FLOW MEASUREMENT OF COMPRESSIBLE FLUID: A STUDY ON MEASREMENT OF NGL FLOW BETWEEN SGFL AND RPGCL.

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A Project
Submitted to the Department of Petroleum & Mineral Resources Engineering in partial fulfillment of the requirements for the Degree of Master of Engineering in Petroleum Engineering.

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CANDIDATE'S DECLARATION

It is hereby declared that this project or my any part of it has not been submitted elsewhere for the award of any degree or diploma.

Signature of the Candidate

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RECOMMENDATION OF THE BOARD OF EXAMINERS

The project title "*FLOW MEASUREMENT OF COMPRESSIBLE FLUID: A STUDY ON MEASREMENT OF NGL FLOW BETWEEN SGFL AND RPGCL*, submitted by Md. Monwarul Islam, Roll No. 100713026 has been accepted as satisfyactory in partial fulfillment of the requirements for the degree of Master of Engineering in Petroleum Engineering.

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DEDICATED TO MY BELOVED PARENTS AND RESPECTED TEACHERS OF PETROLEUM AND MINERAL RESOURCES ENGINEERING DEPARTMENT.

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Abstract

Compressible fluid flow appears in many natural and technical processes. All gas flow and some fluid meet the compressible flow criteria. For instance, the flow of Natural Gas Liquids in a pipe system is considered a compressible flow. Flow measurement of compressible fluid is difficult due to changes in thermodynamic properties at varying operating conditions. This work investigates the difference of NGL flow measurement readings that occurs using different flow meters in the same pipeline.

The analysis of NGL flow measurement has been done from real readings of different flow meters in pipe lines. This paper covers the measurement of NGL by orifice and Turbine meters. It examines the characteristics, installation, operation, accuracy and calculation methods of these meters for determining volumetric and mass flow.

The report presents the equation which governs the flow of Natural Gas Liquids through pipes and practical equations were developed to solve intense numerical problems. Particular emphasis is placed on those used within the natural gas industry in the hope that engineers within the industry can make knowledge able decision on different flow meter measurement, installation of flow meter and mass balance in fractionation process. This paper also recommended the necessary corrective factors and operative requirement for the use of orifice and turbine meters.

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NOMENCLATURE

BBLS	Barrels
BPC	Bangladesh Petroleum Corporation
COP	Conditioning Orifice Plate
HSD	High Spirit Diesel
KTL	Kailashtila Limited
LPG	Liquefied Petroleum Gas
MMSCF	Million Standard Cubic Feet
MS	Motor Spirit
MSTE	Molecular Sieve Turbo-expander
NGL	Natural Gas Liuids
RPGCL	Rupantarita Prakritik Gas Company Limited
SGFL	Sylhet Gas Fields Limited
A	Cross Section Area
C	Orifice Flow Coefficient
C_d	Coefficient of Discharge
D	Pipe Diameter
f	Friction Factor
G	Specific Gravity of NGL
K	Specific Heat Ratio
L	Pipe Length
m	Mass Flow Rate
M	Molar Mass

N_{re}	Reynolds' Number
P_a	Average pressure
P_1	Upstream Pressure
P_2	Downstream Pressure
Q	Volumetric Flow Rate
R	Universal Gas Constant
T_a	Average Temperature
v	Fluid Velocity
v_1	Upstream Fluid Velocity
v_2	Downstream Fluid Velocity
Y	Expansion Factor
Z	Compressibility Factor
μ	Fluid Viscosity
ρ	Fluid Density

Subscripts

b	Base Condition
d	Discharge
f	Flowing Condition
r	Rate Condition
tp	Specific Temperature and Pressurse Conditions

Chapter 1

INTRODUCTION

Compressible fluid flow measurement is critical to determine the amount of material purchased and sold, and in these applications, very accurate flow measurement is required. The appropriate flow measurement devices are required to measure the fluid flow. For compressible fluid the discrepancy in flow rate is related to i) Energy losses due to Turbulence and Viscosity ii) Energy losses due to friction against the pipe and element surfaces iii) Unstable location of vena contracta with changes in flow iv) Uneven velocity profiles caused by irregularities in the pipe v) Fluid Compressibility vi) Non-ideal pressure Tap location (s) vii) Excessive turbulence caused by rough internal pipe surfaces [1]. The purpose of this work is to provide the causes of deviance in compressible fluid flow measurement by different meters in same pipeline. Also provide an example of compressible fluid flow study that is NGL flow measurement in same line between SGFL and RPGCL.

The theoretical Foundations for flow measurements are the conservation equations of mass and energy [2]. Fundamental and Practical correlations of compressible fluid flow measurement are used to estimate information about the fluid dynamics conditions of fluid in flow lines and measurement related devices. Compressibility factor is an important quantity for NGL custody transfer applications because the fluid is highly compressible. The conservation equations, mathematical correlations and expansion factor are used to achieve acceptable measurement accuracy in the field for Orifice and Turbine meters.

The NGL was transferred by custody meter of SGFL. There were two custody meters: Orifice and Turbine meters used in measurement of NGL flow. Compressible fluid flow measurement data are used in this project work from practical field of NGL flow in pipeline between SGFL and RPGCL. Some differences occurred in flow measurement of NGL by different meter between MSTE, SGFL and KTL-1, RPGCL. Analysis has been done on Orifice and Turbine meter readings in NGL transferred pipeline.

1.1 Molecular Sieve Turbo-expander Plant (MSTE):

In SGFL the 90 million cubic feet/day capacity Molecular Sieve Turbo-expander (MSTE) plant situated at Kailashtilla-2 location was installed in 1992-95 which went into commercial operation in September 1995. This plant, first of its kind in Bangladesh, employs modern cryogenic mechanism to recover liquefiable hydrocarbons. The advantage of employing this mechanism is that an additional amount of Natural Gas liquids (NGL) in the range of 8-10 BBLS/MMSCF is being recovered which would have otherwise remained unrecovered had conventional plant been used.

The present average condensate/NGL recovery from the MSTE plant is about 18 BBLS/MMSCF. The gas delivered from the MSTE plant is fed through the 24-inch National Gas-Grid line. Of the total condensate 550 BBLs/day and NGL 650 BBLs/day recovered at the MSTE Plant, are supplied as feed to KTL-1 fractionation Plant of RPGCL to fractionate the NGL into LPG and Motor Spirit [3].

1.2 Kailashtila Fractionation Plant :

The Kailashtila Fractionation Plant has been installed during 1986-1997 to reduce the dependence of imported oil as well as to provide environment friendly clean fuel. Later another NGL and Condensate Fractionation plant was installed in November,2007 within the development programmes. These two plants are producing sulphur and lead free and *environment friendly quality LPG, Motor Spirit (Petrol) and HSD through the processing of NGL and Condensate respectively. LP Gas Limited, a BPC owned company at Kailashtila, is marketing LPG ; while Padma, Meghna and Jamuna Oil Companies of the same corporation are marketing Motor Spirit and HSD.*

It is possible to produce a total of 62 M. ton LPG, 2,70,000 litres MS and 43,000 litres HSD daily through processing of 175 M. ton (110 M. ton + 65 M. ton) NGL and 110 M. ton condensate within the existing facilities at the two plants at Kailashtila . But at present the KTL plant (Unit-1) is shut down due to lack of raw material. This problem could be solved by setting up a 2nd MSTE plant by the Sylhet Gas Fields Limited [4].

1.3 NGL Measurement History between MSTE & KTL Fractionation Plant:

KTL Fractionation Plant went into commercial production in March, 1998. From beginning MSTE was delivered NGL through a 4-inche pipe line measured by Turbine Meter in KTL-1 Fractionation Plant till April 2003. From April 2003 to June 2007 SGFL delivered same product through orifice meter located in MSTE Plant and at this period Turbine Meter was also used in KTL-1 Fractionation Plant. Billing was done on Orifice meter reading.

1.4 Statement of the Problem

During the period from April 2003 to June 2007 a cumulative difference occurred between Orifice meter (SGFL) and Turbine meter (RPGCL) reading [5]. This anomaly in reading created departmental problem and several investigations were conducted to find the reason. Even anticorruption proceeding is being carried out [6-7]. This study will investigate the performances of these meters and will examine the extent of the error in the readings.

1.5 Objectives

The objectives of the project are:

i).To make a mathematical correlations which are used to estimate information about the thermophysical and fluid dynamic conditions of fluids in flow line and measurements related devices.

ii)To make a comparison between the readings of Orifice meter (SGFL) and Turbine Meter (RPGCL) in NGL transportation line.

iii) To know the Limitations and Accuracy of both meters (Orifice and Turbine) in compressible fluid flow measurement.

iv) To identify main causes of different readings shown by Orifice and Turbine meter in general NGL transportation line from MSTE to Kailashtila Fractionation Plant in particular.

1.6 Methodology

To achieve the above objectives the following methods are adopted:

I) Design and calculation to establish fundamental and practical equations to measure compressible fluid flow through pipeline.

ii) Examine flow calculation Equation for Orifice and Turbine meter of compressible fluid flow through pipeline.

iii) Analyze the working principle of Orifice and Turbine Meter in compressible fluid flow.

iv) Analyze the advantage and limitation of both Orifice and Turbine Meters in compressible fluid flow measurement.

v) Study the accuracy of both meters.

vi) Collect all relevant data from MSTE and KTL Plant.

vii) Analyze the results and summarize the reasons behind the differences in readings.

Chapter 2

LITERATURE REVIEW

2.1 Compressible Fluid Flow

In compressible fluid, the fluid density varies significantly in response to a change in pressure. For fluid in which the density does not vary significantly, this is an idealization, which leads to the theory of incompressible fluid. However in many cases dealing with gases, natural gas liquids especially at higher velocity and those cases dealing with liquids with large pressure change, the significant variation in density can occur and the flow should be analyzed as a compressible flow if the accurate results are to be obtained.

Incompressible flows, which can usually be solved by considering only the equations from conservation of mass and conservation of momentum. Usually the principle of conservation of energy included[8].

However in compressible flow introduces another variable temperature and so a fourth equation such as ideal gas equation is required to relate the temperature to the other thermodynamic properties in order to fully describe the flow [9].

2.2 Characteristics of Compressible Fluid

Density

A measure of mass per unit of volume (lb/ft^3 or kg/m^3).

Specific Gravity

The ratio of the density of a material to the density of water or air depending on whether it is a Liquid or a Gas.

Linear

Transmitter output is directly proportional to the flow input.

Square Root

Flow is proportional to the square root of the measured value.

Beta Ratio (d/D)

Ratio of a differential pressure flow device bore (d) divided by internal diameter of pipe (D).A higher Beta ratio means a larger orifice size. A larger orifice plate bore size means greater flow capacity and a lower permanent pressure loss.

Pressure Head

The Pressure at a given point in a fluid measured in terms of the vertical height of a column of the fluid needed to produce the same pressure.

Laminar Flow

Is Characterized by Concentric Layers of Fluid moving in parallel down the length of a pipe. The highest velocity (Vmax) is found in the center of the pipe. The lowest velocity (V=0) is found along the pipe wall. Figure 2.2.1 illustrates the laminar flow profile[10].

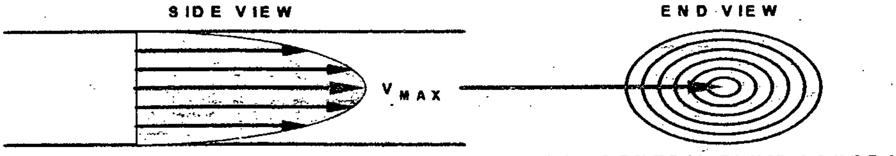


Fig. 2.2.1 Laminar Flow.

Turbulent Flow

Is Characterized by a fluid motion that has local velocities and pressures that fluctuate randomly. This causes the velocity of the fluid in the pipe to be more uniform across a cross section. Figure2.2.2 illustrates the turbulent flow profile[10].

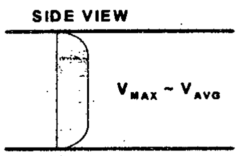


Fig. 2.2.2 Turbulent Flow.

Reynolds number

The Reynolds number is the ratio of inertial forces (velocity and density that keep the fluid in motion) to viscous forces (frictional forces that slow the fluid down) and is used for determining the dynamic properties of the fluid to allow an equal comparison between different fluids and flows [11].

Laminar Flow occurs at low Reynolds numbers, where viscous forces are dominant, and is characterized by smooth, constant fluid motion Turbulent Flow occurs at high Reynolds numbers and is dominated by inertial forces, producing random eddies, vortices and other flow fluctuations.

The Reynolds number is the most important value used in fluid dymanics as it provides a criterion for determining similarity between different fluids, flowrates and piping configurations. Figure 2.2.3 shows the limiting Reynolds number for laminar, transition, turbulent flow in pipe line.

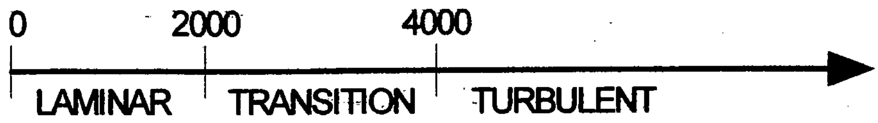


Fig. 2.2.3 Reynolds' Number Vs Fluid flow

For purposes determining friction factor, it has been found that the fluid flow may be characterized by a dimensionless grouping of variables known as Reynolds' Number, which is defined as

$$N_{re} = \frac{Dv\rho}{\mu}$$

For compressible fluid, we can determine density from the equation of state to substitute for ρ and determine velocity as flow rate/area corrected to actual conditions to substitute for v. By including specific gravity of compressible fluid, we are left with the following expression [12]:

$$N_{re} = \frac{.015379QgP_b}{\mu DT_b}$$

English

$$N_{re} = \frac{49.44QgP_b}{\mu DT_b}$$

Metric

Where

N_{re} = Reynolds' Number, dimensionless

Q = Fluid Flow Rate

G = Specific Gravity of Compressible Fluid dimensionless

D = Pipe Diameter

μ = Fluid Viscosity, pascal-sec

T_b = Base Temperature

P_b = Base Pressure

It is point out that in compressible fluid the Reynolds' Number is proportional to the flow rate.

Friction Factor:

Friction factor is related as a function of the Reynolds' number and the relative pipe roughness. This function is usually presented in the familiar Moody Diagram in Figure 2.2.4[13].

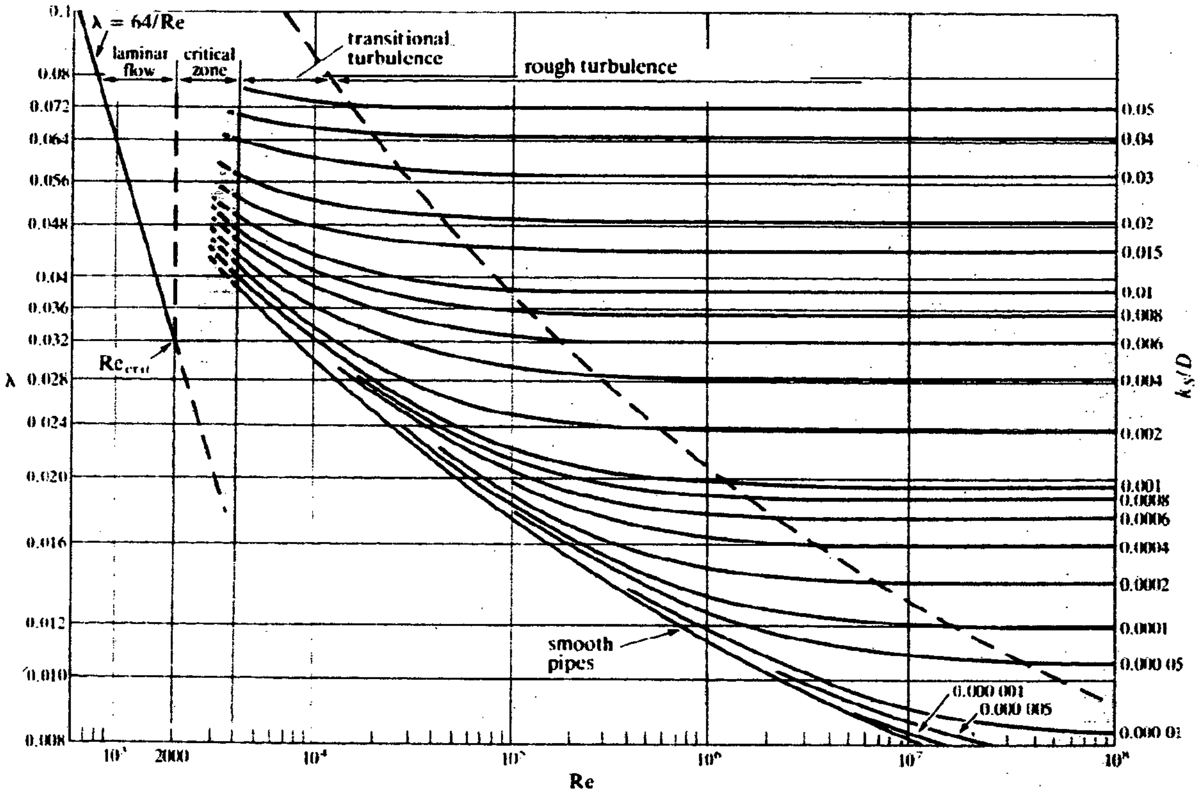


Fig 2.2.4 Moody Diagram [The version of the Moody diagram shown uses λ (=4f) for friction factor rather than f. The shape of the diagram will not change if f were used instead.]

