3.91 mm

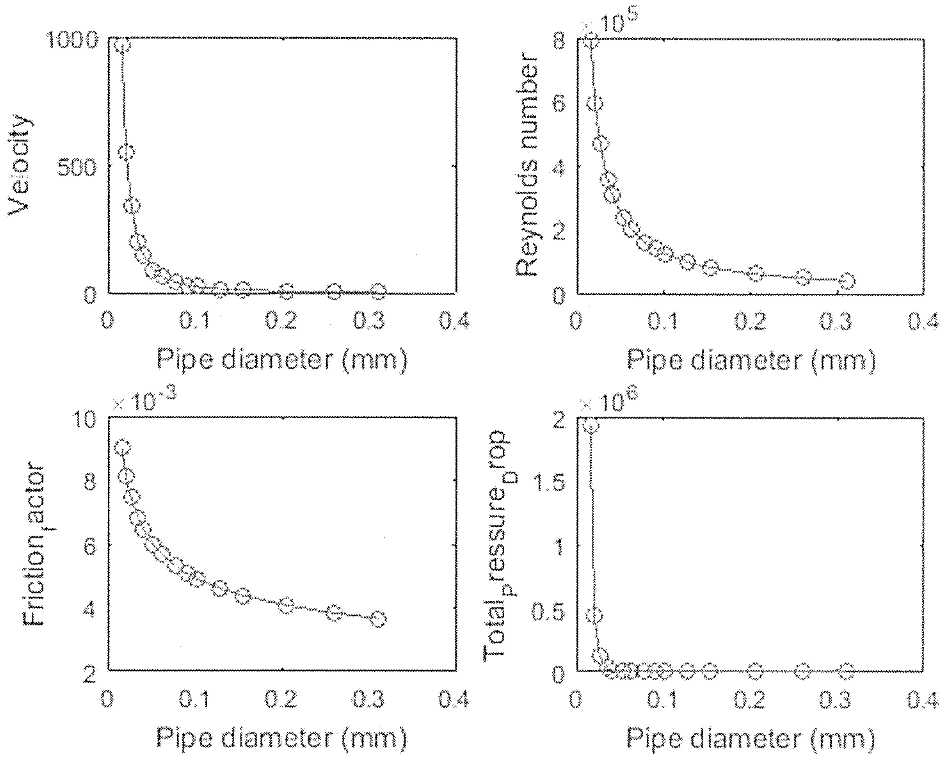

Figure 5 - Velocity, Reynolds number, friction factor and total pressure drop behaviour with respect to different pipe diameter for pipeline 2

4.3. Pipe between compressor & cooler

Pipeline Number	:	3
Location	:	Compressor and cooler
Pressure	:	4 MPa
Temperature	:	718 K
State	:	Gas

Properties at specified temp and pressure as per NIST data

Mass Flow rate	:	0.11574 Kg/s
Density	:	12.246 Kg/m^3
Viscosity	:	2.02e-5 Pa-s

Table XIII - Minimum required thickness of pipe according to nominal diameter for Pipeline number 3

Pipe Nominal Diameter	Minimum required thickness (mm)
15	2.237
20	2.343
25	2.474
32	2.647
40	2.766
50	3.002
65	3.251
80	3.562
90	3.811
100	4.060
125	4.589
150	5.119
200	6.115
250	7.173
300	8.169

Table XIV - Friction factor and total pressure drop in pipe line 3 due to flow with pipe specification

Pipe Specification	Pipe outer diameter (mm)	Thickness (mm)	Reynolds Number	Friction factor	Total Pressure Drop (Pa)
15 x 80	21.3	3.73	527389.1836	0.009463156	191510.759
20 x 80	26.7	3.91	386603.088	0.008415537	37839.39721
25 x 40	33.4	3.38	273988.9753	0.00744518	6420.864609
32 x 40	42.2	3.56	208069.1648	0.006785341	1587.038964
40 x 40	48.3	3.68	178286.915	0.006452725	730.4039636
50 x 40	60.3	3.91	139082.8182	0.005967109	212.6467002
65 x 40	73	5.16	116449.6857	0.005652639	88.9139875
80 x 40	88.9	5.49	93673.84883	0.005300062	30.92555744
90 x 40	101.6	5.74	80992.74635	0.005082494	15.38567859
100 x 40	114.3	6.02	71377.53081	0.004904164	8.430634546
125 x 40	141.3	6.55	56934.99455	0.004607748	2.907086781
150 x 40	168.3	7.11	47371.92563	0.004386031	1.235700831
200 x 20	219.1	6.35	35363.69332	0.004065115	0.322972742
250 x 20	273.1	6.35	28030.20853	0.003834477	0.112809909
300 x 20	323.9	6.35	23454.58323	0.003670655	0.050763154

Table XIII shows the minimum thickness required for pipe as per operating pressure in pipeline 3. Table XIV and Figure 6 shows the Reynolds Number, friction factor and total Pressure drop in Pipeline 3. Considering 5% of maximum pressure drop for working pressure of 1 atm. So from table XIV, pipe specification of 32 X 40 is selected. The minimum thickness of pipe is 3.68 mm which is more than minimum thickness required as per table XIII, which has required minimum pipe thickness of 2.467 mm. So Selected pipe specification are as

Pipe Specification	:	32 x 40
Pipe outer diameter	:	42.2 mm
Pipe thickness	:	3.56 mm

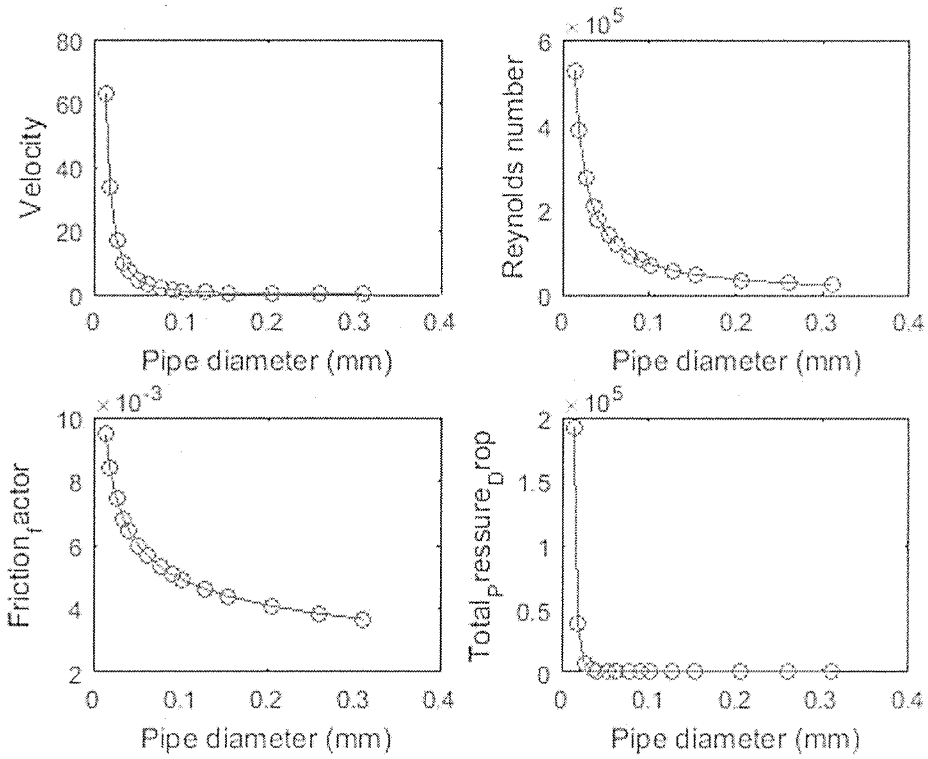

Figure 6 - Velocity, Reynolds number, friction factor and total pressure drop behaviour with respect to different pipe diameter for pipeline 3

