A Report of Major Project on

PLANNING AND DESIGNING OF GAS DISTRIBUTION NETWORK

Submitted in Partial Fulfillment of the

B.Tech degree

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CERTIFICATE

This is to certify that project report on **"Planning and Designing of Gas Distribution Network"** submitted to **University of Petroleum & Energy Studies**, Dehradun by **Somya Pande** in partial fulfillment of the requirement of the award of degree of **Bachelor of Technology in Applied Petroleum Engineering**, session (2003-2007) is a bonafied work carried out by her under my supervision and guidance. This work has not been submitted anywhere else for any degree or diploma.

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EXECUTIVE SUMMARY

India today has a vast network of underground pipelines that is being used for transportation and distribution of natural gas. Big power plants, fertilizer plants and other industrial enterprises are the main consumers of natural gas as on today. However, with the increase in its popularity, it is now being used in the domestic sector as well as a fuel in the automotive sector in the metropolitan cities. To take gas to such end users who are located within the boundaries of a main city, there's a need to build up city gas distribution pipeline networks.

Depending upon the pressure, flow and economic criteria, these networks can either be constructed using steel pipelines, polyethylene (PE) pipes or a hybrid system of both PE and steel pipelines. Unlike cross-country pipelines which runs straight for kilometers through open fields, city gas distribution network are more complex in nature. These are laid in densely populated areas and there are a large number of branches in the network catering to the need of users in different localities within a city. Though, these are much smaller in length and size than cross-country pipelines, the network in a city is much more distributed and varied. Increased number of branches means more number of joints, bends, reducers, fittings etc. in the network apart from more number of delivery points for the supply of natural gas. Coupled with all these factors, the pipelines have to pass through the congested areas within the city criss-crossing the various other underground utilities. Due to various activities by other third party agencies within the city area, the risk of damages and accidents is all the more high as compared to cross-country pipelines. Further, the consumers to whom the gas is being supplied through the network are small scale industrial, commercial or domestic consumers whose gas requirements are quite low and many of them don't have well defined infrastructure facilities. All these factors call for greater in-built safety systems in the network and presents greater challenges to the operation and maintenance personnel who are responsible for monitoring and maintaining health of the system.

This report is divided in chapters giving various steps for planning, designing and construction of pipeline network.

Chapter 1 gives the fundamental of fluid mechanics and thermodynamics necessary in order to understand the flow of gas through pipeline.

Chapter 2 design and safety aspects of pipeline network gives, the basic requirements of planning and designing the network. Preliminary information required, route selection criteria, installation features are included. Steady state flow of gas explains various kinds of flow in pipe, friction factor, pipe roughness, maximum allowable pressure and velocity in pipeline. Common flow equations and Kirchoff's law are included in design fundamentals.

Chapter 3 Pipeline construction lists out various constructional activities and gives salient quality checks during construction.

Chapter 4 Operation and Maintenance gives the requirements each operating company having gas transmission or distribution facilities should have. It also summarizes pipeline maintenance, safety aspects related to pipeline and various regulation followed by oil and gas industries.

Chapter 5 Gas Transmission Economics gives insight of pipeline economics and gas transmission economics.

Chapter 6 Hypothetical calculations, two examples are taken, one each for medium and high pressure network. Medium pressure network refers to a mild steel pipeline in a colony and high pressure network refers to trunk pipeline conveying high load. In both the cases the loop less network is taken for sake of simplicity. In medium pressure network due to very minimal losses friction factor is ignored, while in case of high pressure network it is assumed to be 0.01.

At the end, conclusion explains the results drawn from the calculation and details us on the development of more complicated networks.

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INTRODUCTION

The Natural Gas is most benign fuel on 21st century and its use is increasing globally. The world over Natural Gas contributes 28% of the energy consumption. In India the use of gas is expected to increase from present 9% to 24% by 2020.

However, the spread of gas reserves is inequitably distributed in the world. Only 10 countries in the world own 80% of the Natural Gas reserves. Besides maximum gas using countries are not the ones which are either maximum gas reserves countries or maximum gas producing countries. Precisely this is the reason why gas transportation is required.

Production of natural gas, which was almost negligible at the time of independence, is at present at the level of around 87 million standard cubic meters per day (MMSCMD). The main producers of natural gas are Oil & Natural Gas Corporation Ltd. (ONGC), Oil India Limited (OIL) and JVs of Tapti, Panna-Mukta and Ravva. Under the Production Sharing Contracts, private parties from some of the fields are also producing gas. Government have also offered blocks under New Exploration Licensing Policy (NELP) to private and public sector companies with the right to market gas at market determined prices.

Out of the total production of around 87 MMSCMD, after internal consumption, extraction of LPG and unavoidable flaring, around 74 MMSCMD is available for sale to various consumers.

Most of the production of gas comes from the Western offshore area. The on-shore fields in Assam, Andhra Pradesh and Gujarat States are other major producers of gas. Smaller quantities of gas are also produced in Tripura, Tamil Nadu and Rajasthan States. OIL is operating in Assam and Rajasthan States, whereas ONGC is operating in the Western offshore fields and in other states. The gas produced by ONGC and a part of gas produced by the JV consortiums is marketed by the GAIL (India) Ltd. The gas produced by OIL is marketed by OIL itself except in Rajasthan where GAIL is marketing its gas.

Gas produced by Cairn Energy from Lakshmi fields and Gujarat State Petroleum Corporation Ltd. (GSPCL) from Hazira fields is being sold directly by them at market determined prices.

Natural gas has been utilised in Assam and Gujarat since the sixties. There was a major increase in the production & utilisation of natural gas in the late seventies with the development of the Bombay High fields and again in the late eighties when the South Bassein field in the Western Offshore was brought to production.

UTILISATION OF NATURAL GAS

The gas produced in the western offshore fields is brought to Uran in Maharashtra and partly in Gujarat. The gas brought to Uran is utilised in and around Mumbai. The gas brought to Hazira is sour gas which has to be sweetened by removing the sulphur present in the gas. After sweetening, the gas is partly utilised at Hazira and the rest is fed into the Hazira-Bijaipur-Jagdhishpur(HBJ) pipeline which passes through Gujarat, MadhyaPradesh, Rajasthan, U.P., Delhi and Haryana. The gas produced in Gujarat, Assam, etc; is utilised within the respective states.