The Moody Diagram consists of four zone i.e. laminar, transition, partially Turbulent, fully Turbulent.

In laminar zone the fluid flows strictly in one direction and the friction factor dependency on flow rate, is defined by the Hagen-Poiseuille equation [14]:

$$f = \frac{64}{N_{re}}$$

In fully Turbulent zone of extremely high flow rate the fluid flows laterally within the pipe in complete Turbulence as well as in the primary direction and the the friction factor shows no dependency on flow rate. The friction factor is given by the rough pipe law of Nikuradse [15]:

$$\frac{1}{\sqrt{f}} = 2\log\frac{D}{\varepsilon} + 1.14$$

In partially Turbulent zone of moderately high flow rate the fluid flows laterally within the pipe as well as in the primary direction although some laminar boundary layer outside the zone of roughness still exists and the flow is governed by the smooth pipe law of von karman and Prandtle [15]:

$$\frac{1}{\sqrt{f}} = 2\log(N_{re}\sqrt{f}) - 0.8$$

The straight horizontal line of the rough pipe law should be extended to the smooth pipe law forming a corner at the intersection. The nature of corners and Colebrook-White equation, which is nothing more than a combination of the two, is the proper method [15]:

$$\frac{1}{\sqrt{f}} = -2\log\left[\frac{\frac{\varepsilon}{D}}{3.7} + \frac{2.51}{N_{re}\sqrt{f}}\right]$$

Compressibility

The term "compressibility" is used to describe the deviance in the thermodynamic properties of a real gas from those expected from an ideal gas.

Compressibility Factor (Z) - The compressibility factor can be defined through its relation to density and is a particularly important quantity for gas custody transfer applications because the fluid is highly compressible.

Real Gas Behavior can be calculated as:

$PV = nZRT$

The compressibility factor, Z, is defined as the ratio of the real gas volume to the ideal gas volume. The real gas volume and ideal gas volume are determined at the same temperature, pressure and gas composition. The real gas volume is the measured volume of a given mass of gas at an equilibrium temperature and pressure. The ideal gas volume is a calculated volume at the same temperature, pressure, and gas composition as the measured volume.

$$Z = \frac{V_{real}}{V_{ideal}}$$

$$V_{real} = V_{measured,\,T,P,n}$$

$$V_{ideal} = \frac{nRT}{P}$$

A comparable way to define the compressibility factor is

$$z = \frac{PV}{RT}$$

where

n = number of moles (mass)

R = gas constant

T = temperature, absolute

P = pressure, absolute

V_{real} *= real gas volume*

V_{ideal} *= ideal gas volume*

Z = compressibility factor

V = is the real molar volume (inverse of the molar volume is the molar density).

The real gas compressibility factor corrects the volume relative to the assumptions in the ideal gas equation. A real gas that behaves as an ideal gas has a compressibility factor value of 1, this generally occurs at low pressures and high temperatures. Figure 2.2.5 illustrates the variation in values for methane's compressibility factor [16]. The compressibility factor chart shows a wide range of temperature and pressure conditions. Each curve is at constant temperature. The temperature range illustrates the behavior of methane's compressibility factor at conditions for liquefied natural gas, gas processing, surface exposed pipe conditions, transmission lines, and well conditions.

Figure 2.2.5 shows that as methane is compressed, molecular effects reduce the volume occupied by the real gas relative to the ideal gas volume, i.e. the real to ideal volume ratio is less than 1. This results in compressibility factors that are less than 1. The amount of compression in the volume *depends on the chemical component, temperature and pressure. As pressure is further increased, repulsive forces between molecules begin to dominate. This leads to a reversal in the compressibility factor value and results in an expansion in the real to ideal volume ratio as pressure is further increased.*

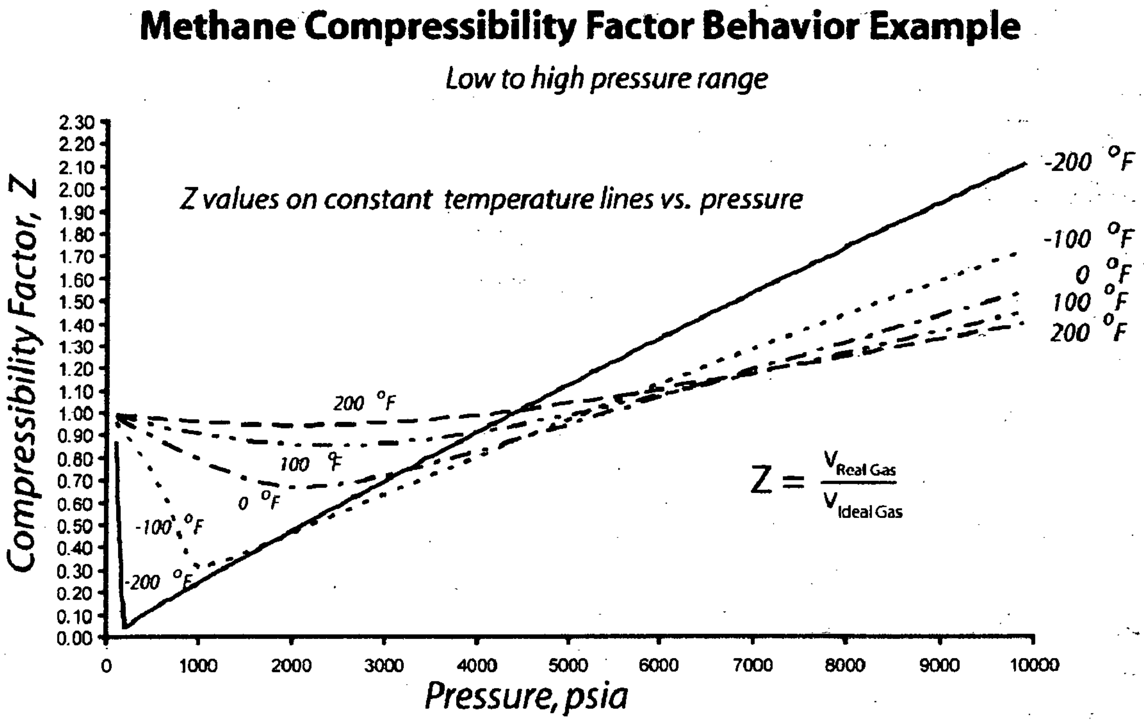


Figure 2.2.5 Methane compressibility factor example, low to high pressure range.

Figure 2.2.6 focuses on a small portion of Figure 2.2.5 to show in more detail the range of compressibility factor values for pure methane on constant temperature curves for pressures up to 2000 psia[16]. The constant temperature between 0 °F and 100 °F cover most gas phase measurement conditions.

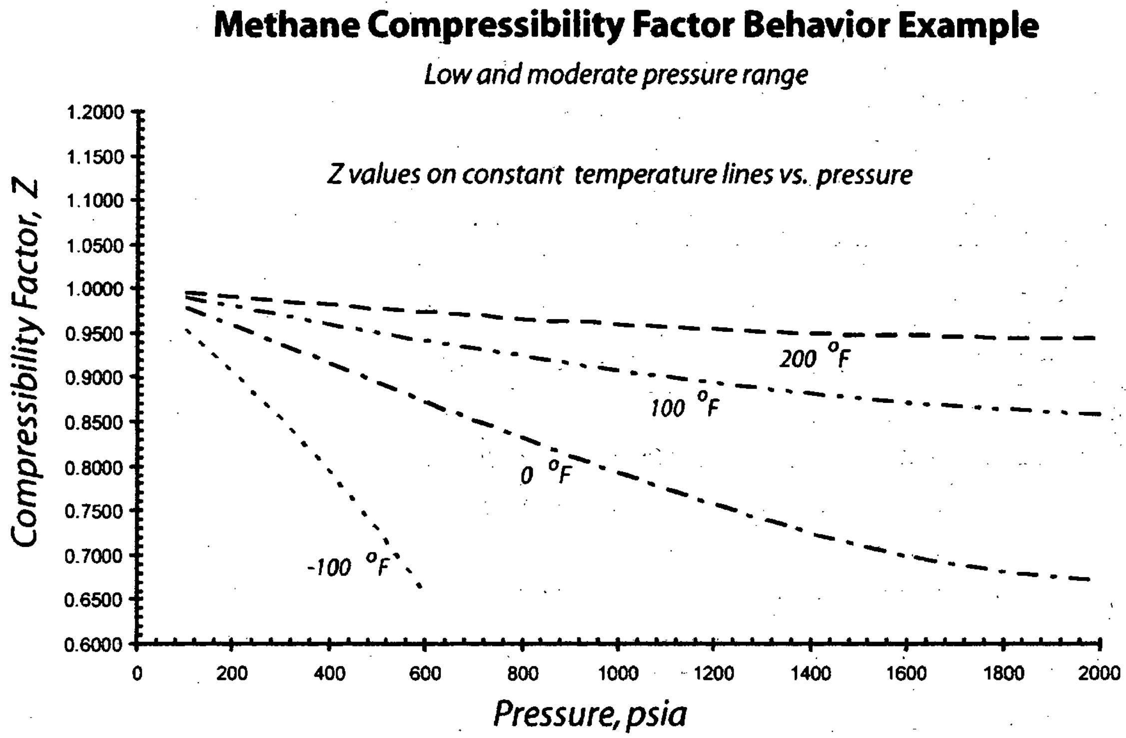


Figure 2.2.6 Methane compressibility factor example, low and moderate pressure range.

Natural gas mixtures are mostly methane. It is the most important component for calculating the compressibility factor of a natural gas mixture. Other hydrocarbon components, e.g. ethane, propane, etc. and diluents found in natural gases also contribute to the overall compressibility factor value for real mixtures. There contributions are generally proportional to their concentrations. As the components in a mixture change, there is a corresponding change in their contribution to the compressibility factor.

Bulk modulus of compression, κ & Mach number M

All fluids are compressible and when subjected to a pressure field causing them to flow, the fluid will expand or be compressed to some degree. The acceleration of fluid elements in a given pressure gradient is a function of the fluid density, ρ, whereas the degree of compression is determined by the *isentropic bulk modulus of compression, κ. The speed of sound in a medium is given by, $a = (\kappa/\rho)^{1/2}$ and compressibility effects are apparent when the flow velocity, u, becomes significant compared to the local speed of sound. The local Mach number $M = u/a$ is the primary parameter which characterizes the effects of compressibility.*

The role of Mach number in compressible gas flow may be derived from the governing equations of motion and state.

Prandtl–Glauert transformation

The Prandtl-Glauert transformation is found by linearizing the potential equations associated with compressible, inviscid flow. The Prandtl–Glauert transformation or Prandtl–Glauert rule (also Prandtl–Glauert–Ackeret rule) is an approximation function which allows comparison of aerodynamical processes occurring at different Mach numbers. It was discovered that the linearized pressures in such a flow were equal to those found from incompressible flow theory multiplied by a correction factor. This correction factor is given below

$$c_p = \frac{c_{p0}}{\sqrt{1 - M^2}}.$$

where

- c_p *is the compressible pressure coefficient*
- c_{p0} *is the incompressible pressure coefficient*
- M *is the Mach number.*

This correction factor is correct only for two-dimensional flow. For general three-dimensional flows, it is necessary to apply the full Prandtl-Glauert transformation to the geometry, and then apply Göthert's Rule to get the physical pressure coefficient and forces.

This 2D Prandtl-Glauert Rule, or the general 3D Göthert's Rule, work well until transonic flow starts to appear, typically for Mach numbers below 0.7 for 2D airfoils.

Karman-Tsien correction factor

The Karman-Tsien transformation is a nonlinear correction factor to find the pressure coefficient of a compressible, inviscid flow. It is an empirically derived correction factor that tends to slightly overestimate the magnitude of the fluid's pressure. In order to employ this correction factor, the incompressible, inviscid fluid pressure must be known from previous investigation.

$$C_P = \frac{C_{P0}}{\sqrt{1-M^2} + \frac{C_{P0}}{2}\left(M^2/(1+\sqrt{1-M^2})\right)}$$

where

- c_p *is the compressible pressure coefficient*
- c_{p0} *is the incompressible pressure coefficient*
- M *is the Mach number.*

Like the Prandtl-Glauert Rule, this is only valid for 2D flows, and only until transonic flow starts to appear.

2.3 The Fundamental Equation of Compressible Fluid:

There has always been need workable equations to relate the flow of compressible fluid through pipe to the properties of both the pipe and the fluid and to the operating conditions such as pressure and temperature. The fundamental flow equation as described universally accepted as a full and *complete statement of how fluid works. The end result for flow in a horizontal pipe is the following equation [12]:*

$$Q = C\frac{T_b}{P_b}D^{2.5}e\left(\frac{P_1^2 - P_2^2}{LGT_aZ_a\text{f}}\right)^{0.5}$$

Z_a the compressibility factor is a function of pressure and temperature; it must be evaluated at average conditions for the pipe. For temperature is usually used while the following equation, which accounts for non linearity of pressure drop with distance, is generally accepted for determining average pressure:

$$Pav = \frac{2}{3}\left(P_1 + P_2 - \frac{P_1P_2}{P_1 + P_2}\right)$$

Incorporate super compressibility evaluated separately at inlet and outlet conditions & it is common in reservoir work.

$$Q = C\frac{T_b}{P_b}D^{2.5}e\left(\frac{\frac{P_1^2}{Z_1} - \frac{P_2^2}{Z_2}}{LGT_a\text{f}}\right)^{0.5}$$

D= Pipe diameter
G = Specific Gravity of NGL
L = Pipe length
P_1 & P_2 pressure in different point.
Q = Flow rate
f = Friction factor
Z = Compressibility
b = Base

Pipes are usually not horizontal. So long as the slope is not great, a correction for the static head of fluid may be incorporated and determined as follows:

$$Q = C\frac{T_b}{P_b}D^{2.5}e\left(\frac{P_1^2 - P_2^2 - H_c}{LGT_aZ_a\text{f}}\right)^{0.5}$$

Where

$$Q = \frac{0.0375g(H_2 - H_1)P_a^2}{ZT_a} \qquad \textit{English}$$

$$Q = \frac{0.06835g(H_2 - H_1)P_a^2}{ZT_a} \qquad \textit{Metric}$$

2.4 Practical Equations of Compressible Fluid:

The Fundamental equation may be reduced by factoring the $p_1^2 - p_2^2$ term into $(p_1 - p_2)(p_1 + p_2)$ and assuming an appropriate average pressure. The equation then becomes:

$$Q = \frac{C}{2}\frac{T_b}{P_b}D^{2.5}e\left(\frac{(P_1 - P_2)P_a}{LGT_aZ\text{f}}\right)^{0.5}$$

At Equivalent friction factor f=0.0291 then

$$Q = 1350D^{2.5}\left(\frac{(P_1 - P_2)}{LG}\right)^{0.5}$$

Constant friction factors are certainly not the most realistic. At the very least one would expect the friction factor to vary with the pipe diameter. That are described in Spitzglass equation in bellow and Figure 2.4.1 shows the correlation of friction factor with fluid flow of Moody diagram by Spitzglass.

At Equivalent friction factor

$$f = \frac{4\left(1 + \frac{3.6}{D} + .03D\right)}{354}$$

Then the Spitzglass equation is

$$Q = 1172D^3 e\left(\frac{(P_1 - P_2)P_a}{LG(D + 3.6 + .03D^2)}\right)^{0.5}$$ *At low pressure*

$$Q = 1128D^3 e\left(\frac{(P_1 - P_2)P_a}{LG(D + 3.6 + .03D^2)}\right)^{0.5}$$ *At high pressure*

This equation is a minor improvement in that it allows the friction factor too vary with the pipe size.