4.4. Pipe between cooler and Heat exchanger 1

Pipeline Number	:	4
Location	:	Cooler and Heat Exchanger 1
Pressure	:	4 MPa

Temperature : 320 K

State : Gas

Properties at specified temp and pressure as per NIST data

Mass Flow rate : 0.11574 Kg/s

Density : 25.391 Kg/m^3

Viscosity : 1.25 e-5 Pa-s

Table XV - Minimum required thickness of pipe according to nominal diameter for Pipeline number 4

Pipe Nominal Diameter	Minimum required thickness (mm)
15	2.237
20	2.343
25	2.474
32	2.647
40	2.766
50	3.002
65	3.251
80	3.562
90	3.811
100	4.060
125	4.589
150	5.119
200	6.115
250	7.173
300	8.169

Table XVI - Friction factor and total pressure drop in pipeline 4 due to flow with pipe specification

Pipe Specification	Pipe outer diameter (mm)	Thickness (mm)	Reynolds Number	Friction factor	Total Pressure Drop (Pa)
15 x 80	21.3	3.73	852260.9	0.009463	92365.04
20 x 80	26.7	3.91	624750.6	0.008416	18249.82
25 x 40	33.4	3.38	442766.2	0.007445	3096.763
32 x 40	42.2	3.56	336239.8	0.006785	765.4239
40 x 40	48.3	3.68	288111.7	0.006453	352.2716
50 x 40	60.3	3.91	224757.8	0.005967	102.5588
65 x 40	73	5.16	188182.7	0.005653	42.88294
80 x 40	88.9	5.49	151376.9	0.0053	14.9153
90 x 40	101.6	5.74	130884.3	0.005082	7.420465

100 x 40	114.3	6.02	115346.1	0.004904	4.066069
125 x 40	141.3	6.55	92006.95	0.004608	1.402079
150 x 40	168.3	7.11	76553.03	0.004386	0.595975
200 x 20	219.1	6.35	57147.73	0.004065	0.155769
250 x 20	273.1	6.35	45296.82	0.003834	0.054408
300 x 20	323.9	6.35	37902.61	0.003671	0.024483

Table XV shows the minimum thickness required for pipe as per operating pressure in pipeline 4. Table XVI and Figure 7 shows the Reynolds Number, friction factor and total Pressure drop in Pipeline 4. Considering 5% of maximum pressure drop for working pressure of 1 atm. So from table XVI, pipe specification of 25 X 40 is selected. The minimum thickness of pipe is 3.38 mm which is more than minimum thickness required as per table IX, which has required minimum pipe thickness of 2.474 mm. So Selected pipe specification are as

Pipe Specification	:	25 x 40
Pipe outer diameter	:	33.4 mm
Pipe thickness	:	3.38 mm

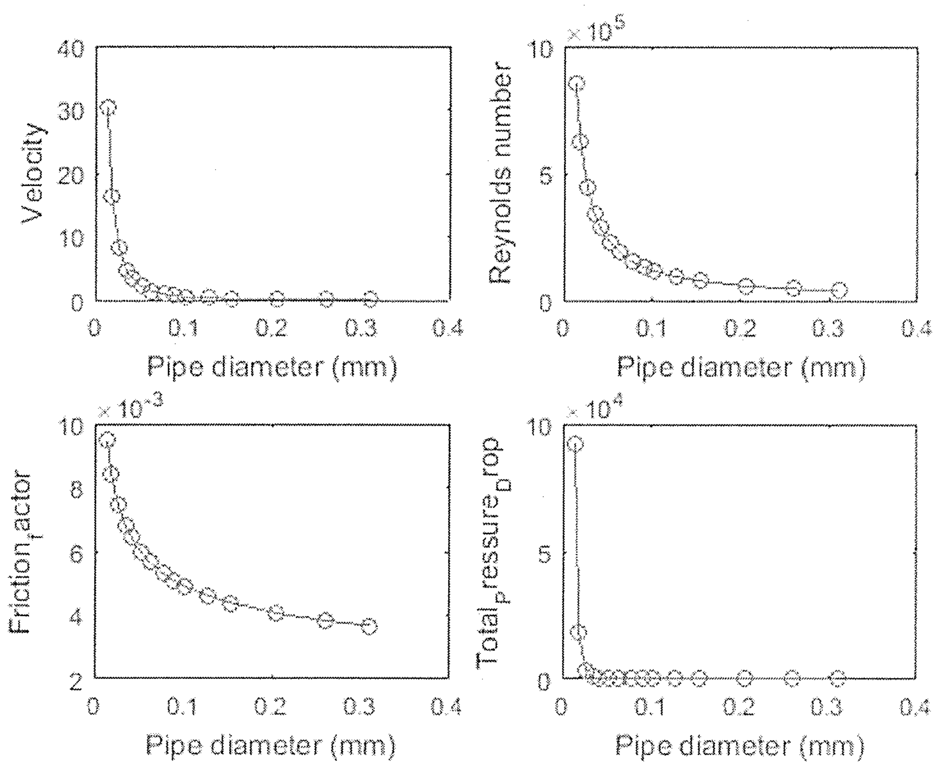

Figure 7 - Velocity, Reynolds number, friction factor and total pressure drop behaviour with respect to different pipe diameter for pipeline 4

4.5. Pipe between Heat exchanger 1 & Heat exchanger 2

Pipe Number : 5

Location : Heat Exchanger 1 and Heat exchanger 2

Pressure : 4 MPa

Temperature : 190 K

State : Gas

Properties at specified temp and pressure as per NIST data

Mass Flow rate : 0.11574 Kg/s

Density : 70.942 Kg/m^3

Viscosity : 9.63e-6 Pa-s

Table XVII - Minimum required thickness of pipe according to nominal diameter for Pipeline number 1

Pipe Nominal Diameter	Minimum required thickness (mm)
15	2.237
20	2.343
25	2.474
32	2.647
40	2.766
50	3.002
65	3.251
80	3.562
90	3.811
100	4.060
125	4.589
150	5.119
200	6.115
250	7.173
300	8.169

Table XVII shows the minimum thickness required for pipe as per operatlng pressure in pipeline 5. Table XVIII and Figure 8 shows the Reynolds Number, friction factor and total Pressure drop in Pipeline 5. Considering 5% of maximum pressure drop for working pressure of 1 atm. So from table XVIII, pipe specification of 25 X 40 is selected.

Table XVIII - Friction factor and total pressure drop in pipeline 5 due to flow with pipe specification

Pipe Specification	Pipe outer diameter (mm)	Thickness (mm)	Reynolds Number	Friction factor	Total Pressure Drop (Pa)
15 x 80	21.3	3.73	1106258	0.009463	33058.57
20 x 80	26.7	3.91	810943.1	0.008416	6531.832
25 x 40	33.4	3.38	574722.5	0.007445	1108.369
32 x 40	42.2	3.56	436448.3	0.006785	273.9545
40 x 40	48.3	3.68	373976.7	0.006453	126.0822
50 x 40	60.3	3.91	291741.7	0.005967	36.70705
65 x 40	73	5.16	244266.2	0.005653	15.34832
80 x 40	88.9	5.49	196491.4	0.0053	5.338366
90 x 40	101.6	5.74	169891.3	0.005082	2.655874
100 x 40	114.3	6.02	149722.3	0.004904	1.455295
125 x 40	141.3	6.55	119427.5	0.004608	0.501821
150 x 40	168.3	7.11	99367.9	0.004386	0.213307
200 x 20	219.1	6.35	74179.29	0.004065	0.055752
250 x 20	273.1	6.35	58796.49	0.003834	0.019473
300 x 20	323.9	6.35	49198.61	0.003671	0.008763

The minimum thickness of pipe is 3.38 mm which is more than minimum thickness required as per table IX, which has required minimum pipe thickness of 2.474 mm. So Selected pipe specification are as