Natural Gas is currently the source of half of the LPG produced in the country. LPG is now being extracted from gas at Duliajan in Assam, Bijaipur in M.P., Hazira and Vaghodia in Gujarat, Uran in Maharashtra, Pata in UP and Nagapattinam in Tamil Nadu. Two new plants have also been set up at Lakwa in Assam and at Ussar in Maharastra in 1998-99. One more plant is being set up at Gandhar in Gujarat. Natural gas containing C2/C3, which is a feedstock for the Petrochemical industry, is currently being used at Uran for Maharashtra Gas Cracker Complex at Nagothane. GAIL has also set up a 3 lakh TPA of Ethylene gas based petrochemical complex at Auraiya in 1998-99.

Basic thermodynamics and fluid mechanics

GAS LAWS

Boyle's law (1662)

If the temperature of a given quantity of gas is held constant, the volume of gas varies inversely to the absolute pressure. This relationship, written as an equation, is

$$P1/P2=V1/V2 \text{ or } PV=\text{constant}$$

Charle's law

If the pressure exerted on a particular quantity of gas is held constant, then with any change of state the volume will vary directly as the absolute temperature, which can be expressed by the equation, is

$$V1/V2=T1/T2 \text{ or } T/V=\text{constant}$$

Ideal gas law

The relations of Boyle's and Charle's laws may be combined to yield

$$P1V1/T1=P2V2/T2 \text{ or } PV/T=\text{constant}$$

$$PV=RT$$

Where, R=universal gas constant.

FUNDAMENTALS OF GAS FLOW IN PIPELINE

Viscosity

An important property of the gas is its viscosity. Viscosity (μ) is the gas resistance to flow, which reveals itself as a shearing stress within a flowing gas and between a flowing gas and its container. The viscosity is defined as the ratio of the shearing stress (τ) to the rate of change in velocity (*w*)

$$\tau = \mu\ (dw/dx)$$

Where, x=distance

Reynolds number

The Reynolds number is a dimensionless number which is used to characterize the gas flow conditions. It is dependent on the properties of the gas, on the gas velocity and the diameter of the pipe. The Reynolds number is defined

$$Re = Dw\ \rho/\mu$$

Where: D=inner diameter of the pipe (m)

w=velocity of gas (ms^{-1})

ρ=density of gas ($kg\ m^{-3}$)

μ=the coefficient of the dynamic viscosity (Nsm^{-3})

In physical terms,

$$Re = \text{inertial force}/\text{viscous forces}$$

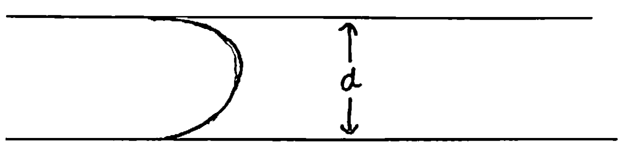
TYPES OF FLOW IN PIPES

Three types of flow in pipes: laminar flow, partially turbulent flow and fully turbulent flow.

Laminar flow

It is observed at very low Reynolds number (<2000) and only in ideally smooth pipes. The fluid can be imagined to move in layers which slide over each other, the inner layers moving at a greater velocity than the outer ones.

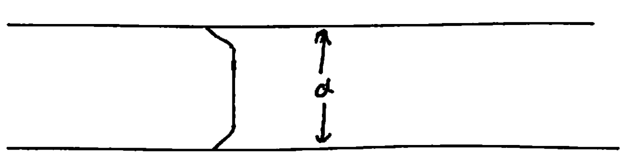
Frictional resistance to flow depends on the velocity gradient and the viscosity of the fluid. If the increases above a certain limit, eddy currents develop in the centre of the flow stream and the laminar flow breaks down. The Reynolds number at which this occurs is known as the critical Reynolds number.



DIRECTION OF FLOW →

Turbulent flow

Types of turbulence are considered depending on whether the eddy currents occur only in the centre of the pipe (partial turbulence) or whether the eddies fill the whole pipe (full turbulence). In partially turbulent flow there is a laminar layer adjacent to the pipe wall known as the boundary layer, while the centre of the flow stream is turbulent. The velocity profile is flatter than that in laminar flow. The frictional resistance to flow is due to viscous effects in the laminar layer and depends on the Reynolds number. The frictional resistance depends on the roughness of the pipe wall.



DIRECTION OF FLOW →

Design and safety aspects of pipeline network

The natural Gas Distribution System requires engineering, procurement, construction and commissioning of natural gas distribution facilities adequate to serve Industrial units, households, commercial establishments and Automobile segment. These facilities include high & medium pressure pipelines, distribution regulator stations, medium pressure mains and services, meter sets, and CNG stations. The size of the distribution system related to area covered, density of consumers, and types of customers served, have to be identified.

The objective of the design basis is to provide the required engineering basis to ensure the gas facilities considered in the feasibility study are of demonstrated quality and capable of providing reliable gas service to identified customer groups in a safe, efficient manner in accordance with the expectations of the owner.

DESIGN PHILOSOPHY

The design philosophy shall be to:

- Optimize the use of each component of the overall system (i.e. do not make uneconomical decision on one component to compensate for another).
- Conserve available energy to distribute the gas (i.e. fewer pressure regulating stations).
- Generally minimize the use of mechanical components in the system (i.e. stations, regulators, meters, and valves which are high capital cost, high maintenance and generally reduce pressure availability for distributing natural gas).

The design philosophy is achieved by:

- Operating the system at the appropriate rated pressure for each component. Failure to do so leaves latent capacity unused and generally results in expenditures on other system components to compensate.
- Minimizing the number of different system pressures

Planning and designing of gas distribution network

- Carefully evaluating the use of mechanical components and minimize usage.

PRELIMINARY INFORMATION USED FOR DESIGN

The following preliminary information has to be collected for system design purposes:

1. Sector wise natural gas requirement.
2. Size of the market.
3. Geographical data of city.
4. Forecasts provided by the market survey.