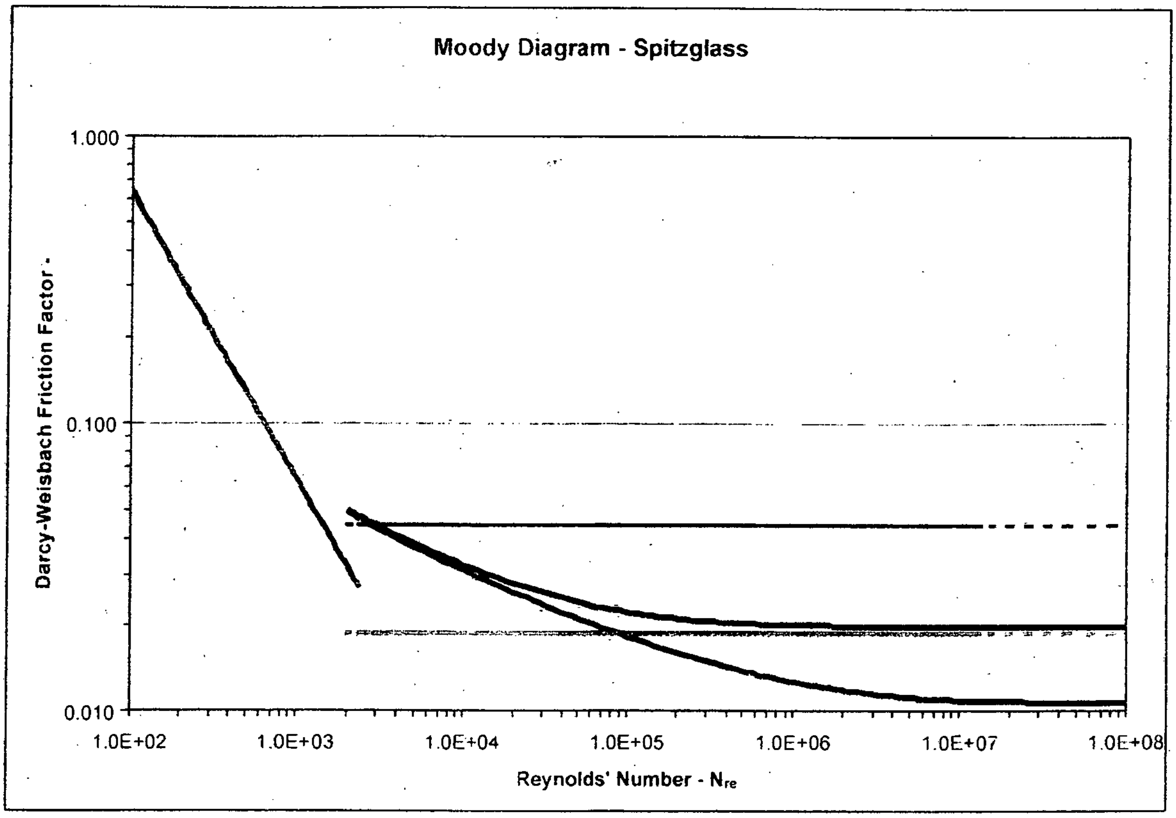


Fig.2.4.1 Moody Diagram-Spitzglass

The Weymouth described the fluid flow in bellow equation and Figure 2.4.2 shows the correlation of friction factor with fluid flow of Moody diagram by Weymouth. Equivalent friction factor for Weymouth was

$$f = \frac{4}{\left(11.18D^{\frac{1}{6}}\right)^2}$$

Then Weymouth equation is

$$Q = 433.49\frac{T_b}{P_b}D^{\frac{8}{3}}e\left(\frac{P_1^2 - P_2^2 - H_c}{LGT_aZ_a}\right)^{0.5}$$

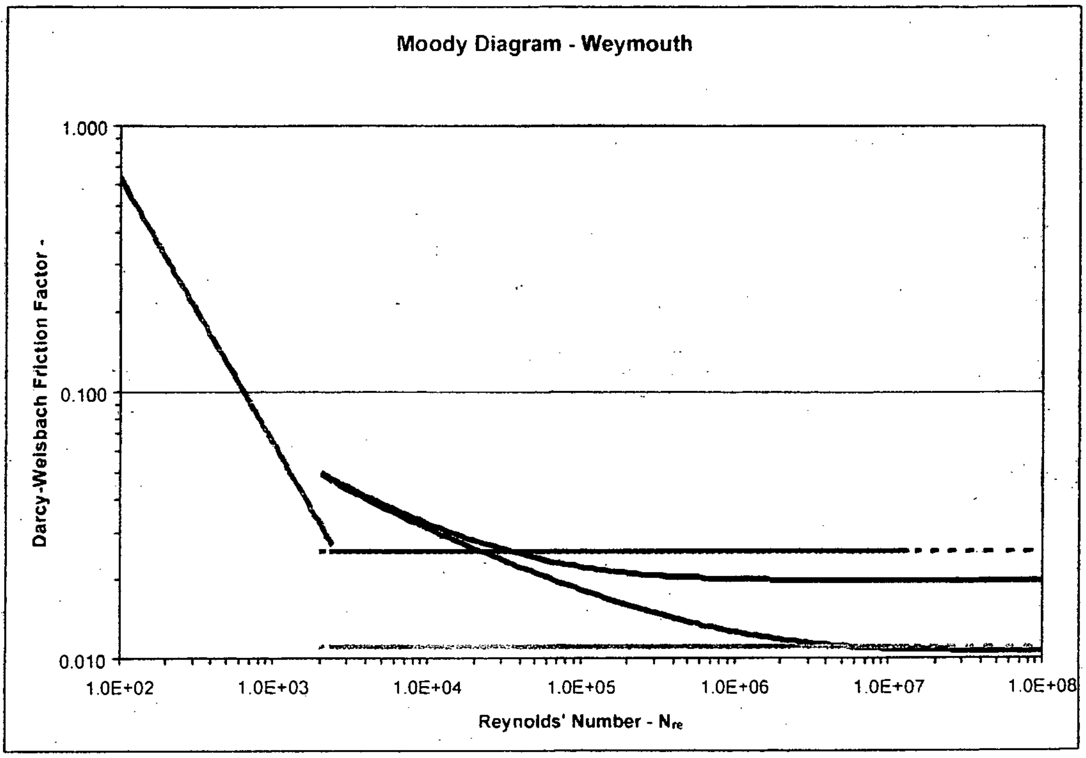


Fig. 2.4.2 Moody Diagram Weymouth

The friction factor decreases consistently with increasing the pipe size and it does so in the range of 0.008 – 0.02 and that is appropriate to high flow situation.

The Panhandle described the fluid flow in bellow equation and Figure 2.4.3 shows the correlation of friction factor with fluid flow of Moody diagram by Panhandle. Equivalent friction factor for Panhandle was

$$f = \frac{4}{\left(6.87\, N_{re}^{\ 0.07305}\right)^2}$$

The Panhandle "A" equation

$$Q = 435.87\left[\frac{T_b}{P_b}\right]^{1.0788} D^{2.6182} e\left(\frac{P_1^2 - P_2^2 - H_c}{LG^{.8538}T_a Z_a}\right)^{0.5394} \qquad \textit{English}$$

$$Q = .0045965\left[\frac{T_b}{P_b}\right]^{1.0788} D^{2.6182} e\left(\frac{P_1^2 - P_2^2 - H_c}{LG^{.8538} T_a Z_a}\right)^{0.5394}$$

Metric

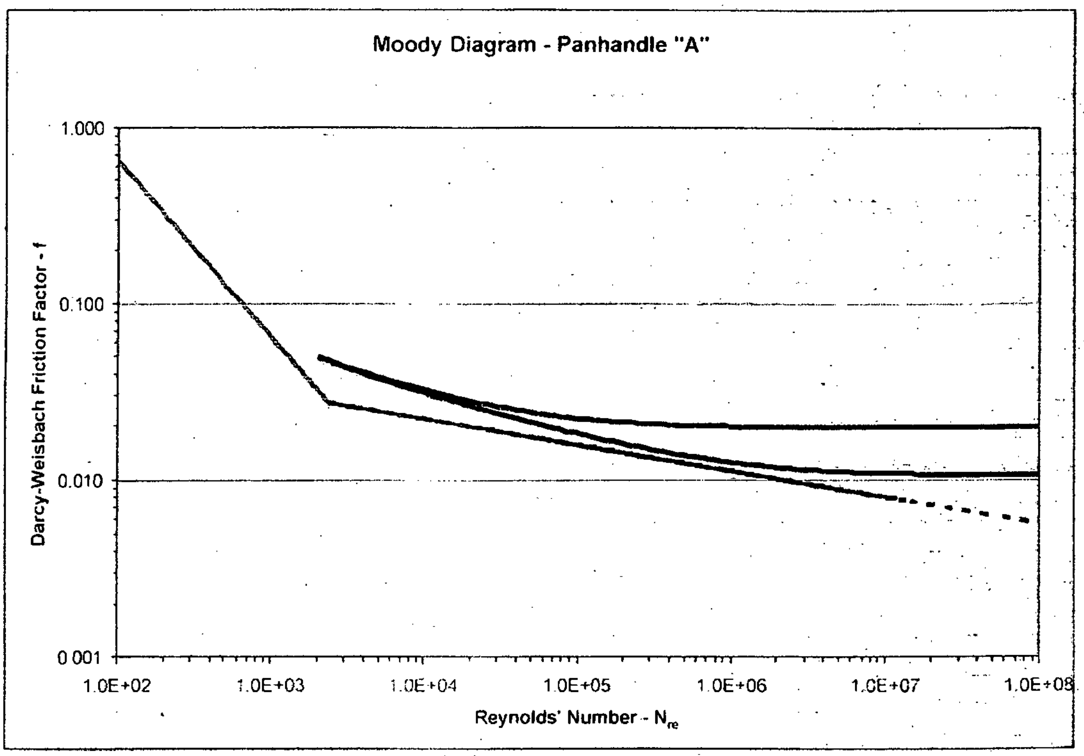


Fig. 2.4.3 Moody Diagram Panhandle "A"

Chapter 3

FLOW MEASUREMENT AND FLOW METER SELECTION

3.1 Introduction:

The importance of flow measurement in the industry was widespread use for accounting purposes, such as custody transfer of fluid from supplier to customers, but also because of its application in manufacturing processes. Examples of the industrial involvement in flow measurement includes food and beverage, oil and gas industrial, medical, petrochemical, power generation, and water distribution and etc. Flow measurement is the determination of the quantity of a fluid, either a liquid, or vapor, that passes through a pipe, duct or open channel. Flow may be expressed as a rate of volumetric flow (such as gallons per minute, cubic meters per minute, cubic feet per minute), mass rate of flow (such as kilograms per hour, pounds per hour), or in terms of a total volume or mass flow (integrated rate of flow for a given period of time).Fluid flow measurement can be divided into several types; each type requires specific considerations of such factors as accuracy requirements, cost considerations, and use of the flow information to obtain the required end results. Normally the flow meter is measure flow indirectly by measuring a related property such as a differential pressure across a flow restriction or a fluid velocity in a pipe.

3.2 Flowmeters:

A number of different fundamental physical principles are used in flow measurement devices.

There is various kind of the flowmeter available in market; they can be classifier types as

i) Difference pressure flow meter

a. Orifice plate

b. Venturi tube

c. Pitot tube and

d. Nozzle

ii) Variable area flowmeter

a. Rotameter

b. Movable vane meter, and

c. Weir, flume

iii) Positive displacement flowmeter

a. Sliding-vane type PD meter,

b. Tri-rotor type PD meter,

c. Birotor PD meter,

d. Piston type PD meter,

e. Oval gear PD meter,

f. Nutating disk type PD meter,

g. Roots PD meter,

h. The CVM meter ,and

i. Diaphragm meter

iv) Turbine flowmeter

v) Electromagnetic flowmeter

vi) Ultrasonic flowmeter

a. Doppler

b. Transit- Time

vii) Coriolis (Mass) flowmeter

3.3 Measurement Criteria of Flowmeter:

Bernoulli's Law

Bernoulli's Law describes the behavior of an ideal fluid under varying conditions in a closed system. It states that the overall energy of the fluid as it enters the system is equal to the overall energy as it leaves [17].

$$PE_1 + KE_1 = PE_2 + KE_2$$

PE = Potential Energy

KE = Kinetic Energy

Flow Range and Rangeability

Flow range is the differential between the minimum and maximum flow rate over which a meter produces acceptable performance within the basic accurately specification of meter. Rangeability is a flow meter's ability to cover a range of flow rates within specified accuracy limits. It is usually defined as the ratio of the maximum to minimum flow rates and is also known as meter turndown. This is important parameter when do selecting *of the flowmeter -(specific rangeability of respectively flowmeter are discussed in the following section). For example, a meter with maximum flow (100%) of 100 gallons per minute and minimum flow of 10 gal/min (within a stated tolerance such as ±0.5%) has a 10:1 rangeability or turndown of 10. It will be accurate ±0.5% from 10 to 100 gal/min.*

Accuracy

A term used frequently in flow measurement is accuracy. Accuracy is more abused than correctly used. Unfortunately, it is a sales tool used commercially by both suppliers and users of metering equipment. The supplier with the best number wins the bid. Likewise, the user will sometimes require accuracies beyond the capabilities of any meter available.

In pervious decades, accuracy was the term most commonly used to describe a meter's ability to measure flow. It was defined as the ratio of indicated measurement to true measurement. The antithesis of uncertainty and is an expression of the maximum possible limit of error at a defined confidence.

Why is accuracy is important for flow meter? The important point for custody transfers because it is related to money. A meter station measuring product worth $2 million a day, an inaccuracy of ± 0.2% represents $4,000 a day, or $1,460,000 a year and the amount that justifies considerable investment to improve flow measurement. The same error for a station measuring $1,000 worth of product a day represents only $2 a day, and the law of diminishing returns limits investment justifiable to improve measurement accuracy.

Discharge Coefficient (C_d)

The discharge coefficient corrects the theoretical flow rate equation for the influence of velocity profile (Reynolds number). Specific discharge coefficients for various flow meter geometries have been determined by *actual tests run by many different organizations (e.g., API, ASME, and ISO). The discharge coefficient is a very important factor in defining the shape of the flow path. It is heavily influenced by factors such as: the size of the orifice bore, the size of the pipe, fluid velocity, fluid density, and fluid viscosity.*

Discharge coefficient, C_d is defined as the ratio between actual volumetric flow rate and ideal volumetric flow rate.

where $$C_d = \frac{q_{\text{actual}}}{q_{\text{ideal}}}$$

q_{actual} = *Actual volumetric flow rates*

q_{ideal} = *Ideal volumetric flow rate. (Theoretical)*

Flow Coefficient (C)

$C = C_d / 1 - \beta^4$

where C = Flow coefficient

C_d = *discharge coefficient*

β = *ratio of diameters* = d/D

where $1/1 - \beta^4$ is known as velocity approach factor

3.4 Flow of Incompressible Fluids in Pipes

Section-1 is the position of upstream tap and Section-2 that for downstream. The terms T, A, ρ, V, P and Z represent Temperature, Area, Density, Stream velocity, Pressure and Central line elevation respectively. If this elevation is quite small such that $Z_2 - Z_1$ is negligible, the Bernoulli's equation for an incompressible ($\rho_1 = \rho_2$) frictionless and adaptive flow is written as Bernoulli's equation reduces to an equation relating the conservation of energy between two points on the same streamline:

$$P_1 + \frac{1}{2} \cdot \rho \cdot V_1^2 = P_2 + \frac{1}{2} \cdot \rho \cdot V_2^2$$

The continuity equation for this type of flow is

$Q = A_1V_1 = A_2V_2$

where Q = volume flow rate in ft³/sec.

Combining above equations and manipulating, one gets

$$Q = A_2 \sqrt{\frac{2\,(P_1 - P_2)/\rho}{1 - (A_2/A_1)^2}}$$

The above expression for Q gives the theoretical volume flow rate.

For actual flow conditions with frictional losses present, a correction to this formula is necessary. Besides, the minimum area of flow channel occurs not at the restriction but at some point slightly downstream, known as the 'Venacontracta'. This in turn depends on the flow rate. While the tapping positions are fixed, the position of maximum velocity changes with changing

flow rate. The basic equations are Introducing beta factor β as well as the co-efficient of discharge c_d.

$$Q = \frac{C_d A_2}{\sqrt{1-\beta^4}} \sqrt{\frac{2g(P_1 - P_2)}{\rho}}$$

Finally Introducing flow coefficient

$$C = \frac{C_d}{\sqrt{1-\beta^4}}$$

Then

$$Q = CA_2 \sqrt{\frac{2g(P_1 - P_2)}{\rho}}$$

This is equation for the actual volume flow rate.

where V = Velocity of Fluid

Q = Volume flow rate

A = Cross-sectional area of the pipe.

h = *differential head between points of measurement.*

ρ = density of the flowing fluid

C = Constant which includes ratio of cross-sectional area of pipe to cross-sectional area of nozzle or other restrictions.