Pipe Specification : 25 x 40

Pipe outer diameter : 33.4 mm

Pipe thickness : 3.38 mm

4.6. Pipe between Heat exchanger 2 & JT valve

Pipe Number : 6

Location : Heat exchanger 2 and JT valve

Pressure : 4 MPa

Temperature : 182 K

State	:	Gas

Properties at specified temp and pressure as per NIST data

Mass Flow rate	:	0.11574 Kg/s
Density	:	80.873 Kg/m^3
Viscosity	:	9.93e-6 Pa-s

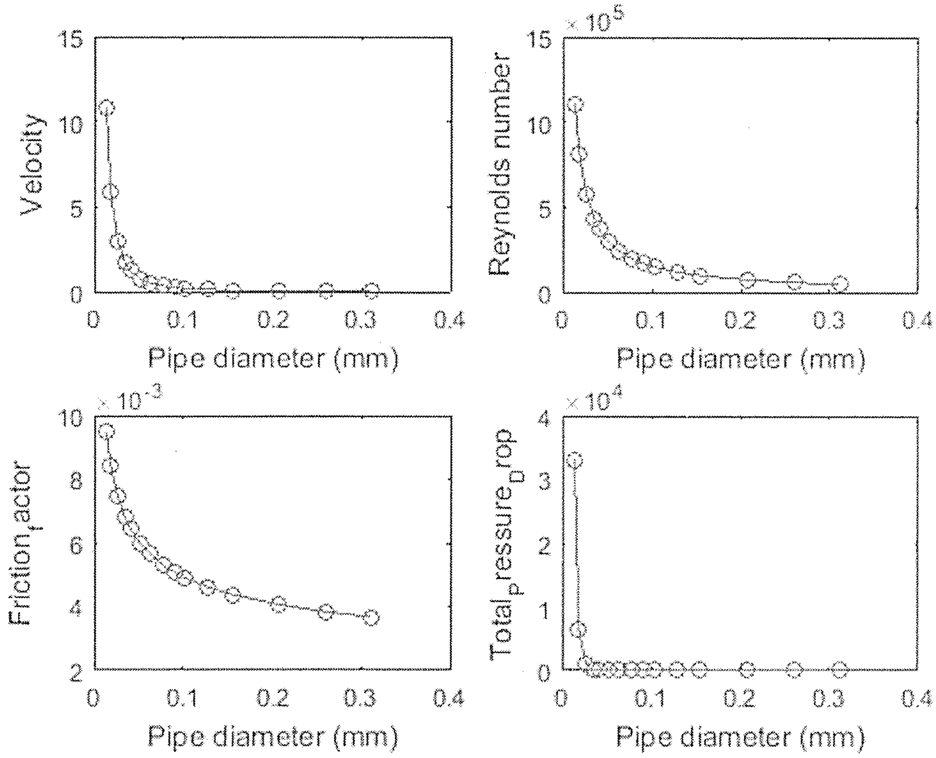

Figure 8 - Velocity, Reynolds number, friction factor and total pressure drop behaviour with respect to different pipe diameter for pipeline 5

Table XIX - Minimum required thickness of pipe according to nominal diameter for Pipeline number 6

Pipe Nominal Diameter	Minimum required thickness (mm)
15	2.237
20	2.343
25	2.474
32	2.647
40	2.766
50	3.002
65	3.251
80	3.562

90	3.811
100	4.060
125	4.589
150	5.119
200	6.115
250	7.173
300	8.169

Table XX - Friction factor and total pressure drop in pipeline 6 due to flow with pipe specification

Pipe Specification	Pipe outer diameter (mm)	Thickness (mm)	Reynolds Number	Friction factor	Total Pressure Drop (Pa)
15 x 80	21.3	3.73	1072836	0.009463	28999.06
20 x 80	26.7	3.91	786443.3	0.008416	5729.74
25 x 40	33.4	3.38	557359.2	0.007445	972.264
32 x 40	42.2	3.56	423262.6	0.006785	240.3136
40 x 40	48.3	3.68	362678.3	0.006453	110.5997
50 x 40	60.3	3.91	282927.8	0.005967	32.19952
65 x 40	73	5.16	236886.6	0.005653	13.46359
80 x 40	88.9	5.49	190555.1	0.0053	4.682828
90 x 40	101.6	5.74	164758.7	0.005082	2.329739
100 x 40	114.3	6.02	145199	0.004904	1.276589
125 x 40	141.3	6.55	115819.4	0.004608	0.440199
150 x 40	168.3	7.11	96365.85	0.004386	0.187113
200 x 20	219.1	6.35	71938.23	0.004065	0.048905
250 x 20	273.1	6.35	57020.16	0.003834	0.017082
300 x 20	323.9	6.35	47712.24	0.003671	0.007687

Table XIX shows the minimum thickness required for pipe as per operating pressure in pipeline 6. Table XX and Figure 9 shows the Reynolds Number, friction factor and total Pressure drop in Pipeline 6. Considering 5% of maximum pressure drop for working pressure of 1 atm. So from table XX, pipe specification of 25 X 40 is selected. The minimum thickness of pipe is 3.38 mm which is more than minimum thickness required as per table IX, which has required minimum pipe thickness of 2.474 mm. So Selected pipe specification are as

Pipe Specification	:	25 x 40
Pipe outer diameter	:	33.4 mm
Pipe thickness	:	3.38 mm

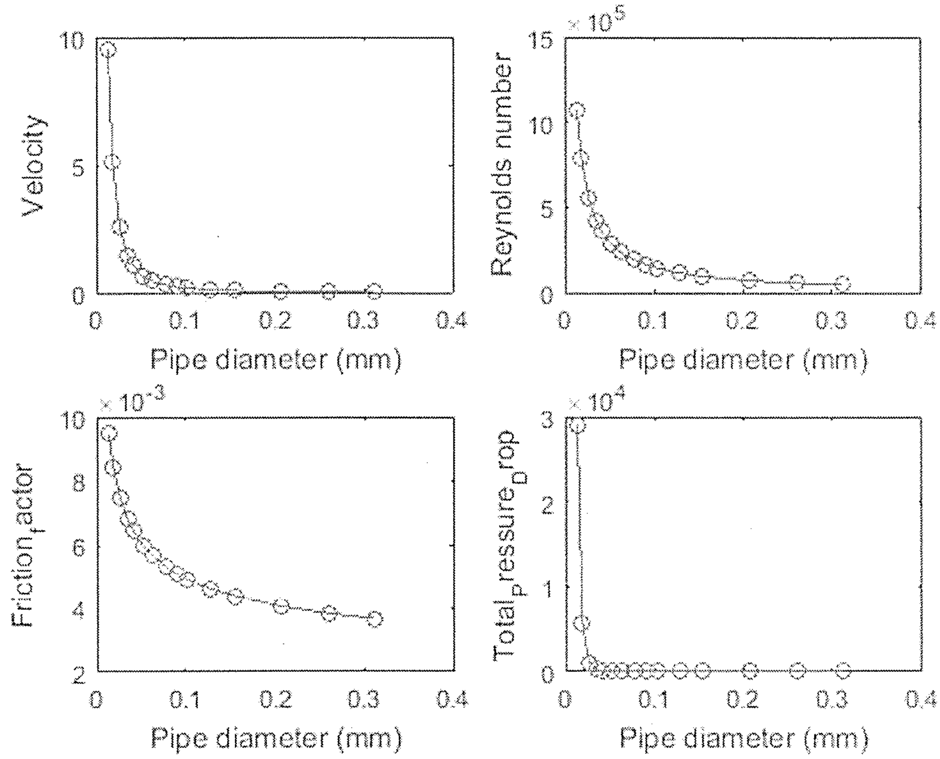

Figure 9 - Velocity, Reynolds number, friction factor and total pressure drop behaviour with respect to different pipe diameter for pipeline 6