DISTRIBUTION SERVICES

Distribution services are used to connect customers from the mains. As most services must cross roads /footpaths, to reach the customers, they are often installed by boring, to reduce reinstatement costs. Open excavation is then only needed at the connection to the main and at the service. Where open excavation has taken place, Marker tape is installed.

INSTALLATION FEATURES

Safety Piping will carry flammable gas and hence it is much safer to lay underground, away from sources of ignition. This will also give protection from physical damage and ultra-violet radiation to MDPE pipe. However, limited piping within the gate station for custody transfer and flow measuring instruments will be above ground. Piping with in CNG service stations will be either above ground or in trenches.

Standards As per Explosive Rule 1976 (clause no. 92.2) pipe lines shall be laid below the ground level except when laying them above the ground level as desirable for topographical, economic or other special reasons.

Design Basis The distribution system shall consist of primarily of underground piping. Installation may be completed by the following methods.

1 Trenching

2 Trench less

3 Auguring

4 Plowing

5 Boring

6 Directional Drilling

SERVICE LINES

To facilitate access for meter reading and operating functions meter sets will be located at the property boundary. If there is no boundary wall meter sets may be located at the building wall.

LINE MARKERS

Safety Line markers shall be put at suitable distances for HP Line only to identify the locations of underground pipes to other agencies before laying their pipes as well as to locate the pipes for future maintenance/repair.

VALVING

Safety Valves will be provided to sectionalize the grid in case of emergency, or to repair a particular section.

Planning and designing of gas distribution network

Standards ANSI/ASME B31.8 Clause 846.11

Design Basis Valves are installed for disaster response situation. Emergency response (i.e. broken gas main) as well as operating and maintenance functions is completed using other methods of gas flow control including use of stopple equipment and/or squeeze tools.

With the exception of valves installed in stations all valves are underground. All underground valves are welded or fused. No mechanical joints are used. Above ground valves are weld end, flanged or for smaller sizes screwed.

CATHODIC PROTECTION

Safety All equipment for cathodic protection coming along the grid will be fenced all around for safety and security reasons.

Standards ANSI/ASME B31.8

Design Basis All underground steel piping as well as the tracer wire installed with the PE pipe will be cathodically protected. Cathodic Protection will be provided by an impressed current system to be designed to accommodate effects of inductive currents and ground fault conditions from adjacent High Voltage AC power lines. The impressed current systems will include a rectifier for the DC power source and shallow anode ground beds. The status of protection will be monitored by use of test stations installed at certain intervals to measure the pipe-to-soil potentials along the pipeline. These distance intervals depending on the local climate, soil conditions and the depth of cover for the pipeline system. The stations shall be easily accessible (i.e. adjacent to roads), if possible. Insulating flanges shall be installed at station limits of this Project.

PRESSURE REGULATORS

A distribution pressure of 4 bar requires pressure regulation be installed at each meter set to reduce the pressure delivered to the consumer to between 20 and 70mbar. As per ANSI/ASME B31.8, a single regulator is acceptable for this purpose. If, however, a distribution pressure of exceeds 4 bar, ANSI/ASME B31.8 requires additional overpressure protection such as is provided via two pressure regulators at each meter set.

ROUTE SELECTION

In consideration of the Environment requirements, construction methodology, design and engineering factors, availability of the logistic support during construction, operation and maintenance of pipelines various feasible alternatives are identified based on the desktop study of the relevant topographic maps of the area.

After the desktop study of the route, reconnaissance study of the route is carried out for the collection of the various details of the route. After collection of the field data once again desktop analysis of data is carried out for arriving at the optimum route.

The optimum route is selected based on the following factors:

- Shortest length of the pipeline grid
- Least topographical variations and minimum obstacles in the form of rail/ road/ river /canal crossings
- Minimum cost of the system layout
- Density of traffic flow
- Minimum number of turning points
- Availability of sufficient space on both sides of the road.

On completion of the above exercise final route is selected for the pipeline network. After selection of the route, detailed survey for the final route is carried out. During the detailed survey pipeline alignment is decided. The main purpose of the detailed survey is to prepare drawings and report for the pipeline construction.

The details of the topography along the identified routes are surveyed and marked on the base map. The running distance from the starting point is also indicated. The main obstructions like culvert, road cuttings, nala/ drain, power line, pylons and buildings are recorded. Areas like flyover / canal crossings are avoided wherever possible. Main consideration is given for position of CNG filling station for sketching the position of DRS and CNG station. Suitable sites for PNG and CNG are selected specially on road bends. The feasible routes are marked on the existing base map and the best possible route amongst them has been indicated.

CONTROL PHILOSOPHY

General

The purpose of SCADA (Supervisory Control and Data Acquisition) system is to provide operational interface to the complete gas pipeline network and the SCADA system has the capability to perform the following functions:

- Acquire pipeline, off take and pressure reduction operating conditions and status
- Remotely control selected valves
- Show abnormal or alarm conditions
- Produce screen based or hardcopy reports
- In addition data will be acquired and will be available to other parts of the overall management information system.

CGS, DRS and MRS will be primarily monitored and controlled. Although SCADA will be designed for local attended operation, remote SCADA and control facility will be provided. At each CGS, DRS and MRS a Remote Telemetry Unit (RTU) will be installed to provide an interface with SCADA for remote monitoring and control.

SYSTEM BASIC CONCEPT

Pressure levels

The concept is based on the pressure levels given in the following sections.

High-Pressure

This applies to the pipelines connecting the Gas transmission System to the "City Gates". It generally operates at 90 bars pressure.

Design data for HP system

- The maximum inlet pressure for the City Gate was taken as 49 barg being known at off-take points.

Medium pressure

Usually, two main pressure levels are considered for "Gas Distribution Networks"

MPS

- MOP = 19 barg (compatible with ASA Class 150 flanges and fittings);
- Basic Material of Construction - Steel
- Operating Pressure fluctuating between said MOP and level MPS Pressure depending on actual operating pressure and pressure drops.