3.5 Flow of Compressible Fluids in Pipes

For compressible flow, a correction factor called the expansion factor, Y, is used.All obstruction meters, then, are covered by the below equation

$$Q = CA_2Y\sqrt{2g(P_1 - P_2)}$$

Y < 1 if ΔP/P1> 0.02

Y = 1 for incompressible fluids (including all liquids)

3.6 Orifice meter

An orifice plate is a device used for measuring flow rate. Either a volumetric or mass flow rate may be determined, depending on the calculation associated with the orifice plate. An orifice plate is a thin plate with a hole in the middle. It is usually placed in a pipe in which fluid flows. When the fluid reaches the orifice plate, the fluid is forced to converge to go through the small hole; the point of maximum convergence actually occurs shortly downstream of the physical orifice, at the so-called vena contracta point in Figure 3.6.1. As it does so, the velocity and the pressure changes. Beyond the vena contracta, the fluid expands and the velocity and pressure change once again. By measuring the difference in fluid pressure between the *normal pipe section and at the vena contracta, the volumetric and mass flow rates can be obtained from Bernoulli's equation.*

The orifice plate is commonly used as an instrument to meter or control the rate of flow of the most common or Newtonian fluids. These comprise all gases, including air and natural gas, and many liquids, such as water, and most hydrocarbons. With no moving parts and a simple design, the orifice is easily machined, and thus has been a popular flow-measuring device. The orifice meter is one of a category of meters that require a pressure drop larger than the pressure drop in normal piping for proper measurement. If insufficient pressure drop is available for measurement, then a head meter cannot be used accurately. The general disadvantages of the orifice plate are its limited range, cause high pressure loss in system and sensitivity to flow disturbances. Orifice plates have several differences design, which are Segmental, Eccentric, Quadrant Edge and typical design Concentric Sharp Edged for special measurement application.

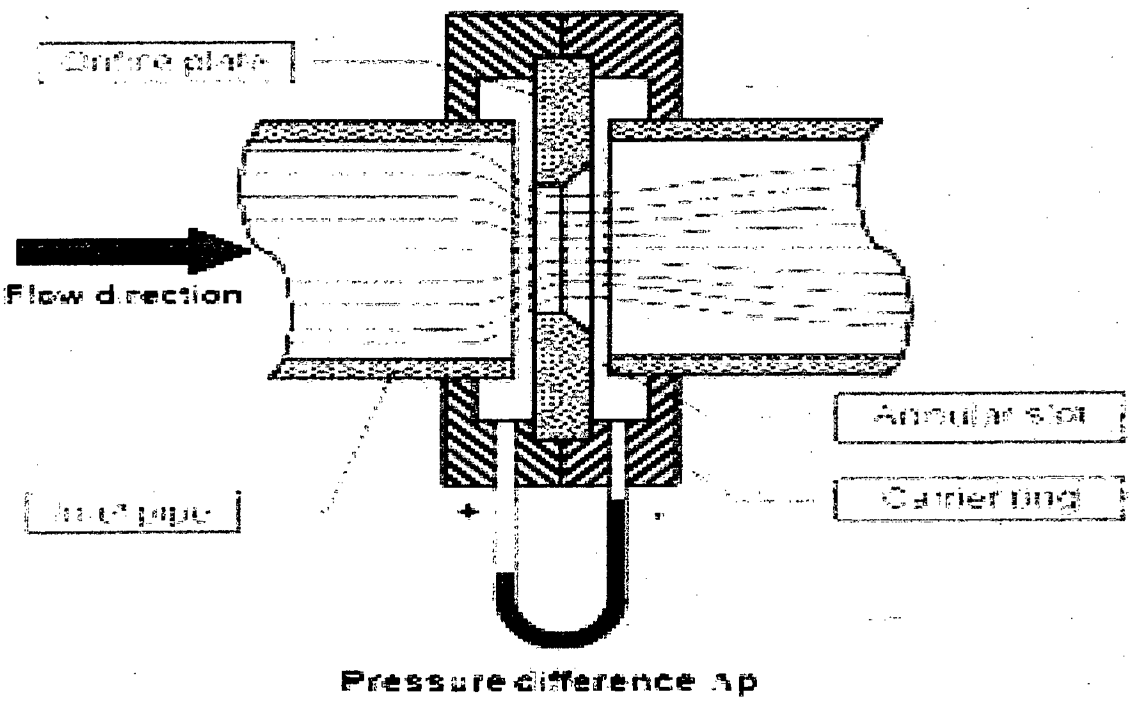


Fig. 3.6.1 Orifice meter

3.6.1 Working principle of orifice meter

An obstruction (orifice) is placed in a pipe filled with fluid. The pressure of the fluid is measured at two different points: 1) just upstream of the orifice and, 2) close to the contraction of the fluid (vena contracta). The difference in these two pressures is known as differential pressure. The differential pressure across an obstruction (orifice) in a pipe of fluid is proportional to the square of the velocity of the fluid [18].

Thus the velocity through an orifice meter:

$$u_o = \frac{C_o}{\sqrt{1-\beta^4}}\sqrt{\frac{2g_c(P_a-P_b)}{\rho}}$$

where,

Co - Orifice coefficient

β *- Ratio of CS areas of upstream to that of down stream*

Pa-Pb - Pressure gradient across the orifice meter

ρ *- Density of fluid*

3.6.2 Compressible Flow Through an Orifice:

The American Gas Association (AGA) provides a formula for calculating volumetric flow of any gas using orifice plates in their #3 Report, compensating for changes in gas pressure and temperature. A variation of that formula is shown here :

$$Q = N \frac{CYA_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \sqrt{\frac{Z_s P_1 (P_1 - P_2)}{G_f Z_{f1} T}}$$

Where,

Q = Volumetric flow rate (SCFM = standard cubic feet per minute)

N = Unit conversion factor

C = Discharge coefficient (accounts for energy losses, Reynolds number corrections, pressure tap locations, etc.)

A_1 = Cross-sectional area of mouth

A_2 = Cross-sectional area of throat

Z_s = Compressibility factor of gas under standard conditions

Z_{f1} = Compressibility factor of gas under flowing conditions, upstream

G_f = Specific gravity of gas (density compared to ambient air)

T = Absolute temperature of gas

P_1 = Upstream pressure (absolute)

P_2 = Downstream pressure (absolute)

This equation implies the continuous measurement of gas pressure (P_1) and temperature (T) inside the pipe, in addition to the differential pressure produced by the orifice plate ($P_1 - P_2$). These measurements may be taken by three separate devices, their signals routed to a gas flow computer in Figure3.6.2.

Note the location of the RTD (thermowell), positioned downstream of the orifice plate so the turbulence it generates will have negligible impact on the fluid dynamics at the orifice plate. The American Gas Association (AGA) *allows for upstream placement of the thermowell, but only if located at least three feet upstream of a flow conditioner.*

In order to best control all the physical parameters necessary for good orifice metering accuracy, it is standard practice for custody transfer flowmeter installations to use honed meter runs rather than standard pipe and pipe fittings. A "honed run" is a complete piping assembly consisting of a manufactured fitting to hold the orifice plate and sufficient straight lengths of pipe upstream and downstream, the interior surfaces of that pipe machined ("honed") to have a glass-smooth surface with precise and symmetrical dimensions. Such piping "runs" are quite expensive, but necessary if flow measurement accuracy worthy of custody transfer is to be achieved.

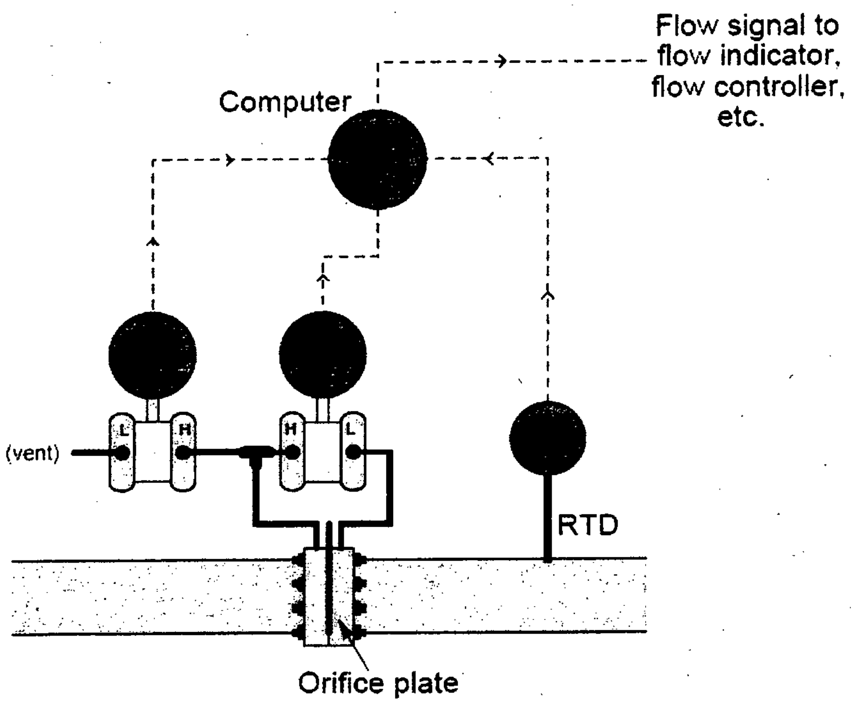


Fig. 3.6.2 Instrumentation of flow Measurement by Orifice meter.

An alternative to multiple instruments (differential pressure, absolute pressure, and temperature) installed on each meter run is to use a single multi-variable transmitter capable of measuring gas temperature as well as *both static and differential pressures in Figure 3.6.3. This approach enjoys the advantage of simpler installation over the multi-instrument approach:*

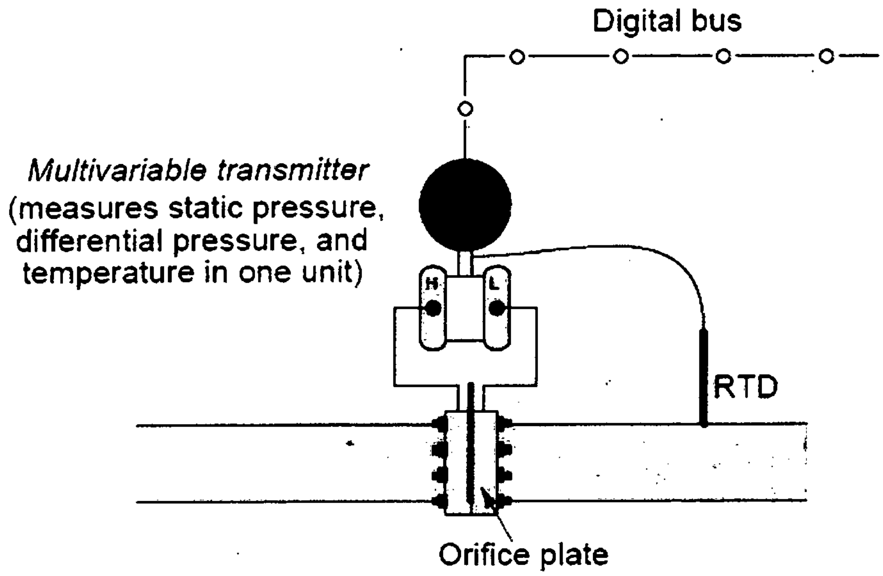


Fig. 3.6.3 An alternate Instrumentation of flow Measurement by Orifice meter.

The temperature-compensation RTD may be clearly seen on the photograph in Figure 3.6.4, installed at the elbow fitting in the copper pipe.

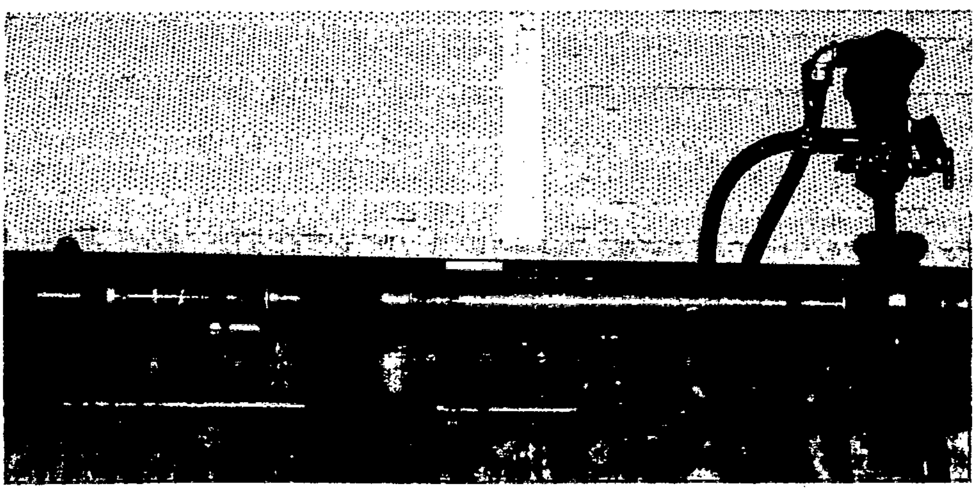


Fig. 3.6.4 Rosemount 3095 MV transmitter, Model EJX910

3.6.3 Incompressible Liquid Flow Through an Orifice:

Liquid flow measurement applications may also benefit from compensation, because liquid density changes with temperature. Static pressure is not a concern here, because liquids are considered incompressible for all practical purposes. Thus, the formula for compensated liquid flow measurement does not include any terms for static pressure, just differential pressure and temperature:

$$Q = N \frac{CYA_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \sqrt{(P_1 - P_2)[1 + k_T(T - T_{ref})]}$$

The constant k_T shown in the above equation is the proportionality factor for liquid expansion with increasing temperature. The difference in temperature between the measured condition (T) and the reference condition (T_{ref}) multiplied by this factor determines how much less dense the liquid is compared to its density at the reference temperature. It should be noted that some liquids – notably hydrocarbons – have thermal expansion factors significantly greater than water. This makes temperature compensation for hydrocarbon liquid flow measurement very important if the measurement principle is volumetric rather than mass-based.

3.6.4 Characteristics of Orificemeter

- *Recommended Service: Clean & Dirty Liquids, Some slurry services.*
- *Rangeability: 4 to 1*
- *Pressure Loss: Medium*
- *Accuracy: 2 to 4 of full scale.*
- *Straight Run Required: 2.5 times of pipe dia. Upstream*
- *Viscosity Effect: High*
- *Relative Cost: Low*

- *The head loss is about 70 – 75% of the Orifice differential.*
- *Connections: Flanged*
- *Type of Output: Linear*

3.6.5 Advantages of Orificemeter

a. Easy to install (between flanges)

b. Easy to change β(substituting plates)

c. Relatively inexpensive

d. The pressure loss is medium.

3.6.6 Limitations of Orificemeter:

a.The pressure recovery is limited for an Orifice plate and permanent pressure loss depends primarily on the area ratio.

b. High permanent pressure loss.

c. Susceptible to wear from particulates.

d. Can be damaged by pressure transients.

e. Formation of vena-contracta – Fluid stream separates from the downstream side of the Orifice plate and forms a free flowing jet in the downstream side.

3.7 Turbine flow meter

The turbine flow meter (better described as an axial turbine) translates the mechanical action of the turbine rotating in the liquid flow around an axis into a user-readable rate of flow (gpm, lpm, etc.). The turbine tends to have all the flow traveling around it.

The turbine wheel is set in the path of a fluid stream. The flowing fluid impinges on the turbine blades, imparting a force to the blade surface and setting the rotor in motion. When a steady rotation speed has been reached, the speed is proportional to fluid velocity.

Shaft rotation can be sensed mechanically or by detecting the movement of the blades. Blade movement is often detected magnetically, with each blade or embedded piece of metal generating a pulse. Turbine flowmeter sensors are typically located external to the flowing stream to avoid material of construction constraints that would result if wetted sensors were used. When the fluid moves faster, more pulses are generated. The transmitter processes the pulse signal to determine the flow of the fluid. Transmitters and sensing systems are available to sense flow in both the forward and reverse flow directions.

3.7.1 Working principle of Turbine flowmeter

Fluid entering the meter passes through the inlet flow straightener which reduces its turbulent flow pattern and improves the fluid's velocity profile. Fluid then passes through the turbine blades causing it to rotate at a speed proportional to the fluid velocity. As each blade passes through the magnetic field, created at the base of the pickoff transducer, AC voltage (pulse) is generated in the pick-up coil (see Figure 3.7.1). These impulses produce an output frequency proportional to the volumetric flow through the meter. The output frequency is used to represent flow rate and/or totalization of fluid passing through the turbine flow meter.