4.7. Pipe between JT valve & separator

Pipe Number	:	7
Location	:	JT valve and Separator
Pressure	:	0.101325 MPa
Temperature	:	111.67 K
State	:	Two Phase

Properties at specified temp and pressure as per NIST data

For Liquid

Mass Flow rate	:	0.011574 Kg/s
Density	:	80.873 Kg/m^3
Viscosity	:	0.0001167 Pa-s

For Gas

Mass Flow rate : 0.10422 Kg/s

Density : 1.8164 Kg/m^3

Viscosity : 4.46e-6 Pa-s

Table XXI- Minimum required thickness of pipe according to nominal diameter for Pipeline number 7

Pipe Nominal Diameter	Minimum required thickness (mm)
15	2.237
20	2.343
25	2.474
32	2.647
40	2.766
50	3.002
65	3.251
80	3.562
90	3.811
100	4.060
125	4.589
150	5.119
200	6.115
250	7.173
300	8.169

Table XXI shows the minimum thickness required for pipe as per operating pressure in pipeline 7. Table XXI and Figure 10 shows the Reynolds Number, friction factor and total Pressure drop in Pipeline 7. Considering 5% of maximum pressure drop for working pressure of 1 atm, no one specification satisfy that condition. So two phase flow have completely different phenomenon as compared to single phase flow. We will take consideration of minimum pressure loss. So from table XXI, pipe specification of 32 X 40 is selected. The minimum thickness of pipe is 3.56 mm which is more than minimum thickness required as per table IX, which has required minimum pipe thickness of 2.647 mm.

So Selected pipe specification are as

Pipe Specification : 32 x 40

Pipe outer diameter : 42.2 mm

Pipe thickness : 3.56 mm

Table XXII - Friction factor and total pressure drop in pipe line 1 due to flow with pipe specification

Pipe Specification	Pipe outer diameter (mm)	Thickness (mm)	Reynolds number liquid	Reynolds number Gas	frictional Pressure loss	Total Pressure Drop (Pa)
15 x 40	21.3	2.77	5578.654	1887861	3.381083	39885.42
20 x 40	26.7	2.87	4194.637	1419499	1.510188	18710.38
25 x 40	33.4	3.38	3300.285	1116843	1.180254	15386.93
32 x 40	42.2	3.56	2506.259	848138.4	1.059967	14838.6
40 x 40	48.3	3.68	2147.523	726739	1.032909	15149.85
50 x 40	60.3	3.91	1675.297	566934	1.012682	16185.42
65 x 40	73	5.16	1402.674	474676.1	1.006438	17255.9
80 x 40	88.9	5.49	1128.331	381836.5	1.00281	18935.95
90 x 40	101.6	5.74	975.5835	330145.3	1.001616	20306.44
100 x 40	114.3	6.02	859.7651	290951.5	1.000999	21679.29
125 x 40	141.3	6.55	685.8002	232080.3	1.000423	24625.22
150 x 40	168.3	7.11	570.61	193099	1.00021	27570.92
200 x 20	219.1	6.35	425.967	144150.7	1.000069	33531.92
250 x 20	273.1	6.35	337.6328	114257.7	1.000029	39686.74
300 x 20	323.9	6.35	282.5179	95606.35	1.000015	45477.46

4.8. Pipe between separator & tank

Pipeline Number : 8

Location : Separator to tank

Pressure : 1 atm (101.325 kPa)

Temperature : 111.67 K (saturation temperature)

State : Liquid

Properties at specified temp and pressure as per NIST data

Mass Flow rate : 0.011574 Kg/s

Density : 422.36 Kg/m^3

Viscosity : 0.00011677 Pa-s

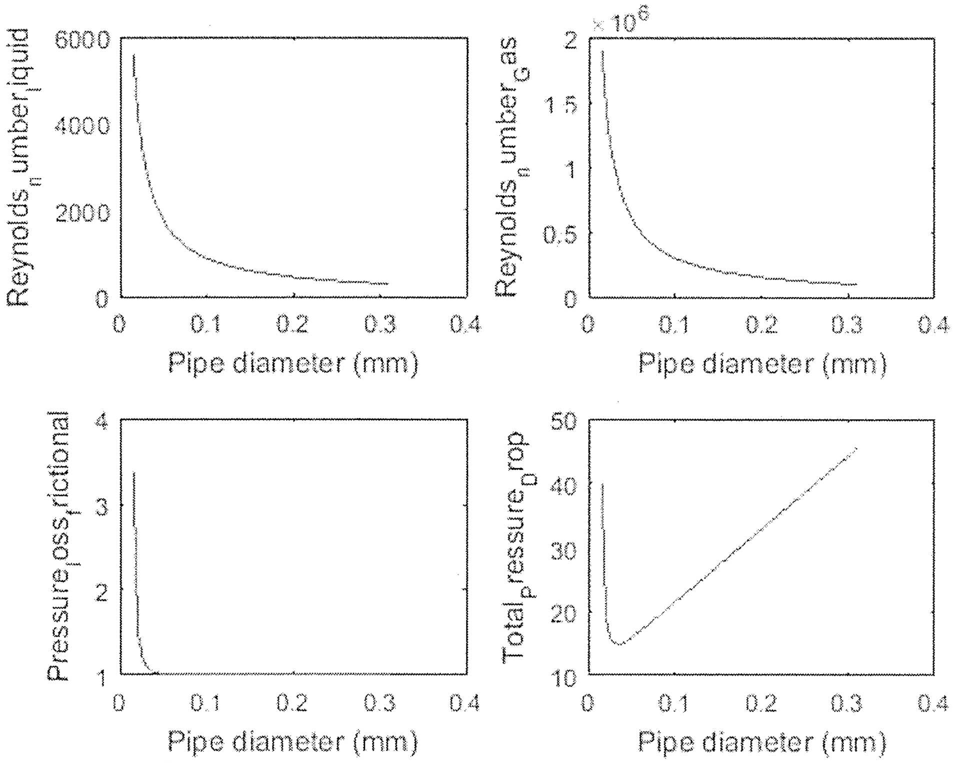

Figure 10 - Reynolds number for liquid, Reynolds number for Gas, friction pressure loss and total pressure drop behaviour with respect to different pipe diameter for pipeline 1

Table XXIII - Minimum required thickness of pipe according to nominal diameter for Pipeline number 8

Pipe Nominal Diameter	Minimum required thickness (mm)
15	1.830
20	1.833
25	1.836
32	1.841
40	1.844
50	1.850
65	1.856
80	1.864
90	1.871
100	1.877
125	1.891
150	1.904
200	1.930
250	1.957
300	1.983

Table XXIV - Friction factor and total pressure drop in pipeline 8 due to flow with pipe specification

Pipe Specification	Pipe outer diameter (mm)	Thickness (mm)	Reynolds Number	Friction factor	Total Pressure Drop (Pa)
15 x 40	21.3	2.77	8011.820021	0.00900233	28.10973567
20 x 40	26.7	2.87	6024.154749	0.008101849	6.385634012
25 x 40	33.4	3.38	4739.725358	0.00744518	1.861679799
32 x 40	42.2	3.56	3599.380944	0.006785341	0.460149615
40 x 40	48.3	3.68	3084.178885	0.006452725	0.211774954
50 x 40	60.3	3.91	2405.988634	0.005967109	0.061655258
65 x 40	73	5.16	2014.458895	0.005652639	0.02577992
80 x 40	88.9	5.49	1620.460518	0.005300062	0.008966625
90 x 40	101.6	5.74	1401.090585	0.005082494	0.004460958
100 x 40	114.3	6.02	1234.75732	0.004904164	0.002444397
125 x 40	141.3	6.55	984.9164082	0.004607748	0.000842887
150 x 40	168.3	7.11	819.4852254	0.004386031	0.000358282
200 x 20	219.1	6.35	611.7552497	0.004065115	9.36434E-05
250 x 20	273.1	6.35	484.893562	0.003834477	3.27084E-05
300 x 20	323.9	6.35	405.7399856	0.003670655	1.47184E-05