MPP

- MOP = 4 barg
- Basic Material of construction - Polyethylene

SYSTEM PLANNING ASSUMPTIONS

In modern gas distribution systems, a steel supply mains system provides transmission pressure gas, regulated at City Gate Station to the distribution network. Major industrial customers are supplied directly from this steel system, but the high pressure (above 19 bar) makes it an unsafe pressure for direct reticulation to domestic consumers. The transmission pressure gas supply is reduced to 19 bar Medium Pressure (MPS) in a City

Gate Station where the supply pressure is up to 49 bar. At a DRS or MRS, the supply pressure is up to 19 bar but the outlet pressure is limited to 2 to 4 bars. Distribution pressure is recommended to be 4 bar (MPP). It is recommended that due to cost savings in polyethylene (PE) material over steel that PE be used as the principal distribution network. Medium Density Polyethylene (MDPE) is recommended to standardize the distribution system as much as possible. Further, it is proposed to have only three principal distribution pipe sizes of nominal outside diameters of 63 mm, 90 mm and 110 mm. This material is only capable of containing pressures of up to 7 bar; and therefore only steel pipes will be used above 7 bar pressure.

STEADY STATE FLOW IN PIPELINE SYSTEM

Pipes provide an economic means of producing (through tubing or casing) and transporting (via flow lines or pipelines) fluids in large volumes over great distances. They are convenient to fabricate and install, and provide an almost indefinite life span. Because flow is continuous, minimum storage facility is required at both the ends (field supply and the consumer end), Operating costs are very low, and flow is guaranteed under all conditions of weather, with good control (an installed pipeline can generally handle a wide range of flow rates). There is no spillage or other handling losses, unless the line develops a leak, which can be easily located and fixed for surface lines.

Types of single-phase flow regimes and Reynolds number

Four types of single-phase flow are possible: *laminar, critical, transition,* and *turbulent.* Reynolds applied dimensional analysis to flow phenomena, and concluded that the flow regime that will prevail is a function of the following dimensional group known as the *Reynolds number,* N_{Re}:

$$N_{Re} = \text{inertia forces/viscous forces} = dvp/u$$

Where,

d= (inside) diameter of the conduit through which the fluid is flowing

v= velocity of fluid

p= density of the fluid

u= viscosity of fluid

For cross-section other than circular, an equivalent diameter is used.

FLOW TYPE	N_{Re}, SMOOTH PIPE
Laminar (or viscous)	<2,000
Critical	2,000-3,000
Transition (or intermediate)	3,000-4,000 (or 10,000)
Turbulent	>4,000 (or10, 000)

Pipe roughness

Friction to flow through pipe is affected by pipe-wall roughness. The absolute pipe roughness is E is defined as the means height of protrusions in uniformly sized, tightly packed sand grains that give the same pressure gradient as the given pipe. This roughness may change with pipe use and exposure to fluids. Initially the pipe contains mill scale that may be removed by fluids flowing inside the pipe. The fluid may also increase roughness by erosion or corrosion, or by precipitating materials that stick to the pipe wall. From dimensional analysis, it has been deduced that relative roughness, the ratio of' absolute roughness and the inside diameter of the pipe, E/d, rather than absolute, affects flow through pipes.

Friction factor

Friction factor, f, is defined as the ratio of the shear stress at the fluid solid interlace and the kinetic energy of the fluid per unit volume. It is used in calculating pressure drop due to friction.

For steady state flow in a uniform circular conduit such as pipe it is given by *Fanning equation:*

$$\Delta p_f = \frac{2f'L L p v^2}{(g \times d)}$$

Where, d is the inside pipe diameter

Friction factor f' is called fanning friction factor. Moody friction factor f is equal to 4f. Fanning equation in terms of moody friction factor is given as:

$$\Delta p_f = \frac{f L v^2}{(2 \times g \times d)}$$

The friction factor includes, besides roughness, the flow characteristics of the flow regime. It is therefore a function of Reynolds number and relative roughness:

$$f = f(N_{Re}, \Sigma E/d)$$

Allowable working pressure for pipes

It is desirable to operate a pipe at a high pressure in order to achieve higher throughputs. This is, however, limited by the maximum stress the pipe can handle. The maximum allowable internal working pressure can be determined using the following ANSI(1976) specification:

$$p_{max}=2(t-c)\ SE/([do-2(t-c)Y]$$

Where,

p_{max}=maximum allowable working pressure, psig

t- pipe thickness

c- sum of mechanical allowances (thread and groove depth), corrosion, erosion etc.

S-allowable stress (minimum yield strength) for the pipe material

E- longitudinal weld joint factor (i.e. the anomaly due to weld seam)

= I for seamless pipe

=0.8 for fusion-welded and spiral-welded

=0.6 for butt-welded pipes

d_0-outside of the pipe, in.

Y-temperature derating factor, equal to 0.4 up to 900"F, 0.5 for 950°F, and 0.7 For 1,000°F and greater

Allowable flow velocity in pipe

High flow velocity in pipes can cause pipe erosion problems, especially for gases that may have a have flow velocity-exceeding 70-ft/sec. The velocity at which erosion begins to occur is dependent upon the presence of solid particles, their shape, etc., and is, therefore, difficult to determine precisely. The following equation can be used:

$$v_e=C/p^{0.5}$$

Where, v_e=erosional velocity, ft/sec

p= fluid density, lbm/ft3 -

c =a constant ranging between 75 and 150

The gas flow rate at standard conditions for erosion to occur, $(q_e)_{Sc}$, can be given

by: $(q_c)sc=v_c(PTsc/ZTp_{sc})(d^2/4)$

Where, $(q_e)_s$,=gas flow rate for onset of e

osion,scf/sec

d= diameter of the pipe, ft

p= flowing pressure, psia

T=flowing temperature, $^\circ$R

R= gas constant (=10.732 psia-ft^3/lbmole-$^\circ$R)

Z= gas compressibility factor at pressure p and temperature T

Design Fundamentals

The two basic elements of a pipeline network are the *nodes* and the *node connecting elements (NCEs).* Nodes include those points where a pipeleg ends, or where two or more *NCEs* join, or where there is Injection or delivery of gas. Node pressures determine the pressure map of the network. The most important NCEs are pipelegs, compressor stations, regulators, valves, and underground gas storages. Prior to construction of a complex system it is necessary to establish mathematical models for individual NCEs.