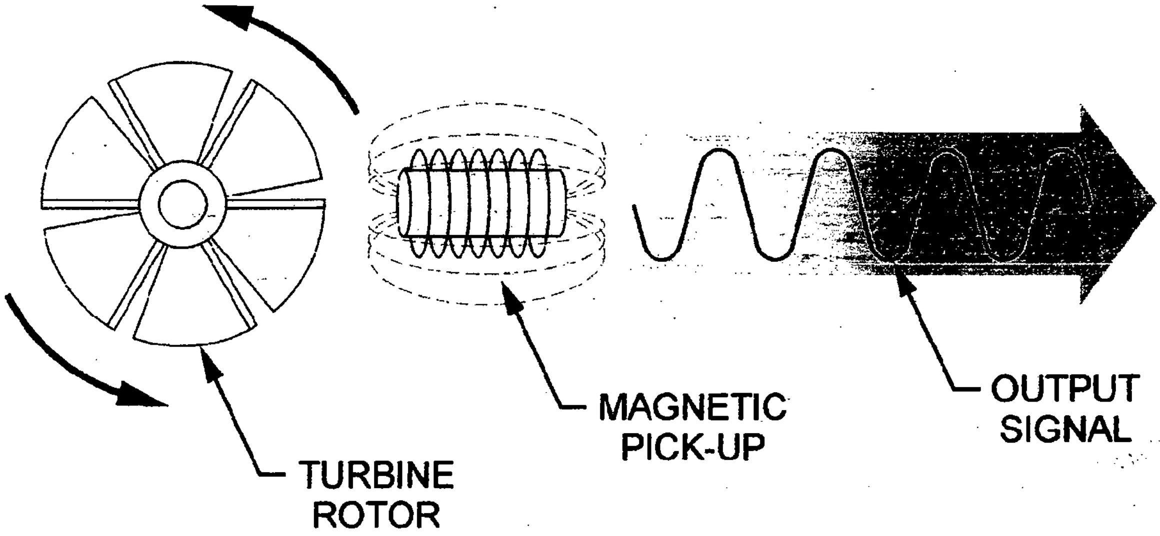


FIGURE 3.7.1 Schematic illustration of electric signal generated by rotor movement

3.7.2 Design Equation of Turbine meter for compressible fluid (NGL):

The Turbine meter is a velocity measuring device. Its depends upon the flow of fluid to cause the meter rotor to turn at a speed proportional to the flow rate. Rotor revolutions are counted mechanically or electrically, can be converted to a continuously totalized volumetric registration. Since the registered volume is at flowing pressure and temperature conditions, it must be corrected to the specified base conditions. The index of the turbine meter indicates volume at flowing conditions so this value must be corrected to the base conditions [19].

The basic gas law (compressible fluid) relationship is expressed as follows:

In Flowing Conditions

$P_f V_f = z_f NRT_f$

And In Base Conditions

$P_b V_b = z_b NRT_b$

The Yield of two equations is:

$$V_b = V_f\left(\frac{P_f}{P_b}\right)\left(\frac{T_b}{T_f}\right)\left(\frac{Z_b}{Z_f}\right)$$

The flow rate in flowing conditions:

$$Q_f = \frac{V_f}{t}$$

V_f= Volume timed at flowing conditions = Counter difference on mechanical drive output = Total pulse X $\frac{1}{K}$ X Meter factor on electrical pulse output

K= K factor pulses per cubic foot.

3.7.3 Characteristics of Turbinemeter

- *Recommended Service: Clean & Viscous Liquids, Clean Gases*
- *Rangeability: 20 to 1*
- *Pressure Loss: High*
- *Accuracy: 0.25%*
- *Straight Run Required: 5 to 10D Upstream*
- *Viscosity Effect: High*
- *Relative Cost: High*
- *Sizes: > ¼"*
- *Connections: Flanged*
- *Type of Output: Linear*

3.7.4 Advantages of Turbinemeter

1. Better Accuracy [± 0.25% to ± 0.5%].

2. It provides excellent repeatability [± 0.25% to ± 0.02%] and rangeability (10 : 1 and 20 : 1).

3. It has fairly low pressure drop.

4. It is easy to install and maintain.

5. It has good temperature and pressure ratings.

6. It can be compensated for viscosity variation.

7. Fast response timetypically a few milliseconds.

8. Wide range options for both liquids and gases.

9..Good flexibility with associated digital readout devices including flow control options for both PC and PLC's.

3.7.5 Limitations of Turbinemeter:

1. Require upstream straightener and filter for best results.

2. May over read in pulsating flows

3. Turbine flowmeters for liquid can require regular re-calibration due to bearing wear

4. Particulates can cause line blockage.

5. High cost.

6. It has limited use for slurry applications.

7. It is not suitable for non-lubricating fluids.

8. They cannot maintain its original calibration over a very long period and therefore periodical recalibration is necessary.

9. They are sensitive to changes in the viscosity of the liquid passing through the meters.

10. They are sensitive to flow disturbances.

11. Due to high bearing friction is possible in small meters, they are not preferred well for low flowrates.

3.8 Flow Meter Selection :

The selection of a flow meter for an industrial application is influenced by complex desired data.

Factors to be Considered

There are many factors which are to be considered before drawing up specifications for a flow meter. They are :

1. *Measurement requirements*
2. *External conditions of the flow pipe*
3. *Internal conditions of the flow pipe*
4. *Properties of the flowing fluid*
5. *Installation and accessories and*
6. *Cost consideration.*

Let us examine the above six factors in detail.

3.8.1 Measurement Requirements

The requirements of measurement can be addressed based on.

(i) The measured variable like point velocity, average velocity or volume rate.

(ii) The range of operation. For wide range of operation, electromagnetic, ultrasonic, cross-correlation, turbine type etc. are suitable.

(iii) Cost computation. If it is for costing purpose, the meter should have low and consistent uncertainty in measurement.

(iv) Pressure head loss and maximum pressure of flowing fluid. For high pressure fluids the meter body and inner construction should be sturdy.

(v) Accuracy, Precision and facilities available for maintenance.

(vi) Speed of response. For fluctuating flow, response of the meter should be good with small time constants.

(vii) Calibration facilities and Installation.

3.8.2 External Conditions of the Flow Pipe

Before selection of a flow meter, it is important to examine the environment and the place where the meter is going to get installed. The following points need to be considered.

(i) Approachability. It is better to know that once the meter is installed whether it is accessible for removal, recalibration etc.

(ii) It is important to note that the installation of the meter either in an air conditioned space or in a place which is vulnerable for wide temperature variation.

(iii) Humidity condition, vibration, hostile environment and water facility are the important parameters to be considered.

3.8.3 Conditions Internal to the Flow Pipe

The conditions internal to the pipe affect the accuracy of measurement of flow meters.

Some of the factors that affect the accuracy are protrusions, pipe bore, size, roundness, toughness, hydrodynamic noise pulsations etc.

3.8.4 Properties of the Fluid

The properties of the fluid to be metered should be clearly understood by the person who is to select the meter. Many flow problems are due to the impurities present in the fluid, the effect of which cannot always be quantitatively established.

1. Viscosity. Viscosity of the flowing fluid is a critical factor. If the viscosity of the fluid changes, the Reynolds number changes, which in turn affect the calibration curve of the flow meter.

2. Fluid activity. The fluid to be metered may be radioactive or chemically reactive.

Radioactivity presents special problems. For metering the velocity of fluids having high levels of radiation, flow meters offering long periods of reliable operation without maintenance are required. If the fluid is corrosive, then Electromagnetic flow meter or Vortex flow meter can be used.

3. Flammability. Fluids which are inflammable or react violently with other materials need flow meters like turbine and vortex flow meter. They are suitable for operation in hazardous areas.

4. Scaling Deposits. Special care should be taken for fluids having a property to deposit scales since scaling can block pressure lines and ducts.

5. Other properties. The fluid properties like compressibility, abrasiveness,transparency, electrical conductivity, magnetic properties and lubricity should be noted before selection of flow meter is made.

3.8.5 Accessories

When a flow meter is chosen, the associated accessories should also be chosen which are compatible with the meter. All the precautions and points *considered for the meter should be considered for the accessories also. Some of the accessories for a flow meter are :*

1. Valves and manifolds for equalizing, draining, venting and isolation.

2. Sumps, gas vents, poles and drains.

3. Cooling chambers when measuring condensible vapours.

4. Straighteners for improving velocity profile.

5. Piezometer rings for averaging the flow velocity profile for orifice plates.

6. Separators to prevent contaminating fluids like water in oil from entering the flow meter.

7. Gas detectors to provide a warning if the flow meter is not running full.

3.8.6 Economic Factors

Any decision on the purchase or selection of flow meter will certainly take the economic factors into consideration. But that should not be given the top priority. When computing the cost of flow meters, the cost of accessories, transmitters etc. if needed, the maintenance cost for a period should also be taken into consideration.

3.8.7 List of Desirable Characteristics

A partial list of characteristics that are desirable in a flow meter selection is given below :

(i) A wide operating temperature range.

(ii) A wide dynamic range of measurement.

(iii) Insensitivity to flow profit, viscosity, and other physical properties of the fluid.

(iv) Non-corrodible and non-degradable materials of construction.

(v) Small irrecoverable head loss.

(vi) Suitability for liquids and gases.

(vii) Availability in all practical sizes.

(viii) Safety in all practical sizes.

(ix) Immunity to pulsating flow effects.

(x) Immunity to vibration.

(xi) Fast response to flow changes.

(xii) Accuracy.

(xiii) Calibration.

(xiv) Low cost to purchase and maintain.

Of course, no flow meter is available which meets all these requirements and it is unlikely that one will ever be developed.

The highest possible accuracy of various flowmeters are shown in Table 3.1.

Table 3.1 Highest Possible Accuracy

1	***ORIFICE***	**±**	***2.0%***
2	***VENTURI***	**±**	***1.0%***
3	***NOZZLE***	**±**	***1.5%***
4	***PITOT***	**±**	***0.5%***
5	***EM***	**±**	***0.5%***
6	***UF***	**±**	***1.0%***
7	***CC***	**±**	***0.5%***
8	***VS***	**±**	***1.0%***
9	***ROTAMETER***	**±**	***2.0%***
10	***HOTWIRE***	**±**	***2.0%***
11	***GILFLOW***	**±**	***1.0%***
12	***NMR***	**±**	***0.5%***
13	***LDU***	**±**	***0.05%***
14	***PD***	**±**	***0.1%***
15	***TURBINE***	**±**	***2.0%***
16	***MASSFLOW***	**±**	***1.0%***

In Summary, Table 3.2 gives the guidelines for flow meter selection and Table 3.3 gives the application details of various flow meters.

Table 3.2 Guide to Flow Meter Selection

Property	*Rotameter*	*Orifice*	*Turbine*	*EM Flow Meter*
Service	*Liquid and Gases*	*Liquid and Gases*	*Liquid and Gases*	*Electrically Conducting Liquid and Slurries*
Liquid Flow limits	*0.01 cc/m* *16000 l/m*	*0.1 cm/m* *Large*	*0.001 cc/m* *160000 l/m*	*0.01 cc/m* *2000000 l/m*
Gases at air Equivalent at STP	*0.3 cc/m* *40,000 l/m*	*50 cc/m* *onwards*	*Up to* *50,00000 l/m*	
Scale or Signal Charac.	*Linear or Log*	*Square* *root*	*Linear for Reynolds no. 100000*	*linear*
Range	*5:1 to 12:1*	*4:1*	*10:1 to 15:1*	*10:1*
Range with span adjusted	*12:1 float to be changed*	*12:1*	*15:1 and more*	*100:1*
Accuracy	*+ 2% FS* *If calibrated*	*+ 1% FS* *uncalibrated*	*+ 0.25% of reading*	*+ 0.5% of reading*
Transmitter Types	*Visual or Analog Pneumatic*	*Analog Pneumatic or Elec.*	*Analog* *Elec.* *Digital*	*Analog* *Elec.* *Digital*
Maximum *Overall* *Press. loss*	*1– 10 m* *Of H_2O*	*3– 60 m* *Of H_2O*	*10– 40 m* *Of H_2O*	*Negligible*
Viscosity	*Good* *Immunity*	*Fairly Good* *Immunity*	*Fairly Good* *Immunity*	*No effect*

Table 3.3 Flow Meter Application

S.No. FlowMeterTypes Applications	Water	Solids in Liquid	High Press. Gases	Low Press. Gases	Larger Meter Pipes	Large Air Ducts	Low water Flow	Low Gas Flow	Hot Liquids	Hot Gases	Gyogenic Fluids	High Viscous	Low Viscous
1. Venturi	√		√	√	√				√				√
2. Orifice	√	√	√	√					√	√		√	√
3. Nozzle	√		√	√					√	√			
4. Target		√		√					√	√			
5. Rotameter	√		√				√	√	√	√			√
6. Spring Loaded lower Rotameter	√		√				√		√			√	√
7. Turbine	√		√										√
8. Bypass Rotameter	√		√						√	√			√
9. EM	√	√			√		√		√			√	
10. UF	√	√			√								√
11. VS	√		√								√		√
12. Fluidic							√						√
13. Swirl			√										
14. NMR		√										√	√
15. Mass							√		√		√	√	√
16. Hot Wire			√	√		√		√					
17. Insertion	√		√	√	√	√				√			
18. CC		√								√			√
19. PD				√	√						√	√	√

3.9 Effect of Flow Conditioning

The effect of flow conditioning in Pipe flow for various popular meters which is used in gas measurement is explained below.

3.9.1 Pipe flow conditions

The most important as well as most difficult to measure aspects of flow measurement are flow conditions within a pipe upstream of a meter. Flow conditions mainly refer to the gas velocity profile, irregularities in the profile, varying turbulence levels within the velocity or turbulence intensity profile, swirl and any other fluid flow characteristics which will cause the meter to register flow different than that expected [20].

3.9.2 Effects of flow conditioning on Orifice meter

The basic orifice mass flow equation is given as provided by API 14.3 1990 and ISO 5167,

$$q_m = (C_d)(E_v)(Y)\left[\frac{\pi}{4}\right](d)^2\sqrt{2\rho\Delta P}$$

Where, q_m*= Mass flow*
C_d*= Coefficient of discharge*
E_v*= Velocity of approach factor*
Y = Expansion factor
d = orifice diameter
ρ*= density of the fluid*
ΔP*= differential pressure*

Now to use the above equation, the flow field entering the orifice plate must be free of swirl and exhibit a fully developed flow profile. ISO standards determined the Coefficient of Discharge by completing numerous calibration tests where the indicated mass flow was compared to the actual mass flow to determine coefficient of discharge. In all testing the common requirement was a fully developed flow profile entering the orifice plate. Accurate standard compliant meter designs must therefore ensure that a swirl free, fully developed flow profile is impinging on the orifice plate.

There are numerous methods available to accomplish this. These methods are commonly known as "flow conditioning". The first installation option is to revert to no flow conditioning, but adequate pipe lengths must be provided by the equation mentioned above. This generally makes the manufacturing costs for a flow measurement facility unrealistic due to excessively long meter tubes; Imagine meter tubes 75 diameters long.

The second and most well known option is the 19-tube tube-bundle flow conditioner.

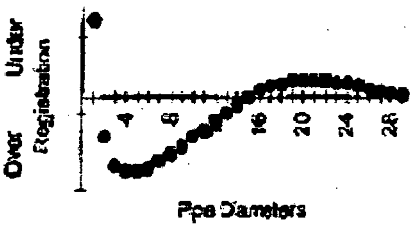


Figure 3.10.1 showing Conventional tube bundle performance

The general indications are that the conventional tube bundle will cause the orifice installation to over register flow values up to 1.5% when the tube bundle is 1 pipe diameter to approximately 11 pipe diameters from the orifice plate. This is caused by a flat velocity profile that creates higher differential pressures than with a fully developed profile. There is a crossover region from approximately 10 to 15 pipe diameters where the error band is approximately zero. Then a slight under-registration of flows occurs for distances between approximately 15 to 25 pipe diameters. This is due to a peaked velocity profile that creates lower differential pressures than a fully developed profile. At distances greater than 25 pipe diameters the error asymptotes to zero. Figure 3.10.2 showing the Conventional Tube Bundle Performance explaining typical characteristic behavior of the popular 19 tube, tube-bundle. An additional drawback of the conventional 19 tube, tube bundle is variation in sizing.

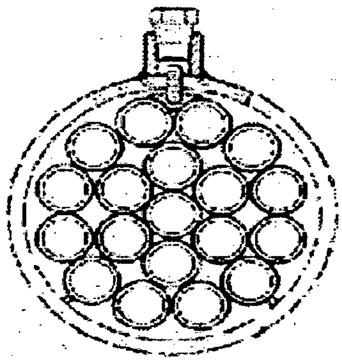


Figure 3.10.2 showing the 19-tube bundle

The conventional tube bundle provides errors very much dependent on installation details, that is, the elbows on and out of plane, tees, valves and distances from the last pipe installation to the conditioner and conditioner to the orifice plate. These errors have a great significance. Therefore the latest findings regarding conventional tube bundle performance should be reviewed prior to meter station design and installation. The final installation option for orifice metering is perforated plate flow conditioners. There is a variety of perforated plates have entered the market. These devices generally are designed to rectify the drawbacks of the conventional tube bundle (accuracy and repeatability insufficiency). The reader is cautioned to review the performance of the chosen perforated plate carefully prior to installation. A flow conditioner performance test guideline should be utilized to determine performance. The key elements of a flow conditioner test are -

1. *Perform a baseline calibration test with an upstream length of 70 to 100 pipe diameters of straight meter tube. The baseline Coefficient of Discharge values should be within the 95% confidence interval for the RG orifice equation .Select values of upstream meter tube length, and flow conditioner location, to be used for the performance evaluation. Install the flow conditioner at the desired location. First, perform a test for either the two 90° elbows out-of-plane installation, or the high swirl installation for β = 0.40 and for β = 0.67. This test will show*

whether the flow conditioner removes swirl from the disturbed flow. If the ΔC_d is within the acceptable region for both values of β i.e. 0.40 and 0.67, and if the C_d results vary as $\beta^{3.5}$, then the conditioner is successful in removing swirl. The tests for the other three installations namely, good flow conditions, partly closed valve and highly disturbed flow) may be performed for $\beta = 0.67$. Otherwise, the tests should be performed for a range of p ratios between 0.20 and 0.75.