Table XXIII shows the minimum thickness required for pipe as per operating pressure in pipeline 8. Table XXIV and Figure 11 shows the Reynolds Number, friction factor and total Pressure drop in Pipeline 8. Considering 5% of maximum pressure drop for working pressure of 1 atm. Total friction drop is less for all size specification of pipe. So there minimum size of pipe is to be taken. So from table XXIV, pipe specification of 15 X 40 is selected. The minimum thickness of pipe is 2.77 mm which is more than minimum thickness required as per table XXIII, which has required minimum pipe thickness of 1.830 mm. So Selected pipe specification are as

Pipe Specification : 15 x 40

Pipe outer diameter : 21.3 mm

Pipe thickness : 2.77 mm

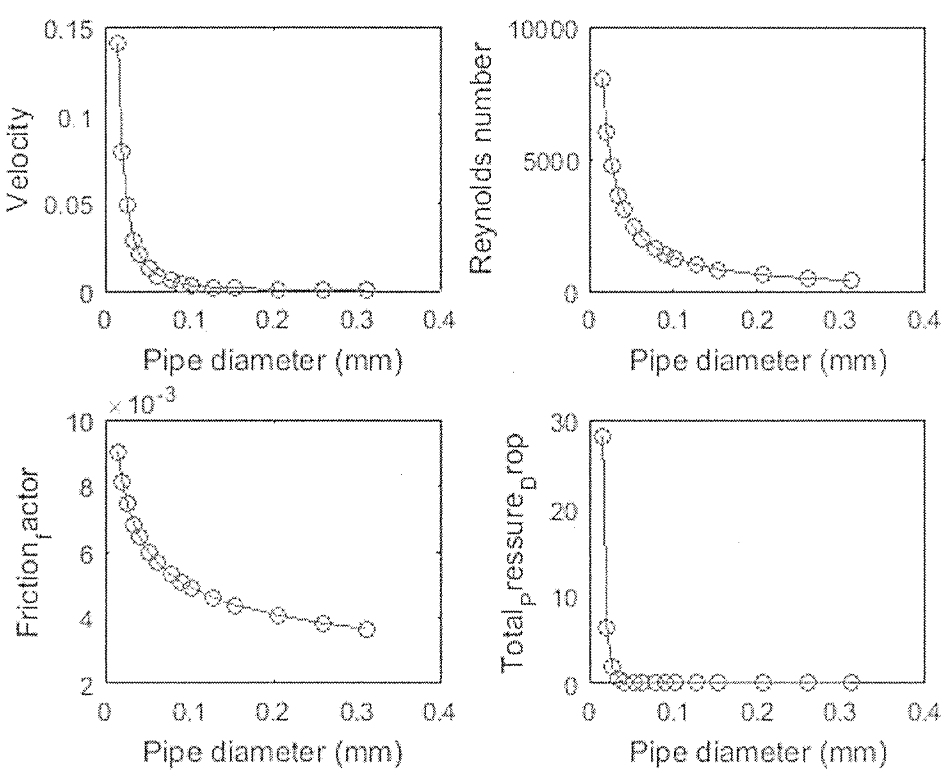

Figure 11 - Velocity, Reynolds number, friction factor and total pressure drop behaviour with respect to different pipe diameter for pipeline 1

4.9. Pipe between separator & Heat exchanger 1

Pipeline Number	:	9
Location	:	Separator and Heat Exchanger 1
Pressure	:	1 atm (101.325 kPa)
Temperature	:	111.67 K
State	:	Gas

Properties at specified temp and pressure

Mass Flow rate	:	0.10422 Kg/s
Density	:	1.8164 Kg/m^3
Viscosity	:	4.46 e-6 Pa-s

Table XXV - Minimum required thickness of pipe according to nominal diameter for Pipeline number 9

Pipe Nominal Diameter	Minimum required thickness (mm)
15	1.830
20	1.833
25	1.836
32	1.841
40	1.844
50	1.850
65	1.856
80	1.864
90	1.871
100	1.877
125	1.891
150	1.904
200	1.930
250	1.957
300	1.983

Table XXVI - Friction factor and total pressure drop in pipeline 9 due to flow with pipe specification

Pipe Specification	Pipe outer diameter (mm)	Thickness (mm)	Reynolds Number	Friction factor	Total Pressure Drop (Pa)
15 x 80	21.3	3.73	2164319	0.009463	1045830
20 x 80	26.7	3.91	1586556	0.008416	206638.9
25 x 40	33.4	3.38	1124406	0.007445	35063.99
32 x 40	42.2	3.56	853882	0.006785	8666.732
40 x 40	48.3	3.68	731660.5	0.006453	3988.696
50 x 40	60.3	3.91	570773.3	0.005967	1161.252
65 x 40	73	5.16	477890.6	0.005653	485.5544
80 x 40	88.9	5.49	384422.3	0.0053	168.8828
90 x 40	101.6	5.74	332381.1	0.005082	84.02034
100 x 40	114.3	6.02	292921.8	0.004904	46.03923
125 x 40	141.3	6.55	233652	0.004608	15.87544
150 x 40	168.3	7.11	194406.7	0.004386	6.748094
200 x 20	219.1	6.35	145126.8	0.004065	1.763736
250 x 20	273.1	6.35	115031.4	0.003834	0.616049
300 x 20	323.9	6.35	96253.8	0.003671	0.277215

Table XXV shows the minimum thickness required for pipe as per operating pressure in pipeline 9. Table XXVI and Figure 4 shows the Reynolds Number, friction factor and total Pressure drop in Pipeline 9. Considering 5% of maximum pressure drop for working pressure of 1 atm. So from table XXVI, pipe specification of 40 X 40 is selected. The minimum thickness of pipe is 3.68 mm which is more than minimum thickness required as per table XXV, which has required minimum pipe thickness of 1.844 mm. So Selected pipe specification are as

Pipe Specification	:	40 x 40
Pipe outer diameter	:	48.3 mm
Pipe thickness	:	3.68 mm

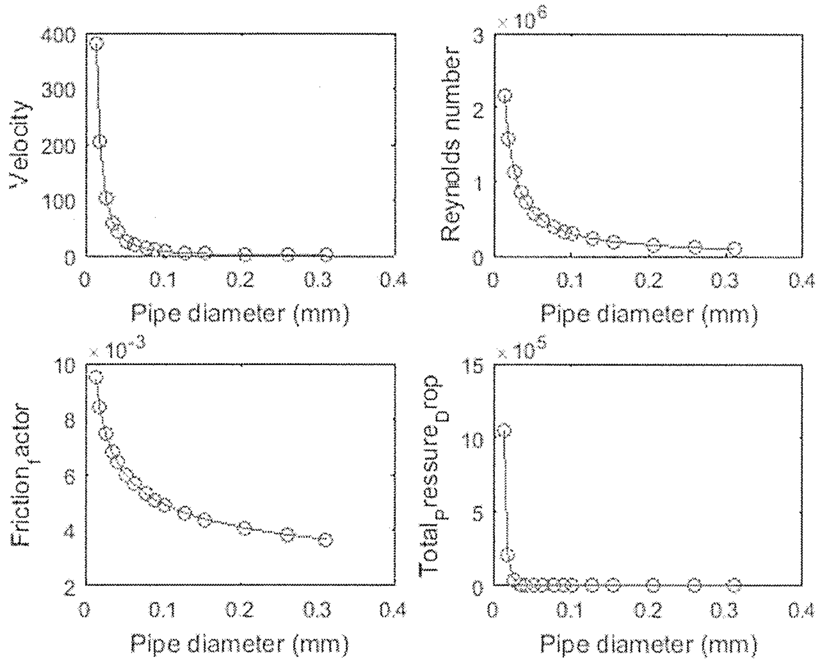

Figure 12 - Velocity, Reynolds number, friction factor and total pressure drop behaviour with respect to different pipe diameter for pipeline 9