Common flow equations

(a) *Lacey 's equation*

This is used for low-pressure network between 0-75 m bar gauge

$$Q_n=5.72 \times 10^{-4} [(pl-p2)D^5/fSL]^{0.5}$$

(b) The Polyflo equation

This is used for medium pressure network operating between 0.75-7.0 bar gauge:

$$Q_n=7.57 \times IO^{-4}(Tn/Pn)\ [(P1^2-p2^2)D^5/fSLT]^{0.5}$$

(c) The Panhandle 'A 'equation

This is used for high-pressure networks operating above 7.0 bar gauge:

$$Q_n=7.57 \times IO^{-4}(Tn/Pn)\ [(P1^2-p2^2)D^5/fSLTZ]$$

(d) The Weymouth equation

This equation is also used for high-pressure networks. The Weymouth equation for the friction factor is diameter dependent only and is applicable in the fully-turbulent flow region:

$$f=0.032/d^{1/3}$$

$$Qsc=31.5027(Tsc/Psc)(p1^2-p2^Z)d^{16/3}\ Zav\ Tav\ L)^{0.5}$$

This is known as the Weymouth equation for horizontal flow. It is used most often for designing gas transmission systems because it generally maximizes pipe diameter requirements for a given flow rate and pressure drop.

In the knowledge of the gas transmission system's elements, a mathematical-hydraulic Model of the entire system may be constructed. In laying down the principles of modeling, the recognition of an analogy between gas flow in the pipe networks and flow of electricity in electric network is extensively exploited. **Kirchoff's laws** apply to gas flow too.

The first law applies to any node; the algebraic sum of gas flow entering and leaving the node is zero, that is

$$\Sigma q_i=0$$

Where m is the number of NCEs meeting at the node.gas flowing into the node is given positive sign.

By Kirchoft's second law, for any loop, in the high pressure system, the algebraic sum of pressure drops, taken with signs corresponding to a consistent sense of rotation around the loop is zero, that is

$$\Sigma\ (p1^2-p2^2)=0$$

Where n is the number of NCEs in the loop, and pl and p2 are respectively the head-end and tail-end pressure of said pipelegs, head and tail being taken with respect to the sense of rotation chosen.

Pipeline construction

Construction activities can be broadly classified as below:-

- Opening of right of way
- Clearing and grading
- Hauling and stringing
- Trenching
- Welding and radiography
- Joint coating
- Lowering
- Back-filling
- Tie-ins
- Crossing
- Hydro-testing
- Valves installation
- Final cleanup
- Nitrogen purging
- Gas charging/Commissioning
- Restoration

Opening of right of way:

The activities to be carried out prior to cleaning are:

- Installing benchmark intersection points and other required survey monuments
- Stake markers in the centerline of the pipeline at distances of maximum 10 meters for horizontal bends.
- Installing distinct markers that locate and indicate special points, but not limited to contract points, obstacles, corresponding change of wall thickness, including corresponding change etc.
- Checking all the deflection angles and marking the trench centerline with red painting on the top form the consecutive TPs on a wooden peg marker.
- Staking two row markers at least every 100 meters.
- Staking out ROW markers at the boundary limits of ROW wherever possible. ROW markers shall be painted red with numbers painted white. Reference markers shall also carry the same information as its corresponding centerline marker.

Clearing and grading:

This activity includes:

- Staking of ROW
- Marking of ROW boundaries
- Clearing of trees, bushes, undergrowth and routes, electrical and telephone poles falling with in the 18 m width of ROW
- Grading of ROW sufficient to be consistent with the maximum permitted pipe bending radius
- Providing ramps, diversion at road crossing

Hauling and stringing

- All care shall be taken for transportation of the pipes from coating yard to ROW without damage to coating and pipe
- Stringing shall be done in such a manner that pipes are easily accessible and shall not hinder the movement of equipment
- In rocky areas, pipe stringing shall be done after rock trenching
- Stringing shall not be done for more than 10 km ahead of trenching
- Pipes of special grades and wall thickness shall be strung at the specific locations

Trenching

- The pipeline shall be laid a distance of 5m frm one edge of the ROW
- Stacking of the trench line
- The width of the trench shall be equal to the pipe diameter plus 400m
- The depth of the trench shall be equal to the pipe diameter of the pipe plus 1m
- Extra width and depth shall be provided in rocky area
- Stripping of the top soil up to 30cm of the trench and sorting separately
- Suitable crossing for passage of men, equipment etc should be provided

Welding

- Welding procedure specification has to be prepared for approval of the procedure an qualification of the welders
- External line clamp shall be used for proper alignment of the joint
- Welding is done using vertical down technique with cellulose coated electrodes

Radiographic inspection

- Radiographic inspection is carried out by using Xrays/ gamma rays
- Qualified welding engineer having minimum qualification of level-II certification, shall carry out visual inspection of all the welds
- All the joints should be 100% radio graphed

Field joint coating

- 250mm either side of the pipe is left un coated in the coating yard to facilitate welding
- The width of the sleeve shall depend upon the cut back length provided in the yard coated pipe
- Heat shrinkable sleeve are used for coating welded joints

Joint coating procedure

- Pipe surface is sand blasted
- Sand blasted area is heated upto 6000c ann epoxy primer is applied on the surface
- The sleeve is wrapped around and then shrunk on the joint using a propane/LPG torche
- Air bubbles trapped are removed using hand rollers
- The integrity of the joint coating is tested by conducting peel test

Lowering

- The excavated trench should be free from excess earth, rock, hard clods and other debris
- Coating of the pipe string shall be checked for damages by using holiday detectors
- Repair of coating damages
- Sand padding and rock shield are provided in rocky areas before lowering

Back filling

- Back filling shall be done immediately after lowering
- Back filling shall be done with earth free of hard lumps, boulders, rock etc
- Sand padding over the pipe shall be provided in rocky areas
- Slope breakers shall be provided in steep gradient to avoid wash out of the trench

Trench-ins

- Situations in mainline such as rail/road/river crossing etc may cause a break in the continuity of mainline laying operation and are normally bypassed by the mainline laying crew
- The process of connecting the un-connected of the pipeline is defined as tie-in operation

Hydrostatic testing

After construction of pipeline is completed, it is necessary to hydrostatically test the pipeline to demonstrate that the pipeline has the strength to meet the design conditions, and to verify that the pipeline is leak free. Hydrostatic testing for pipelines is done at a pressure of 35-kg/sqcm g, which is 1.5 times the design pressure of the pipeline.