2. Perform test and determine the flow conditioner performance for the flow conditioner installed in good flow conditions, downstream of a half closed valve, and for either the double 90° elbow out-of-plane or the high swirl installation.

3.9.3 Effects of flow conditioning on turbine meter

The turbine meter is available in various manufacturer's configurations of a common theme; turbine blades and rotor configured devices. These devices are designed such that when a gas stream passes through them they will spin proportionally to the amount of gas passing over the blades in a repeatable fashion. Accuracy is then ensured by completion of a calibration, indicating the relationship between rotational speed and volume, at various Reynolds Numbers. The fundamental difference between the orifice meter and the turbine meter is the flow equation derivation. The orifice meter flow calculation is based on fluid flow fundamentals (a 1st Law of Thermodynamics derivation utilizing the pipe diameter and vena contracta diameters for the continuity equation). Deviations from theoretical expectation can be assumed under the Coefficient of Discharge. Thus, one can manufacture an orifice meter of known uncertainty with only the measurement standard in hand and access to a machine shop. The need for flow conditioning, and hence, a fully developed velocity flow profile is driven from the original determination of C_d which utilized fully developed or 'reference profiles' as explained above.

Conversely, the turbine meter operation is not rooted deeply in fundamentals of thermodynamics. This is not to say that the turbine meter is in any way an inferior device. There are sound engineering principles providing theoretical background. It is essentially an extremely repeatable device that is then assured accuracy via calibration. The calibration provides the accuracy. It is carried out in good flow conditions (flow conditions free of swirl and a uniform velocity flow profile) this is carried out for every meter manufactured. Deviations from the as-calibrated conditions would be considered installation effects, and the sensitivity of the turbine meter to these installation effects is of interest. The need for flow conditioning is driven from the sensitivity of the meter to deviations from as calibrated conditions of swirl and velocity profile. Generally, recent research indicates that turbine meters are sensitive to swirl but not to the shape of the velocity profile. A uniform velocity profile is recommended, but no strict requirements for fully developed flow profiles are indicated. Also, no significant errors are evident when installing single or dual rotor turbine meters downstream of two elbows out-of-plane without flow conditioning devices.

Chapter 4

RESULT ANALYSIS AND SUMMARIZATION

4.1 Introduction

Kailashtilla Fractionation Plant-1 , RPGCL had been receiving NGL as raw material from MSTE, SGFL and produced Liquefied Petroleum Gas and Motor Spirit by distillation. There were two different meters one was Orifice meter in MSTE and the other was Turbine meter in KTL fractionation plant of NGL transportation line during April 2003 and June 2007 (Table 4.1.The deviation of two meter readings in monthly (Table 4.2) and yearly basis (Table 4.3) are presented here. Mass balance on Kailastilla fractionation plant-1 (Table 4.4) was also calculated. Through these calculations analysis was done NGL flow measurement readings in different flowmeters i.e. Turbine and Orifice meter and compared the deviation with accuracy of two meters. The process loss between product and feed quantities in Kailashtilla fractionation plant-1 has been calculated in Mass Balance. Two summarizations have been presented on different readings shown by Turbine and Orifice meter in NGL transportation line from MSTE to KTL-1 fractionation plant and on deviation between product and feed quantities in fractionation plant- 1. Ranges of Flowmeters that had been using in NGL Transfer line between SGFL and RPGCL and KTL-1 Fractionation Plant is given in Table 4.1. All transfers occurred through these flowmeters were within the range of the particular meters.

Table 4.1. At a Glance of Flowmeters in NGL Transportation line and KTL -1 Fractionation Plant.

Flowmeter Type	Position & Purpose	Model No.	Range in m^3 /hr.
Orifice Meter	MSTE, SGFL NGL custody meter (From April 2003 to continue)	FC 920	0.2 - 11
Turbine Meter	KTL – 1, RPGCL NGL custody meter (From July 2000 to April 2003)	F/1/60	1.6 - 16
Turbine Meter	KTL – 1, RPGCL LPG Product Flow measurement meter (From July 2000 to continue)	F/2/250	6.85 -68.77
Turbine Meter	KTL – 1, RPGCL MS Product Flow measurement meter (From July 2000 to continue)	F/.75/30	.797 – 8.7

4.2 Analysis of NGL Flow measurement Readings:

Sample Calculation:

Example for month May,2003 :

Table 4.2:

The log sheet reading of NGL on May-01,2003 in RPGCL is = 42142499 kgs.

The log sheet reading of NGL on June-01,2003 in RPGCL is = 43918794 kgs.

Thus the consumption of NGL according to Turbine Meter reading for month May,03 is = 43918794 – 42142499 = 1776295 kgs.

Average density of NGL = 0.6114 kg / ltr.

So the consumption of NGL according to Turbine Meter reading for month May,03 is = 1776295/0.6114 = 2905291 liters.

The consumption of NGL according to Orifice Meter reading for month May,03 (SGFL log sheet) is = 2900000 ltr.

The differential between this two meter readings is = 2905291 – 2900000 = 5291 ltrs.

The difference between the two meter readings in percentage is = (5291 × 100) / 2905291 = 0.18.

Table: 4.2 Summarizes the calculated results for determining the difference between Turbine and Orifice meter accuracy in percentage from April'03 to June'07 where the minimum value is 0.01% in Feb.'05, in this duration Turbine meter reading was 2381129 Ltr. and Orifice meter reading was 2381000 ltr. And the maximum value is 5.65% for Feb.' 04, in this duration Turbine meter reading was 2136668 ltr and Orifice meter reading was 2016000 ltr. In full duration from April'03 to June' 07 the difference of accuracy between Turbine and Orifice meter is 1.32%, that is within in limit of fractionation process.

4.3 Analysis of NGL Flow measurement Readings in yearly:

Table 4.3 Summarizes the calculated results for determining the difference between Turbine and Orifice meter readings on yearly basis.

Table. 4.2 Analysis of NGL Flow measurement Readings.

Month	Date	NGL					Percentage
	RPGCL (Turbine Meter)			SGFL (Orifice meter)			
		Logsheet Reading	QTY in Kg	Tubine meter Reading Ltr	Orifice meter Reading Ltr	Deviation	
Apr-03	1/5/2003	42142499					
May-03	1/6/2003	43918794	1776295	2905291	2900000	5291	0.18
Jun-03	1/7/2003	45604862	1686068	2757717	2680000	77717	2.82
Jul-03	1/8/2003	47353054	1748192	2859326	2768000	91326	3.19
Aug-03	1/9/2003	49062140	1709086	2795365	2643000	152365	5.45
Sep-03	1/10/2003	50734006	1671866	2734488	2666000	68488	2.50
Oct-03	1/11/2003	52241354	1507348	2465404	2381000	84404	3.42
Nov-03	1/12/2003	53531247	1289893	2109737	2099000	10737	0.51
Dec-03	1/1/2004	54756746	1225499	2004414	2001000	3414	0.17
Jan-04	1/2/2004	56148389	1391643	2276158	2213000	63158	2.77
Feb-04	1/3/2004	57454748	1306359	2136668	2016000	120668	5.65
Mar-04	1/4/2004	58817863	1363115	2229498	2220000	9498	0.43
Apr-04	1/5/2004	60240678	1422815	2327143	2235000	92143	3.96
May-04	1/6/2004	61558738	1318060	2155806	2132000	23806	1.10
Jun-04	1/7/2004	63161299	1602561	2621133	2595000	26133	1.00
Jul-04	1/8/2004	64518128	1356829	2219217	2223380	-4163	-0.19
Aug-04	1/9/2004	65833210	1315082	2150936	2150936	0	0.00
Sep-04	1/10/2004	66984750	1151540	1883448	1883447	1	0.00
Oct-04	1/11/2004	68296901	1312151	2146142	2184000	-37858	-1.76
Nov-04	1/12/2004	69506791	1209890	1978885	1958000	20885	1.06
Dec-04	1/1/2005	71205740	1698949	2778785	2752000	26785	0.96
Jan-05	1/2/2005	72891096	1685356	2756552	2746000	10552	0.38
Feb-05	1/3/2005	74346918	1455822	2381129	2381000	129	0.01
Mar-05	1/4/2005	75626056	1279138	2092146	2067000	25146	1.20
Apr-05	1/5/2005	76866981	1240925	2029645	2016000	13645	0.67
May-05	1/6/2005	78482880	1615899	2642949	2611000	31949	1.21
Jun-05	1/7/2005	80037897	1555017	2543371	2510000	33371	1.31
Jul-05	1/8/2005	81647611	1609714	2632833	2599000	33833	1.29
Aug-05	1/9/2005	83240241	1592630	2604890	2572000	32890	1.26
Sep-05	1/10/2005	84794834	1554593	2542677	2516000	26677	1.05
Oct-05	1/11/2005	86362161	1567327	2563505	2527000	36505	1.42
Nov-05	1/12/2005	87734731	1372570	2244962	2237000	7962	0.35
Dec-05	1/1/2006	89210570	1475839	2413868	2418000	-4132	-0.17
Jan-06	1/2/2006	90555366	1344796	2199535	2189000	10535	0.48
Feb-06	1/3/2006	91535993	980627	1603904	1600000	3904	0.24
Mar-06	1/4/2006	93236989	1700996	2782133	2775000	7133	0.26
Apr-06	1/5/2006	94746408	1509419	2468791	2458000	10791	0.44
May-06	1/6/2006	96266403	1519995	2486089	2445000	41089	1.65
Jun-06	1/7/2006	97797141	1530738	2503660	2463000	40660	1.62
Jul-06	1/8/2006	99233108	1435967	2348654	2294000	54654	2.33
Aug-06	1/9/2006	100730021	1496913	2448337	2402000	46337	1.89
Sep-06	1/10/2006	102033537	1303516	2132018	2098000	34018	1.60
Oct-06	1/11/2006	102652366	618829	1012151	981000	31151	3.08

Table. 4.2 Analysis of NGL Flow measurement Readings.

Month	Date	NGL					Percentage
	RPGCL (Turbine Meter)			SGFL (Orifice meter)			
		Logsheet Reading	QTY in Kg	Tubine meter Reading Ltr	Orifice meter Reading Ltr	Deviation	
Apr-03	1/5/2003	42142499					
Nov-06	1/12/2006	104406377	1754011	2868844	2837000	31844	1.11
Dec-06	1/1/2007	105824506	1418129	2319478	2325000	-5522	-0.24
Jan-07	1/2/2007	107140508	1316002	2152440	2081000	71440	3.32
Feb-07	1/3/2007	108561001	1420493	2323345	2288000	35345	1.52
Mar-07	1/4/2007	110080869	1519868	2485882	2433000	52882	2.13
Apr-07	1/5/2007	111486914	1406045	2299714	2238000	61714	2.68
May-07	1/6/2007	113013024	1526110	2496091	2537000	-40909	-1.64
Jun-07	1/7/2007	114564201	1551177	2537090	2547000	-9910	-0.39
Total			72421702	118452244	116891763	1560481	1.32

Table 4.3 Analysis of NGL Flow measurement Readings in Yearly.

Financial Year	NGL						Deviation in Percentage
	RPGCL (Turbine Meter)			SGFL (Orifice meter)			
	Date	Logsheet Reading	QTY in Kg	Tubine meter Reading Ltr	Orifice meter Reading Ltr	Deviation	
	1/5/2003	42142499					
2002-2003	1/5/2003	42142499	3462363	5663008	5580000	83008	1.47
2003-2004	1/7/2003	45604862	17556437	28715141	28054000	661141	2.30
2004-2005	1/7/2004	63161299	16876598	27603202	27567763	35439	0.13
2005-2006	1/7/2005	80037897	17759244	29046850	28846000	200850	0.69
2006-2007	1/7/2006	97797141	16767060	27424043	26977000	447043	1.63
	1/7/2007	114564201					
Total			68959339	112789236	111444763	1344473	1.19

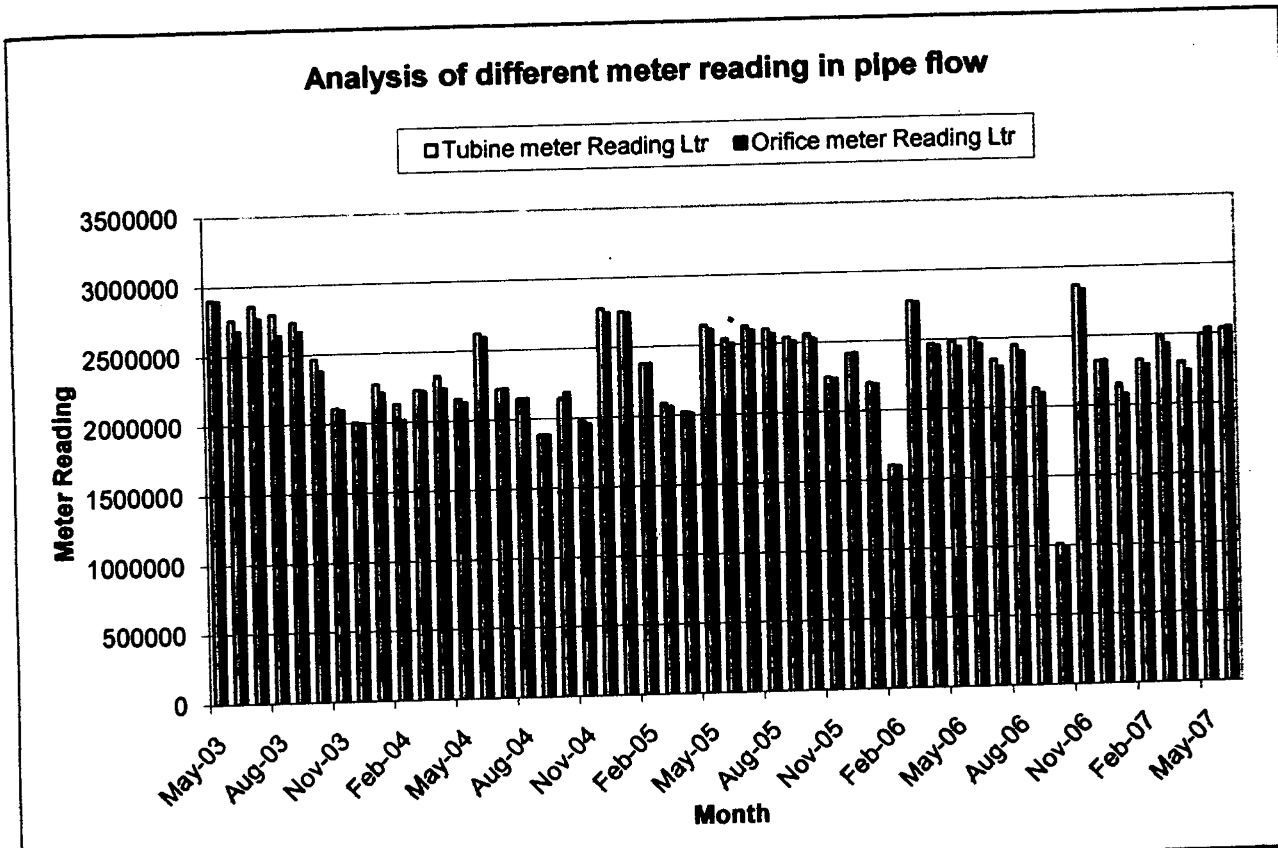
Figure 4.1 column and line graph have been formed by monthly reading of Orifice and Turbine meter. Orifice meter reading was in volume i.e. cubic meter and Turbine meter same reading was in mass i.e. kilogram. Orifice meter capable of measuring Natural Gas Liquids, NGL temperature as well as both static and differential pressure. Then calculate the flow rate by given equation.

$$Q = N\frac{CYA_2}{\sqrt{1-\left(\frac{A_2}{A_1}\right)^2}}\sqrt{\frac{Z_s P_1(P_1 - P_2)}{G_f Z_{f1} T}}$$

Turbine meter capable of measuring NGL density in every pulse and total number of pulses during transferring period. Then Calculate mass as given equation.

Mass = Number of Pulses x Volume / Pulse x Density.