4.10. Pipe between Heat exchanger 1 & Mixer

Pipeline Number	:	10
Location	:	Heat Exchanger 1 and Mixer
Pressure	:	1 atm (101.325 kPa)
Temperature	:	320 K
State	:	Gas

Properties at specified temp and pressure

Mass Flow rate	:	0.10422 Kg/s
Density	:	0.61178 Kg/m^3
Viscosity	:	1.19 e-5 Pa-s

Table XXVII - Minimum required thickness of pipe according to nominal diameter for Pipeline number 10

Pipe Nominal Diameter	Minimum required thickness (mm)
15	1.830
20	1.833
25	1.836
32	1.841
40	1.844
50	1.850
65	1.856
80	1.864
90	1.871
100	1.877
125	1.891
150	1.904
200	1.930
250	1.957
300	1.983

Table XXVIII - Friction factor and total pressure drop in pipe line 1 due to flow with pipe specification

Pipe Specification	Pipe outer diameter (mm)	Thickness (mm)	Reynolds Number	Friction factor	Total Pressure Drop (Pa)
15 x 80	21.3	3.73	805708.9	0.009463	3105111
20 x 80	26.7	3.91	590625.6	0.008416	613519.3
25 x 40	33.4	3.38	418581.5	0.007445	104106.4
32 x 40	42.2	3.56	317873.7	0.006785	25731.88
40 x 40	48.3	3.68	272374.5	0.006453	11842.6
50 x 40	60.3	3.91	212481.1	0.005967	3447.805
65 x 40	73	5.16	177903.8	0.005653	1441.631
80 x 40	88.9	5.49	143108.5	0.0053	501.4199
90 x 40	101.6	5.74	123735.1	0.005082	249.4598
100 x 40	114.3	6.02	109045.7	0.004904	136.6924
125 x 40	141.3	6.55	86981.36	0.004608	47.13484

150 x 40	168.3	7.11	72371.56	0.004386	20.03537
200 x 20	219.1	6.35	54026.21	0.004065	5.236606
250 x 20	273.1	6.35	42822.62	0.003834	1.829074
300 x 20	323.9	6.35	35832.3	0.003671	0.823062

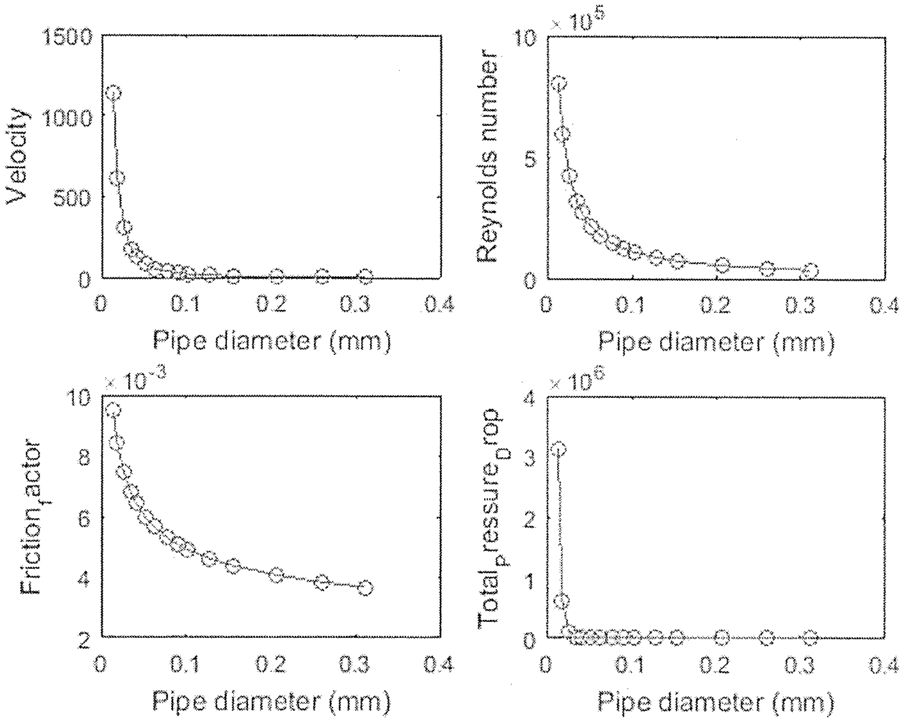

Figure 13 - Velocity, Reynolds number, friction factor and total pressure drop behaviour with respect to different pipe diameter for pipeline 10

Table XXVII shows the minimum thickness required for pipe as per operating pressure in pipeline 10. Table XXVIII and Figure 10 shows the Reynolds Number, friction factor and total Pressure drop in Pipeline 10. Considering 5% of maximum pressure drop for working pressure of 1 atm. So from table XXVIII, pipe specification of 50 X 40 is selected. The minimum thickness of pipe is 3.91 mm which is more than minimum thickness required as per table XXVII, which has required minimum pipe thickness of 1.850 mm. So Selected pipe specification are as

Pipe Specification	:	50 x 40
Pipe outer diameter	:	60.3 mm
Pipe thickness	:	3.91 mm

CHAPTER 5

CONCLUSION

The frictional pressure drop were evaluated in 10 different pipeline with working fluid i.e. Natural Gas. In this study, Natural gas contain only methane. Precooled Linde-Hapmpson cycle is used as Natural Gas liquefaction cycle.

Structural analysis shows that the thickness of pipe greatly depend on internal pressure of following fluid in pipe except material properties. Working fluid also plays an important factor on thickness of pipe. Corrosion factor depend on working fluid flowing in pipe as for natural gas and sea water, the corrosion factor is 0.3 and 3 mm respectively for design point of view for 30 year.

The Liquid flow and Gas flow, in single phase, shows alike behaviour of pressure drop. For constant flow, as the diameter increases, the velocity decreases, by virtue of which the Reynolds number decreases and friction factor decreases. So the total pressure drop due to frictional losses decreases. But by increasing the diameter of Pipe, the weight of pipe increase. This is an unfavourable condition from economic point of view. So there certain limits have to take to limits the pressure drop. We have taken 5 kPa as limit of pressure drop.

The two phase flow shows a completely different phenomenon. The pressure drop is not decreasing continuously its drops to a limit and again start increasing. The pressure drop in pipe is much more than same in single phase flow. So, two phase flow should take care always and if possible, it should be avoided.

CHAPTER 6

FUTURE SCOPE

The literature review shows the earlier studies on basis of which this thesis is done. The future possible area of study are as follows:

- Corrosion allowances for different configuration of natural gas as composition of natural gas.
- Frictional factor and frictional pressure drop variation with different configuration of natural gas
- Possible areas of two phase flow in the cycle
- Exact pressure drop in Pipeline in case of two phase flow because as shown in literature review, there is 30-40 % variation in pressure drop in case of two phase flow.
- Study of frictional factor after considering the pressure drop in next stage.

REFERENCES

[1]. European Environmental Agency. "Final energy consumption by sector and fuel (CSI 027/ENER 016) - Assessment published Jan 2015"

[2]. "International Energy Outlook 2017" (PDF). United States Department of Energy, Washington, DC. Archived from the original on 27 July 2018.

[3]. Scott, R. B., 1958. Cryogenic Engineering, p. 1. Princeton, NJ: D. van Nostrand Co., Inc.