Final cleanup and installation of markers

- After construction, ROW is leveled and restored to the entire satisfaction of the land owners / authorities.
- Pipeline markers such as kilometer post, turning points/direction markers, warning signs and boundary pillars are provided.

Nitrogen Purging

- Purging is a process of removing all or air-gas mixture from natural gas pipeline facilities.
- Generally purging of Natural gas is done using nitrogen due to its inert properties.
- An air-gas mixture is a highly flammable and dangerous substance. It is therefore very important to ensure that air/gas mixtures within flammability limits are minimized.

Gas Charging /Commissioning

- Commissioning is the process of checking the facilities to ensure they are capable of transporting volumes of various fluids and preparing the facilities to perform their functions.
- It covers the period from the time the construction of the facilities is completed until the facility is on-stream. Completion of construction does not necessarily mean the final cleanup is completed, but only that the pipeline facilities are completed, tide-in and ready for use.
- Pipeline commissioning is complete only when the pipeline is on-stream and all measurement facilities has been calibrated and found to operate properly and accurately.
- All valve and piping facilities must be found to be operative and set for operating mode.

SALIENT QUALITY CHECKS DURING CONSTRUCTION

Prior to the pipelines being put into service, the steel pipeline legs would be non-destructively tested by two methods. Firstly, welds would be 100% radio-graphed and, secondly, the completed pipeline extension would be hydro-statically tested at a higher pressure than its operating pressure (at least 1.4 times higher).

After hydrostatic testing, the pipeline would be dried, purged and filled with natural gas. The testing and commissioning procedures will be detailed during the detailed design phase of the project.

To protect the pipeline from corrosion, a cathodic protection (CP) system of impressed current is proposed. During the detailed design phase, the CP capability of the existing transmission system will be investigated to establish if it has the capacity to provide CP to the extension. If it is found that the existing system does not have the capacity, additional CP facilities will be designed.

The steel pipeline grid is proposed to be installed at a minimum depth of 1.0 meter cover, and in accordance with Indian Standards requirements.

OPERATION AND MAINTAINANCE

Basic Requirements:

Each operating company having gas transmission or distribution facilities should have the following basic requirements in acceptance with the respective codes.

- To have a written plan covering operating and maintenance procedures in accordance with the scope and intent of the code.
- To have a written emergency plan covering facility failure or other emergencies.
- Operating and maintaining the facilities in conformance with the plans.
- Modifying the plans periodically as experience dictates and as exposure of the

  Public to the facilities and changes in operating conditions require.
- Providing training for employees in procedures established for operating and maintenance functions.
- The training should be comprehensive and should be designed to prepare employees for service in their area of responsibility.
- Keeping records to administer the plans and training properly.
- The written plan should include detailed plans and instructions for employees covering operating and maintenance procedures for gas facilities during normal operation and repairs.
- Particular attention should be given to those portions of the facilities presenting the greatest hazard to the public in the event of any emergency or because of construction or extraordinary maintenance requirements.

PIPELINE MAINTENANCE:

Periodic Surveillance of Pipelines:

In order to maintain integrity of pipeline system, procedures for periodic surveillance of facilities should be implemented. Studies shall be initiated and appropriate action shall hr taken where unusual operating and maintenance conditions occur, such as failures, leakage history, drop in flow efficiency due to internal corrosion or substantial changes in cathodic protection requirements. When such studies indicate the facility is in unsatisfactory condition, a planned program shall be initiated to abandon, replace, or recondition and proof test. If such facilities cannot be reconditioned or phased out, the maximum allowable operating pressure shall be reduced.

Pipeline Patrolling:

It will maintain a periodic pipeline patrol program to observe surface conditions on and adjacent to each pipeline right-of-way, indications of leaks, construction activity other than that performed by the company, natural hazards, and any other factors affecting the safety and operation of the pipeline. Main highways and railroad crossings should be inspected with greater frequency and more closely than pipelines in open area.

Maintenance of Cover at Road Crossings and Drainage Ditches:

This activity includes determining by periodic surveys if he cover over the pipeline at road crossings and drainage ditches has been reduced below the requirements of the original design. If the normal cover provided at the time of pipeline construction has become unacceptably reduced due to earth removal or line movement, then protection done by providing barriers, culverts, concrete pads, casing, lowering of the line, or other suitable means.

Maintenance of Cover in Terrain:

As a result of patrolling if it is known that the cover over the pipeline in terrain does not meet the original design or the cover has been reduced to an unacceptable level then there should be provision for additional protection by replacing cover, lowering the line, or other suitable means.

Leakage Surveys:

A transmission line should be provided for periodic leakage surveys of the line in its operating and maintenance plan. The types of surveys selected shall be effective for determining if potentially hazardous leakage exists. The extent and frequency of the leakage surveys shall be determined by the operating pressure, piping age, class location and whether the transmission line transports the gas without an odorant

Pipeline Leak Records:

Records shall be made covering all leaks discovered and repairs made. All pipeline breaks shall be reported in detail. These records along with leakage survey records, line patrol records, and other records relating to routine or unusual inspections shall be kept in the file of the operating company, as long as the section of line remains in service.

Pipeline Markers:

- Signs or markers shall be installed where it is considered necessary to indicate the presence of a pipeline at road, highway, railroad, and stream crossings. Additional signs and markers shall be installed along the remainder of the pipeline at locations where there is probability of damage or interference.
- Signs or markers and the surrounding right-of- way shall be maintained so markers can be easily read and are not obscured.
- The signs or markers shall include the words "Gas (or name of gas transported) Pipeline, the name of the operating company, and the telephone number (including area code) where the operating company can be contacted.

SAFETY ASPECTS OF PIPELINE NETWORK

There are three important factors to be considered after laying pipeline network:

1. Corrosion control
2. Third party damage
3. Typical safety program

Corrosion control:

One of the most prominent reasons for pipe depletion in the field is corrosion.