Figure 4.2 column and line graph have been formed by yearly reading of Orifice and Turbine meter. In both figures calculation have been made by assuming average density of NGL. Average density was used to calculate the volume of NGL was not same the actual density read by Turbine meter in every pulse. So In presentation, Figure 4.1, monthly readings have shown greater discrepancy than that in presentation in Figure 4.2 formed by yearly readings. The presentation in Figure 4.2 is more accurate than that is in Figure 4.1. The maximum difference of 2.3 % was found in financial year 2003 – 2004 and minimum difference of 0.13 % in financial year 2004-2005 but the Orifice meter had been faulty from July, 2004 to October, 2004 (table 4.2). In this period billing was made on Turbine meter readings and except this time all other billing was done on Orifice meter reading.



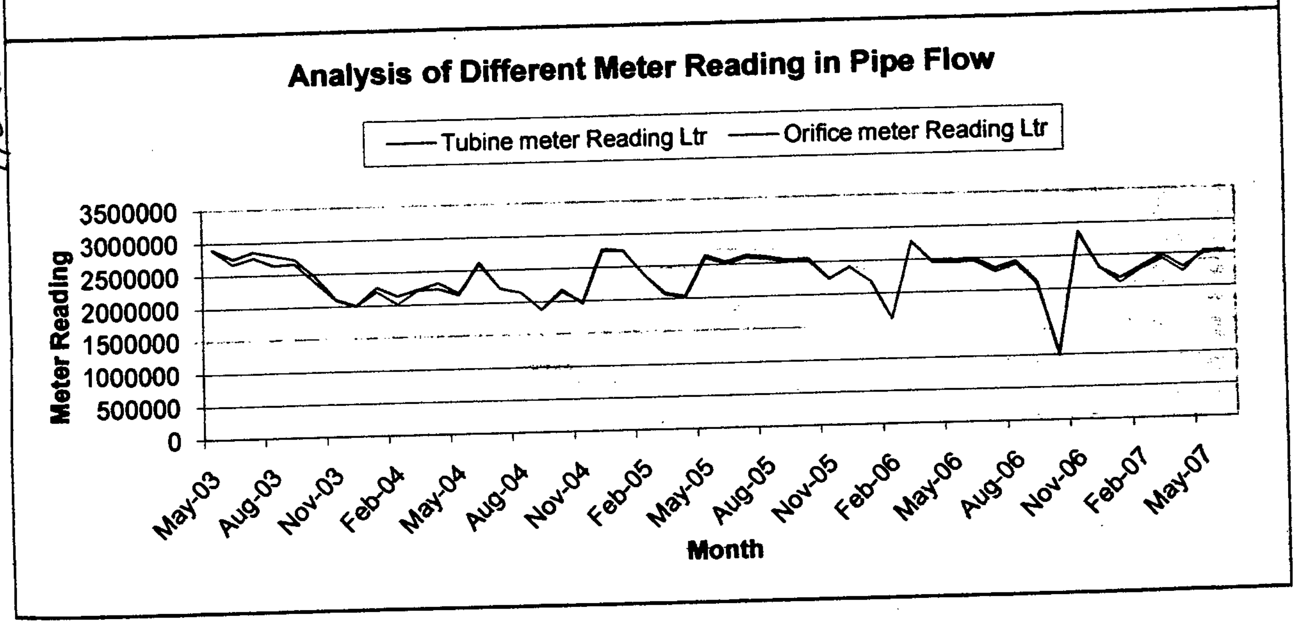
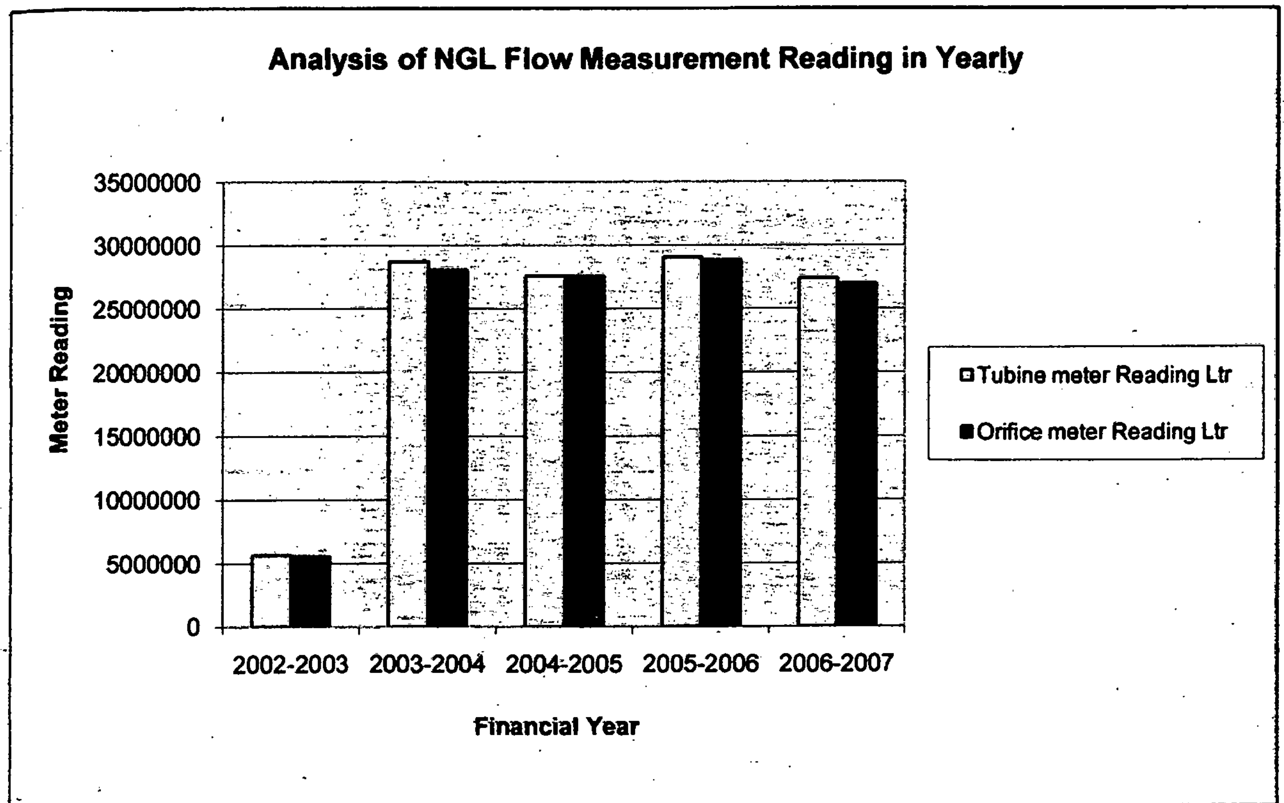


Fig: 4.1. Flow Measurement Reading Analysis of NGL by different meter in same Pipeline.



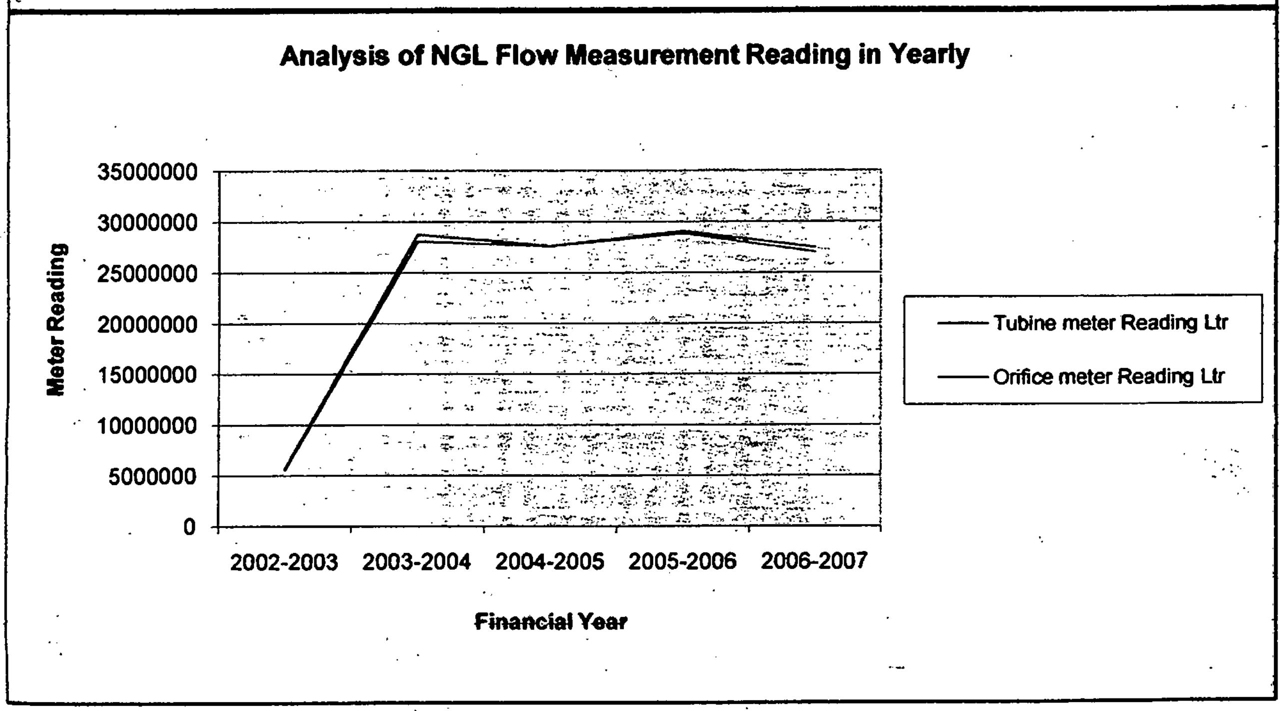


Fig.4.2. Flow Measurement Reading Analysis of NGL in different meter yearly.

Accuracy of Orifice meter is 2 – 4% and Turbine meter is upto 0.5%. So the maximum differential between two meters will be 4.5% in same fluid flow line. In Figure 4.2 differences are 1.47%, 2.30%, 0.13%, 0.69% and 1.63% in financial year from 2002 to 2007. All values are within the accuracy of two meters.

4.4 Mass Balance in KTL-1 Fractionation Plant:

Sample Calculation:

Table 4.4:

Quantity of Feed (NGL) that was fractionate for the month of July,2003 is = 47353054 – 45604862 = 1748192 kgs.

Quantity of LPG that was produced through fractionate for the month of July,2003 is = 763592 kgs.

Quantity of MS that was produced through fractionate for the month of July,2003 is = 40142845 – 39177242 = 965603 kgs.

Quantity of Products that were produced through fractionate for the month of July,2003 is = 763592 + 965603 = 1729195 kgs.

The process loss is = 1748192 – 1729195 = 18997 kgs.

The process loss in percentage = (18997 x 100)/1748192 = 1.09.

Table 4.4 is the picture of Mass Balance of LPG fractionation plant from April'03 to June, 2007. In this project from April'03 to June'07 , where the maximum positive value (i.e . Product > Feed) is 6.97 for Dec'03 due to malfunction of Turbine meter in MS flow line from Nov'03 to Apr'04.During this time mass balance calculations have been taken from marketing reports and MS storage tank readings .The reason is marketing quantities were not same to that in production. But if we calculate in duration from Sep'03 to May'04 the process loss is 0.66%, which is within limit of fractionation. From Table4.4 we find process loss from July'00 to June'07 as 1.99% that is acceptable in fractionation process.

Table 4.5 is the picture of Mass Balance of KTL-1 fractionation plant in financial year from 2002 to 2007.

Table 4.4 Mass Balance in KTL-1 Fractionation Plant

Month	Date	NGL RPGCL (Turbine Meter) Logsheet Reading	NGL QTY in Kg	LPG Prpduction by RPGCL Logsheet Reading	LPG QTY in Kg	MS Prpduction by RPGCL Logsheet Reading	MS QTY in Kg	Feed QTY in Kg	Product QTY in Kg	Differential in Percentage
Apr-03	1/5/2003	42142499	1633174		698777	37325252	898078	1633174	1596855	-2.22
May-03	1/6/2003	43918794	1776295		750144	38285105	959853	1776295	1709997	-3.73
Jun-03	1/7/2003	45604862	1686068		710980	39177242	892137	1686068	1603117	-4.92
Jul-03	1/8/2003	47353054	1748192		763592	40142845	965603	1748192	1729195	-1.09
Aug-03	1/9/2003	49062140	1709086		712438	41114512	971667	1709086	1684105	-1.46
Sep-03	1/10/2003	50734006	1671866		634416	42086416	971904	1671866	1606320	-3.92
Oct-03	1/11/2003	52241354	1507348		592237	42953124	866708	1507348	1458945	-3.21
Nov-03	1/12/2003	53531247	1289893		613197	43501378	656949	1289893	1270146	-1.53
Dec-03	1/1/2004	54756746	1225499		693650	43510634	617265	1225499	1310914.6	6.97
Jan-04	1/2/2004	56148389	1391643		660290	43510634	732570.02	1391643	1392860.02	0.09
Feb-04	1/3/2004	57454748	1306359		625990	43510634	696542	1306359	1322532.48	1.24
Mar-04	1/4/2004	58817863	1363115		650065	43510634	697084	1363115	1347149.32	-1.17
Apr-04	1/5/2004	60240678	1422815		661003	43645565	717383	1422815	1378385.54	-3.12
May-04	1/6/2004	61558738	1318060		637961	44327148	681583	1318060	1319544	0.11
Jun-04	1/7/2004	63161299	1602561		743161	45134235	807087	1602561	1550248	-3.26
Jul-04	1/8/2004	64518128	1356829		650890	45821239	687004	1356829	1337894	-1.40
Aug-04	1/9/2004	65833210	1315082		573726	46486200	664961	1315082	1238687	-5.81
Sep-04	1/10/2004	66984750	1151540		537985	47073431	587231	1151540	1125216	-2.29
Oct-04	1/11/2004	68296901	1312151		667571	47732696	659265	1312151	1326836	1.12
Nov-04	1/12/2004	69506791	1209890		566647	48376250	643554	1209890	1210201	0.03
Dec-04	1/1/2005	71205740	1698949		749377	49310380	934130	1698949	1683507	-0.91
Jan-05	1/2/2005	72891096	1685356		816373	50221545	911165	1685356	1727538	2.50
Feb-05	1/3/2005	74346918	1455822		694490	51006441	784896	1455822	1479386	1.62
Mar-05	1/4/2005	75626056	1279138		574114	51700440	693999	1279138	1268113	-0.86
Apr-05	1/5/2005	76866981	1240925		584400	52432648	732208	1240925	1316608	6.10
May-05	1/6/2005	78482880	1615899		708161	53203243	770595	1615899	1478756	-8.49
Jun-05	1/7/2005	80037897	1555017		732268	54004474	801231	1555017	1533499	-1.38
Jul-05	1/8/2005	81647611	1609714		698167	54843164	838690	1609714	1536857	-4.53
Aug-05	1/9/2005	83240241	1592630		753268	55701431	858267	1592630	1611535	1.19
Sep-05	1/10/2005	84794834	1554593		643446	56546699	845268	1554593	1488714	-4.24
Oct-05	1/11/2005	86362161	1567327		701566	57386146	839447	1567327	1541013	-1.68
Nov-05	1/12/2005	87734731	1372570		627296	58150790	764644	1372570	1391940	1.41
Dec-05	1/1/2006	89210570	1475839		640670	58971768	820978	1475839	1461648	-0.96
Jan-06	1/2/2006	90555366	1344796		597968	59814840	843072	1344796	1441040	7.16
Feb-06	1/3/2006	91535993	980627		388105	60431196	616356	980627	1004461	2.43
Mar-06	1/4/2006	93236989	1700996		775528	61279953	848757	1700996	1624285	-4.51
Apr-06	1/5/2006	94746408	1509419		684313	62070009	790056	1509419	1474369	-2.32
May-06	1/6/2006	96266403	1519995		645378	62859302	789293	1519995	1434671	-5.61
Jun-06	1/7/2006	97797141	1530738		693161	63680148	820846	1530738	1514007	-1.09
Jul-06	1/8/2006	99233108	1435967		579818	64459196	779048	1435967	1358866	-5.37

Table 4.4 Mass Balance in KTL-1 Fractionation Plant

Month	Date	NGL RPGCL (Turbine Meter) Logsheet Reading	NGL QTY in Kg	LPG Prpduction by RPGCL Logsheet Reading	LPG QTY in Kg	MS Prpduction by RPGCL Logsheet Reading	MS QTY in Kg	Feed QTY in Kg	Product QTY in Kg	Differential in Percentage
Aug-06	1/9/2006	100730021	1496913		595384	65352324	893128	1496913	1488512	-0.56
Sep-06	1/10/2006	102033537	1303516		437915	66212402	860078	1303516	1297993	-0.42
Oct-06	1/11/2006	102652366	618829		146558	66712945	500543	618829	647101	4.57
Nov-06	1/12/2006	104406377	1754011		583148	67778053	1065108	1754011	1648256	-6.03
Dec-06	1/1/2007	105824506	1418129		431491	68832276	1054223	1418129	1485714	4.77
Jan-07	1/2/2007	107140508	1316002		308515	69861817	1029541	1316002	1338056	1.68
Feb-07	1/3/2007	108561001	1420493		352599	70948769	1086952	1420493	1439551	1.34
Mar-07	1/4/2007	110080869	1519868		387880	72059173	1110404	1519868	1498284	-1.42
Apr-07	1/5/2007	111486914	1406045		321013	73114599	1055426	1406045	1376439	-2.11
May-07	1/6/2007	113013024	1526110		387999	74263713	1149114	1526110	1537113	0.72
Jun-07	1/7/2007	114564201	1551177		482598	75366265	1102552	1551177	1585150	2.19
						Total		124789077	122310632	-1.99

Table 4.4 Mass Balance LPG Fractionatin Plant.

a. In Feb. 01 Turbine Meter of NGL flow measurement was out of working for few days.

b. From Apr.03 Orifice meter has been lunched.

c. In Sep.01 LPG flow measurement meter reading exceeds capable number of measurement digits.