[4]. World Bank East Asia and Pacific Economic Update, October 2017: Balancing Act

[5]. NIST Strengthens Laboratory Mission Focus with New Structure Archived August 28, 2016, at the Wayback Machine

[6]. Stokes, George (1851). "On the Effect of the Internal Friction of Fluids on the Motion of Pendulums". Transactions of the Cambridge Philosophical Society. 9: 8–106.

[7]. Brown, Glenn. "The Darcy–Weisbach Equation". Oklahoma State University–Stillwater.

[8]. Kaleem, Khan, (2015-07-01). Fluid Mechanics and Machinery. Oxford University Press India. ISBN 9780199456772. OCLC 961849291

[9]. Colebrook, C F (1939). "TURBULENT FLOW IN PIPES, WITH PARTICULAR REFERENCE TO THE TRANSITION REGION BETWEEN THE SMOOTH AND ROUGH PIPE LAWS". Journal of the Institution of Civil Engineers. 11 (4): 133–156. doi:10.1680/ijoti.1939.13150. ISSN 0368-2455

[10]. E. Shashi Menon, Gas pipeline hydraulics, Trafford Publishing, 2013, ISBN 1466976713, 9781466976719

[11]. Ghiaasiaan, S. M.Two-Phase Flow, Boiling, and Condensation: In Conventional and Miniature Systems, Cambridge University Press, 2008. pg 362.

[12]. M. L. Nayyar, Piping Handbook, 7th ed., New York, McGraw-Hill, 2000.

[13]. Lockhart, R.W., Martinelli, R.C.; Chem. Eng. Prog., Vol. 45. 1949, pp. 39–48

[14]. Brownell L.E. and E.H. Young, Process Equipment Design, John Wiley and Sons, Inc. 1959. New York.

[15]. NSI/ASME Standard B31.3, Standard for Chemical Plant and Petroleum Refinery Piping. 2002. New York City: ANSI/ASME.

[16]. Lightfoot, R. Byron Bird; Warren Stewart; Edwin N. (2007). Transport phenomena (Rev. 2. ed.). New York [u.a.]: Wiley. ISBN 978-0-470-11539-8.

[17]. Minor Loss Calculation for Liquid and Gas Flow". www.lmnoeng.com. Retrieved 2017-01-22.

Appendix 1

MATLAB script for calculation of Minimum Pipe thickness

```
%********Script for calcuating the minimum thickness of Pipe********%

%******************** For LNG Plant pipe calculation****************%

%**********************Coeded by SATYA VART GUPTA******************%

%****************According to Code ASME B31.3-2006*****************%

clc

clear

%*******************According to Article 304.1.1******************%

%Gauge Pressure in Pipe (in Pa)%

Pressure = input('Insert Gauge pressure in pipe (Pa):')

%Pipe Specification (in mm)%

pipe = readtable('thickness_input.xlsx')

%Pipe Nominal Diameter AS Per according to ASME/ANSI B36.10M%

Pipe_Nominal_Diameter = pipe.Nominal_Dia

%Pipe Outer diameter %

Pipe_Dia_mm =  pipe.Pipe_outer_dia

%Corrosion Allowance%

corrosion_allowance = input('Insert corrosi0n allowance in pipe(mm):')

%thread or grove depth Allowance%

Allowance_grove = input('Insert thread/grove allowance in pipe(mm):')
```

```
%if Pipe_Dia_mm <= 50

%    Allowance_grove = 2.03

%else

%    Allowance_grove = 2.80

%end

%Allowable stress for pipe%

s = input('Insert allowable stress for pipe(Pa):')

%Derating Factor%

y = input('Insert Derating factor for pipe(mm):')

%longitudinal Weld joint Factor%

E = input('Insert Longitudional weld joint Factor for pipe(mm):')

%Manufacture Mill/production Tolerance%

Tol =input('Insert Manufacture Mill/production Tolerance for pipe(decimal):')


thickness1 = ((Pressure.*Pipe_Dia_mm)/(2*((s*E)+(Pressure*y))))

thickness2 = thickness1./(1-Tol)

Minimum_required_thickness = thickness2 + corrosion_allowance +
Allowance_grove


T = table (Pipe  Nominal  Diameter, Minimum  required  thickness)

 writetable(T,'test.xlsx','Sheet',1)
```

Appendix 2

MATLAB script for calculation of frictional losses for liquid flow in pipe

```
%*******Script for calcuating the frictional losses for liquid *****%

%******************** For LNG Plant pipe calculation****************%

%**********************Coeded by SATYA VART GUPTA******************%

clc

clear

pipe = readtable('Pipe_2.xlsx')

%Pipe Nominal Diameter AS Per according to ASME/ANSI B36.10M%

Pipe_Name = pipe.Name

Pipe_outer_dia =  pipe.Pipe_outer_dia

Thickness =  pipe.Thickness


Pipe_inner_dia =  pipe.Pipe_inner_dia./1000

Pipe_name = pipe.Name

Pipe_Area = (pi/4).*(Pipe_inner_dia.^2)


%mass Flow rate% %(Kg/s)%

Mass  Flow  rate  = 0.01158

%Pressure %% Mpa %

Pressure = 0.0101325
```

```
%Density% %kg/m^3%

Density  = 422.36

%Viscosity% %pa-s%

Viscosity = 0.00011677

%Volume flow rate% %(m3/s)%

Volume_flow_rate = Mass_Flow_rate / Density

%velocity = Volume/Area% % m/s %

Pipe_Velocity = Volume_flow_rate./Pipe_Area

Reynolds_Number = (Density.*Volume_flow_rate .*
Pipe_inner_dia)./(Viscosity.*Pipe_Area)



if(Reynolds_Number<=2000)

   Friction_factor = 64./Reynolds_Number

end

if(Reynolds_Number <=4000)

   %Blausisus%

   Friction_factor = 0.0791./(Reynolds_Number).^0.25

end

A1 = input('does the pipe is smooth pipe {y/n) : ','s')

 if(A1=='y')

   %Von Karman-Nikuradse%

   Friction_factor = 0.001

   e=1
```

```
  while(e>0.0001)

  fc = ((1./(-2.*log(2.51./(Reynolds_Number.*Friction_factor.^0.5)))).^2)

  e = abs(Friction_factor-fc)

  Friction_factor = fc

  continue

  end

 end

 if(A1=='n')

 Friction_factor = 0.001

% e=1

 k = input('enter roughness (in mm): ')

 %while(e>0.0001)

fc = (1./(-2.*log((k./1000)./(3.7.*Pipe_inner_dia)))).^2

 %  e = abs(Friction_factor-fc)

  Friction_factor = fc

 % continue

 %  end

  end

  %Darcy-Weisbach Equation%

  Friction_Loss = (Friction_factor .* Pipe_Velocity .^2)./(2.*9.81.*Pipe_inner_dia)


pipe = readtable('pipe.xlsx')
```

```
L = pipe.Quantity.*pipe.L_DFactor

length = input('Insert pipe length (in m):')

Pipe_length = length + sum (L)*Pipe_inner_dia

Total_Pressure_Drop = Density.* 9.81.* Friction_Loss.* Pipe_length

%Total_Pressure_Drop_2 = 0.42236 *

subplot(2,2,1)

plot(Pipe_inner_dia, Pipe_Velocity, '-o'),xlabel('Pipe diameter (mm)'),
ylabel('Velocity')

subplot(2,2,2)

plot(Pipe_inner_dia, Reynolds_Number, '-o'),xlabel('Pipe diameter (mm)'),
ylabel('Reynolds number')

subplot(2,2,3)

plot(Pipe_inner_dia, Friction_factor, '-o'),xlabel('Pipe diameter (mm)'),
ylabel('Friction_factor')

subplot(2,2,4)

plot(Pipe_inner_dia,Total_Pressure_Drop, '-o'),xlabel('Pipe diameter (mm)'),
ylabel('Total_Pressure_Drop')

T = table (Pipe_Name,
Pipe_outer_dia,Thickness,Reynolds_Number,Friction_factor,
Total_Pressure_Drop)

 writetable(T,'test.xlsx','Sheet',2)
```