Corrosion Degradation of a material (both naturally occurring & manmade such as plastics, ceramics, metals etc.) through the environmental interaction".

External Corrosion control is a primary consideration during the design of a piping/storage system, though this can be done at subsequent stage as well.

Economical and effective protection of pipelines/storage systems consists of conjoint application of protective Coatings and Cathodic Protection.

1. Passive Method : **Coating** External Surface of thePipe

2. Active Method : **Cathodic Protection** System **[ICCP]**

These, protective scheme components, work supplementing each other, thus Coating provides the Primary Di-Electric Barrier between the Corrossive soil Environment & the Pipeline external surface [bare Metal] in contact with Soil (at Coating Holidays),and Cathodic protection supplements this,at Coating Holidays where Metal is in contact with Corrossive Soil/Water electrolyte surrounding pipeline/storage tank surface.

Pipeline coatings and cathodic protection system are designed and constructed as per Standards appropriate to operational requirements which will prevail over the designed life of the installation. Yet, it is difficult to set standards which will anticipate every environmental and operational condition to which these may be subjected. For this reason, there has been a tendency to apply some form of periodic non-destructive examination [NDT] or monitoring system to assess the coating condition and the adequacy of the installed Cathodic Protection system.

Third party damage

In an underground pipeline, there is lot of risk of hitting, striking of pipeline while excavation, so following precautions should be followed:

- Where open excavation has taken place, Marker tape is installed.
- Line markers shall be put at suitable distances for HP Line only to identify the locations of underground pipes to other agencies before laying their pipes as well as to locate the pipes for future maintenance/repair.
- Valves will be provided to sectionalize the grid in case of emergency, or to repair a particular section.
- Pipeline should be painted properly, according to color code.

Safety program

A proper safety program should be designed for pipeline protection. Some duties for which safety administration is responsible are-

- Filing of leak and failure reports with state and central government.
- Keeping update on pipeline safety regulation changes and interpretation.
- Working with other company department to assure pipeline safety procedure.
- Effecting liaisons for local, state, central government on all matter pertaining to pipeline safety.

REGULATIONS & STANDARDS

The petroleum Rule 1976

The rule gives broad guidelines for the import, transport and storage of petroleum products including compressed natural gas (CNG) and natural gas. The Chief Controller of Explosives (CCOE) enforces the Petroleum Rules. Project approvals are essential prior to the start of construction activities. The constructed installation must also be approved before the commissioning.

Factory Act

Building factory equipment/machinery requires approvals from the Inspectorate of Factories. Approvals are required before construction, and subsequent to the installation before commissioning.

Highway Authorities

For installations requiring and approach from a highway or for crossing of highways, approval from Highway Authorities will be required.

Railway Authorities

For crossing Railway property/track, approval from Railway Authorities will be required.

Apart from these Statutory Authorities, **Oil Industry Safety Directorate** (OISD) has prepared OISD Standard-141 "Construction requirements for cross country hydrocarbon pipelines". Part-II of this standard addresses gas transportation and distribution system including gas pipeline, gas compressor station, gas metering and regulation station, gas main and service lines up to the outlet of the customers meter set assembly. OISD-141 standard incorporates major clauses from ANSI/ASME B31.8, 1986 addition. (Gas transmission and distribution pipe system) with certain modification.

Gas transportation economics

PIPELINE ECONOMICS

For a given throughput, the optimum pipeline diameter, using the compression cost and fixed cost for piping system can be computed. But the pipeline chosen may have optimum behavior or some other throughput i.e. it may be able to handle a different throughput more economically. It is an interesting fact that the pipeline's optimum throughput is not the same as the throughput for which it has most economic diameter. If more than one pipe sizes satisfy the requirements and constraints, then one is chosen based on the economics.

(A)COMPRESSION COST

Peters and Temmerhaus obtained following equation for compression cost:

$$C_{comp} = \frac{0.273\, q^{2.84}\, \rho^{0.84}\, \mu^{0.16}\, Ce(1+L_{fp})Hy}{D^{4.84}\, E} + B^*$$

Where,

C_{comp}=compression cost in \$/year per foot of pipe length

q=gas flow rate, ft3/sec

ρ=the gas density, lbm/ft3

μ=gas viscosity,cp

Ce=cost of electrical energy, \$/kwh

Hy =hours of operation per year

d=pipe diameter, in

E=compression efficiency, fraction

B*=a constant independent of pipe diameter d

(B) FIXED COST FOR PIPING SYSTEM

For most type of pipe, the purchase cost per foot of pipe is related to the pie diameter as follows:

$$C_{pipe}=Cp \times D^{n}$$

Where,

C_{pipe}=purchase cost of new pipe of diameter d inches per foot of pipe length, $/ft

Cp=a constant equal to the purchase price per foot for a 1-in diameter pipe, $/ft

d^{n}=pipe diameter, in

The annual cost for an installing piping system can be expressed as [Peter and Timmerhaus (1980)]:

$$C_{pipe}=(1+Rp)cp\ Dn\ Cfp$$

Where,

Rp=ratio of total cost for fittings and installations to the purchase cost for new pipe

Cfp=annual fixed charges, including maintainance, expressed as a fraction of the initial cost for a completey installed pipe

(C) OPTIMUM ECONOMIC PIPE DIAMETER

The total annual cost C_T for the compressor and piping system can be obtained by adding equations above

$$C_T=\frac{0.273\ q^{2.84}\ \rho^{0.84}\ \mu^{0.16}\ Ce(1+L_{fp})Hy}{D^{4.84}\ E}+B^{*}+(1+Rp)cp\ Dn\ Cfp$$

Differentiating C_T expressed by above equation with respect to diameter d, setting the resultant expression to zero, and solving for d gives the optimum pipe diameter d_{opt} in inches, as follows

$$d_{opt}=\frac{[1.32\ q^{2.84}\ \rho^{0.84}\ \mu^{0.16}\ Ce(1+L_{fp})Hy]^{(1/4.84+n)}}{[n\ (1+Rp)cp\ E\ Cfp]^{(1/4.84+n)}}$$

The value for n for steel pipe is about 1.0 for d<1 in.