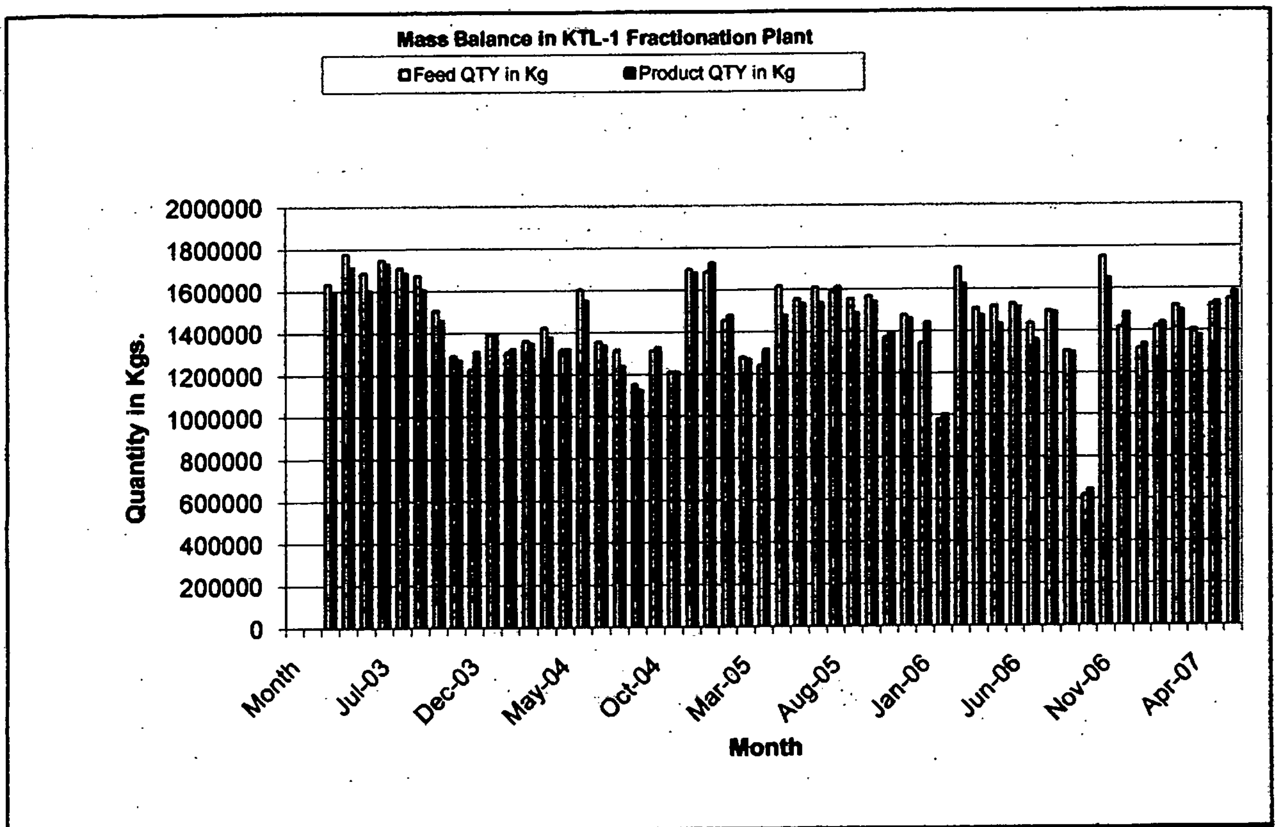
a.Turbine Meter of MS flow measurement had been out of working from Nov-03 to Apr.-04.

Table 4.5 Mass Balance of KTL-1 Fractionation Plant in Yearly

Financial Year	NGL consumption	LPG Produced	MS Produced	Quantity of Feed	Quantity of Product	Differential	Differential in %
2000 - 2001	16828836	5795065	10171449	16828836	15966514	862322	5.12
2001 - 2002	18493915	7956821	10061564	18493915	18018385	475530	2.57
2002 - 2003	20506987	8893905	11109667	20506987	20003572	503415	2.45
2003 - 2004	17556437	7988000	9382345	17556437	17370345	186092	1.06
2004 - 2005	16876598	7856002	8870239	16876598	16726241	150357	0.89
2005 - 2006	17759244	7848866	9675674	17759244	17524540	234704	1.32
2006 - 2007	16767060	5014918	11686117	16767060	16701035	66025	0.39
Total	124789077	51353577	70957055	124789077	122310632	2478445	1.99

Figure 4.3 has presented the difference between product and feed in monthly quantity and in Figure 4.4 has presented that of in yearly quantity. From October,2001 the Turbine meter in LPG flow line was phased out due to flow measurement meter reading exceeded highest number of measuring digits. From this time LPG readings in mass balance was taken from marketing quantities. During the faulty of turbine meter reading in MS product flow measurement line, the calculations have been taken from marketing reports and MS storage tank readings. In yearly readings the anomalous were averaged out and a more acceptable difference could be observed. So the deviation in Figure 4.4 is more reasonable than that is in Figure 4.3.

Figure 4.4 process losses are 2.45%, 1.06%, 0.89% 1.32% and 0.39% in financial year from 2002 to 2007. All values are acceptable for fractionation process.



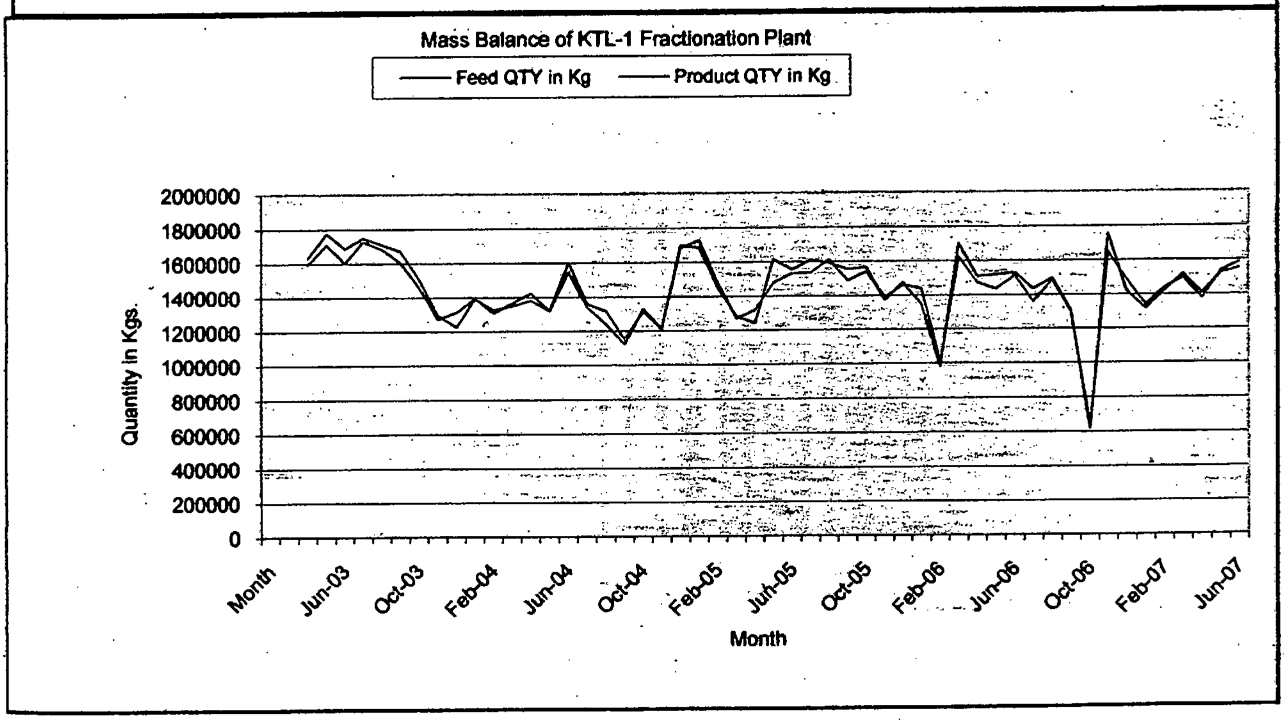
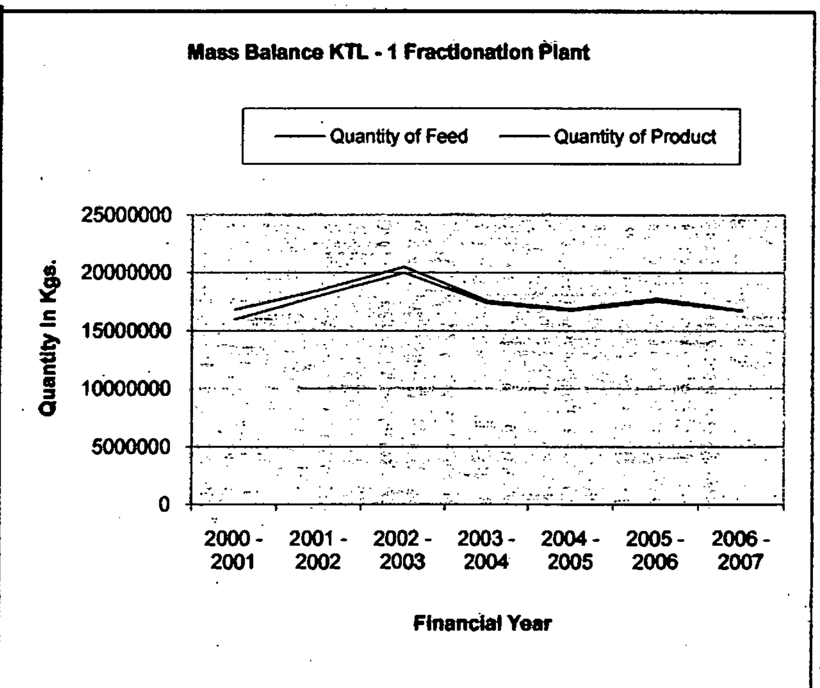


Fig. 4.3 Differential between feed and product in Mass Balance of KTL-1 Fractionation Plant.

Financial Year	Quantity of Feed	Quantity of Product
2000 - 2001	16828836	15966514
2001 - 2002	18493915	18018385
2002 - 2003	20506987	20003572
2003 - 2004	17556437	17370345
2004 - 2005	16876598	16726241
2005 - 2006	17759244	17524540
2006 - 2007	16767060	16701035
Total	124789077	122310632



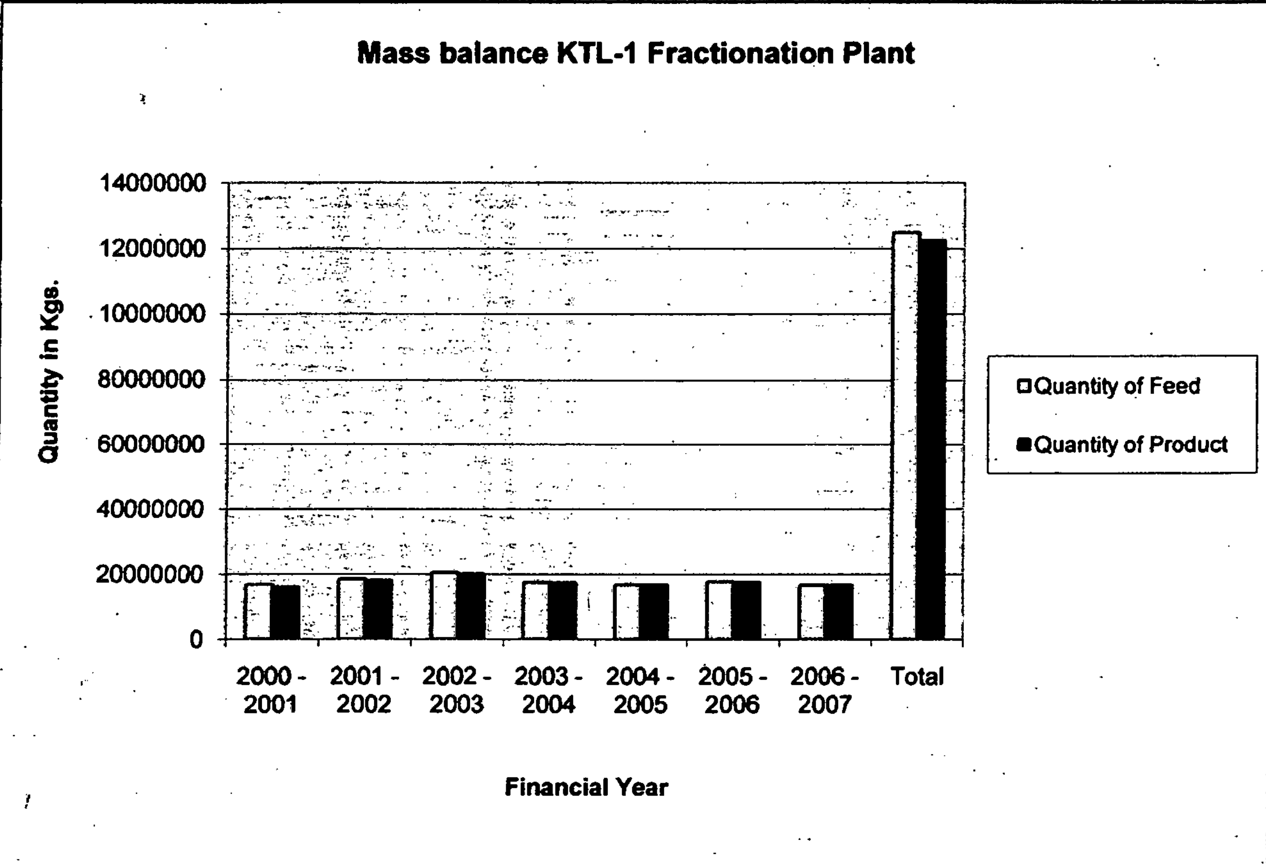


Fig. 4.4 Differential between feed and product in Mass Balance of KTL-1 Fractionation Plant in Yearly.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The accurate measurement of natural gas liquids and natural gas related fluids is difficult. It requires care, experience and insight to achieve consistently accurate measurements that meet stringent fiscal requirements. It is particularly difficult to measure Natural Gas Liquids that are exposed to: (1) a range of operating conditions, (2) dynamic flow and fluid property behavior, and (3) changing equipment conditions. The overall errors in flow measurement are due to uncertainties in flow equation, actual physical properties of the flowing fluid and dimensions of flow meter. The flow rate in orifice is calculated from a number of variables, the discharge coefficient, expansion factor, differential pressure, bore diameter, pipe diameter, fluid density and viscosity which are derived from temperature and pressure values of flowing fluid. Therefore actual fluid properties should be monitored with best possible precision.

Working principle and accuracy of Turbine and Orifice flowmeter have been studied and found that the difference of both meter readings in RPGCL and SGFL are matched with the difference of accuracy of both meters .

In Mass balance of the Feed quantity has been taken from NGL flow line Turbine meter reading and Products LPG and MS have taken from dip reading of marketing tank. So products quantities are realistic.

The Turbine meter in MS product flow measurement line from Nov'03 to Apr'04 had been out of work and In this period the maximum deviation *between product and feed was 6.97% for Dec'03. The reason is that marketed quantities were not same to that in production. But actual deviation between product and feed was 0.66% from Nov'03 to Apr'04. From this study it was found that the deviation between feed and product in mass balance during July'00 to June'07 is 1.99% that is within limit of fractionation process.*

5.2. Recommendations:

- *To do mass balance in fractionation unit and calculate the deviation between feed and product quantity regularly. And to compare this deviation with standard for fractionation process.*
- *To calibrate the flow meter on regular basis in limit.*
- *To check measurement uncertainty within limit regularly.*
- *In replacement of meter, vessel, pump and instrument, a greater care should be taken.*
- *To monitor fluid properties in flow line with best possible precision.*

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