Appendix 3

MATLAB script for calculation of frictional losses for Gas flow in pipe

```
%*******Script for calcuating the frictional losses for Gas*********%

%******************** For LNG Plant pipe calculation****************%

%***********************Coeded by SATYA VART GUPTA******************%

clc

clear

pipe = readtable('Pipe_3.xlsx')

%Pipe Nominal Diameter AS Per according to ASME/ANSI B36.10M%

Pipe_Name = pipe.Name

Pipe_outer_dia =  pipe.Pipe_outer_dia

Thickness =  pipe.Thickness


Pipe_inner_dia =  pipe.Pipe_inner_dia./1000

Pipe_name = pipe.Name

Pipe_Area = (pi/4).*(Pipe_inner_dia.^2)


%mass Flow rate% %(Kg/s)%

Mass_Flow_rate  = 0.10422

%Pressure %% Mpa %

Pressure = 0.0101325
```

```
%Density% %kg/m^3%

Density  = 0.61178

%Viscosity% %pa-s%

Viscosity = 1.19e-5

%Volume flow rate% %(m3/s)%

Volume_flow_rate = Mass_Flow_rate / Density

%velocity = Volume/Area% % m/s %

Pipe_Velocity = Volume_flow_rate./Pipe_Area

Reynolds_Number = (Density.*Volume_flow_rate .*
Pipe_inner_dia)./(Viscosity.*Pipe_Area)


if(Reynolds_Number<=2000)

   Friction_factor = 64./Reynolds_Number

end

if(Reynolds_Number <=4000)

   %Blausisus%

   Friction_factor = 0.0791./(Reynolds_Number).^0.25

end

A1 = input('does the pipe is smooth pipe {y/n) : ','s')

 if(A1=='y')

   %Von Karman-Nikuradsc%

   Friction_factor = 0.001

   e=1
```

```
while(e>0.0001)
fc = ((1./(-2.*log(2.51./(Reynolds_Number.*Friction_factor.^0.5)))).^2)
e = abs(Friction_factor-fc)
Friction_factor = fc
continue
end
end
if(A1=='n')
Friction_factor = 0.001
% e=1
k = input('enter roughness (in mm): ')
%while(e>0.0001)
fc = (1./(-2.*log((k./1000)./(3.7.*Pipe_inner_dia)))).^2
% e = abs(Friction_factor-fc)
Friction_factor = fc
% continue
% end
end
%Darcy-Weisbach Equation%
Friction_Loss = (Friction_factor .* Pipe_Velocity .^2)./(2.*9.81.*Pipe_inner_dia)


pipe = readtable('pipe.xlsx')
```

```
L = pipe.Quantity.*pipe.L_DFactor

length = input('Insert pipe length (in m):')

Pipe_length = length + sum (L)*Pipe_inner_dia

Total_Pressure_Drop = Density.* 9.81.* Friction_Loss.* Pipe_length

%Total_Pressure_Drop_2 = 0.42236 *

subplot(2,2,1)

plot(Pipe_inner_dia, Pipe_Velocity, '-o'),xlabel('Pipe diameter (mm)'),
ylabel('Velocity')

subplot(2,2,2)

plot(Pipe_inner_dia, Reynolds_Number, '-o'),xlabel('Pipe diameter (mm)'),
ylabel('Reynolds number')

subplot(2,2,3)

plot(Pipe_inner_dia, Friction_factor, '-o'),xlabel('Pipe diameter (mm)'),
ylabel('Friction_factor')

subplot(2,2,4)

plot(Pipe_inner_dia,Total_Pressure_Drop, '-o'),xlabel('Pipe diameter (mm)'),
ylabel('Total_Pressure_Drop')

T = table (Pipe_Name,
Pipe_outer_dia,Thickness,Reynolds_Number,Friction_factor,
Total_Pressure_Drop)

 writetable(T,'test.xlsx','Sheet',2)
```

Appendix 4

MATLAB script for calculation of frictional losses for Two phase flow in pipe

```
%**Scrlpt for calcuating the frictional losses for two phase flow***%

%******************* For LNG Plant pipe calculation***************%

%**********************Coeded by SATYA VART GUPTA*****************%

clc

clear

Mass_flow_rate_Liquid = 0.01158

Density_Liquid = 422.36

Mass_flow_rate_Vapour = 0.10422

Density_Vapour = 1.8164

pipe = readtable('Pipe_2.xlsx')

%Pipe Nominal Diameter AS Per according to ASME/ANSI B36.10M%

Pipe_Name = pipe.Name

Pipe_outer_dia =  pipe.Pipe_outer_dia

Thickness =  pipe.Thickness


Pipe_inner_dia =  pipe.Pipe_inner_dia./1000

Pipe_name = pipe.Name

Pipe_Area = (pi/4).*(Pipe_inner_dia.^2)
```

```
Viscosity_Liquid = 0.0001677

Viscosity_Gas = 4.46e-6

length = input('Insert pipe length:')


Reynolds_number_liquid = (Mass_flow_rate_Liquid.*
Pipe_inner_dia)./(Pipe_Area .* Viscosity_Liquid)

Reynolds_number_Gas = (Mass_flow_rate_Vapour.*
Pipe_inner_dia)./(Pipe_Area .* Viscosity_Gas)


if(Reynolds_number_liquid<2000 & Reynolds_number_Gas >2000)

   Kl = 16

   Kg = 0.046

   n = 1.0

   m = 0.2

%end

elseif(Reynolds_number_liquid>2000 & Reynolds_number_Gas <2000)

   Kl = 0.046

   Kg = 16

   n = 0.2

   m = 1

%end

elseif(Reynolds_number_liquid<2000 & Reynolds_number_Gas<2000)

   Kl = 16
```

```
    Kg = 16

    n = 1

    m = 1

%end

else(Reynolds_number_liquid >2000 & Reynolds_number_Gas >2000)

    Kl = 0.046

    Kg = 0.046

    n = 0.2

    m = 0.2

end


Pf_Liquid = (2.*Kl .* Density_Liquid .* Reynolds_number_liquid.^(-
n)).*(Mass_flow_rate_Liquid./(Pipe_Area.*Density_Liquid)).^2

Pf_Vapour = (2.*Kg .* Density_Vapour .* Reynolds_number_Gas.^(-
m)).*(Mass_flow_rate_Vapour./(Pipe_Area.*Density_Vapour)).^2

X= (Pf_Liquid ./Pf_Vapour).^0.5


if(Reynolds_number_liquid<2000 & Reynolds_number_Gas >2000)

    c = 12

%end


elseif(Reynolds_number_liquid>2000 & Reynolds_number_Gas <2000)

    c = 10
```

```
%end

elseif(Reynolds_number_liquid<2000 & Reynolds_number_Gas<2000)

  c = 5

%end

else(Reynolds_number_liquid>2000 & Reynolds_number_Gas >2000)

  c = 20

end


phi_L= (1+ (c./X)+(1./X.^2)).^0.5


Pressure_loss_frictional = (phi_L.^2).^Pf_Liquid

pipe = readtable('pipe.xlsx')

L = pipe.Quantity.*pipe.L_DFactor

Pipe_length = length + sum (L)*Pipe_inner_dia

Total_Pressure_Drop = Pressure_loss_frictional.* Pipe_length


subplot(2,2,1)

plot(Pipe_inner_dia, Reynolds_number_liquid),xlabel('Pipe diameter (mm)'),
ylabel('Reynolds_number_liquid')

subplot(2,2,2)

plot(Pipc_inner_dia, Reynolds_number_Gas),xlabel('Pipe diameter (mm)'),
ylabel('Reynolds_number_Gas')

subplot(2,2,3)
```