(D) ANALYSIS INCLUDING COST OF CAPITAL AND CORPORATE LOSSES

Consideriong some important factors such as the time value of money, corporate taxes, cost of compression, and the cost of capital or return on investment and using a more accurate expression for friction loss due to pipeline fitting and bends Peter and Timmerhaus presented the following equation:

$$\frac{d_{opt}}{1+0.79L_{fd}\, d_{opt}} = \frac{1.046 \times 10\text{-}10\ Hy\ Ce\ m^{2.84}\ \mu^{0.16}\ [Mi^*+(1-tr)(1+(i_{dc}+i_{mc})M]}{n\ (1+Rp)cp[i^*+(1-tr)(i_{dp}+i_{mp})]E\ \rho^2}$$

Where,

d_{opt} =optimum economic inside pipe diameter, in.

m=mass flow rate, lbm/hr

L_{fd} =frictional loss due to fittings and bends expressed as equivalent pipe length in pipe diameters per unit length of pipe ($L_{fd}= L_{fp}/ d_{opt}$)

M=ratio of total compressor installation cost to yearly cost of compression power required

i*=rate of return (or cost of capital before taxex) on incremental investment, fraction

tr=taxation rate, fraction

i_{dp}=depreciation rate for the installed piping system, fraction

i_{dc}= depreciation rate for compressor system, fraction

i_{mp}=fraction of initial cost of installed piping system for annual maintenance, fraction

i_{mc} = fraction of initial cost of compressor system for annual maintenance, fraction

ρ=gas density, lbm/ft^3

Thus, for a given throughput, we can compute the optimum pipeline diameter using the relationship given here. But the pipeline chosen may have some other throughput (i.e. it may be able to handle a different throughput more economically). This is an interesting point that a pipelines optimum throughput is not the same as the throughput for which it has most economic diameter

Gas transmission economics

A complete transmission system or grids include several production wells, storage wells and vast network of pipelines of different dimensions and requirements. The computation made above assumes that the gas throughput Q is known. But it is not true while dealing with natural resources as gas. Some important factors that play role in determining the design capacity and size of gas transportation system are—

- Available supply of gas, the amount (reserves), current production rate, growth rate in supply due to field development activities and/or new discoveries.
- Rate of growth in gas demand. The economics of the variation in pipeline capital factors have to be evaluated.
- Availability of capital.
- Technical probability or feasibility transmission line construction.

The load factor of the system should be as high as possible. The load factor is given by the ratio of mean to maximum hourly gas flow. The load factor of the production system may differ from that of supply system. The main reason for this is that one pipeline may convey gas coming from several gas fields. With a view to increase the load factor, the gas supply company may take the following measures:

- The company may use the pipeline as a buffer storage facility
- The company may establish an underground stratigraphic storage capacity.
- The company may use a source of liquefied gas, propane injection or high pressure gas storage to ensure an excess supply capacity for periods of peak demand.

Therefore, the two major feature of a transmission system that is operating in an optimum manner are high load and capacity factors to ensure uninterrupted gas supply with a high degree of safety.

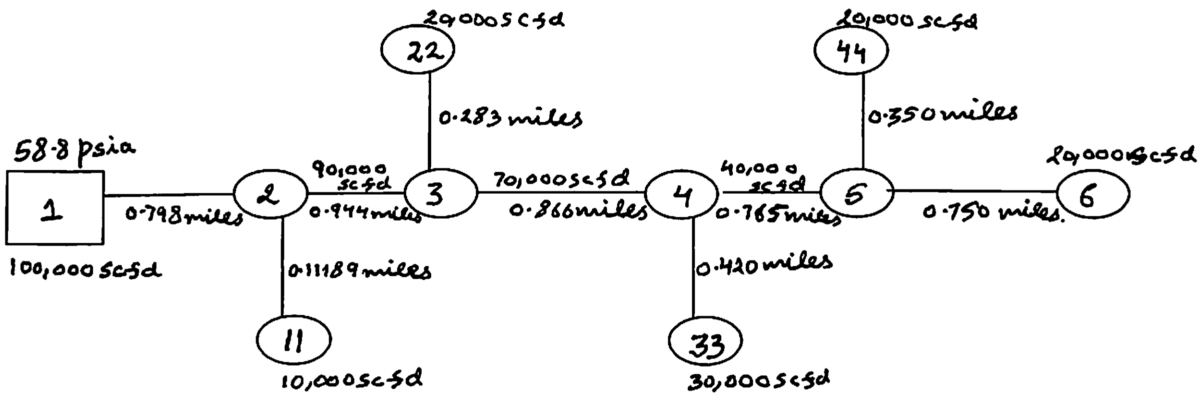
The safety of supply can be measured by two factors—

- The availability, which is the ratio of the aggregate length of uninterrupted supply periods of total time, and
- The reserve factor, which accounts for gas reserves provided in the form of additional parallel lines, underground storage, pipeline buffer capacity or other standby support system.

Higher the availability lower is the reserve factor required.

HYPOTHETICAL CALCULATION

Problem1-Solve the following network for source node pressure 4bars (58.8 psia). Total throughput being 100,000 scfd. Throughput is divided as shown in figure.



Using Weymouth equation for medium pressure network

$$Q_n = \frac{18.063\ T_b\ [(p1^2 - p2^2)\ D^{16/3}]^{1/2}}{P_b\ [\gamma_g\ Z\ T\ L]^{1/2}} \quad *$$

Where,
Q_n=flow (scfd)
T_b=520°R
P_b=14.73 psia
Z=compressibility factor, 0.979 (assumed)
γ_g=gas gravity, 0.64(assumed)
p1=node pressure, psia
p2=node pressure, psia
L=distance between two nodes, miles
D=diameter of pipeline, 8.625 inches (assumed)

Calculating pressure P_2

$$100{,}000 = \frac{18.063 \times 520\ [(58.8^2 - p2^2)\ 8.625^{16/3}]^{1/2}}{14.73[0.979 \times 0.64 \times 528 \times 0.798]^{1/2}}$$

P_2=58.23 psia

Calculating pressure P_4

$$90{,}000 = \frac{18.063 \times 520\ [(58.23^2 - p4^2)\ 8.625^{16/3}]^{1/2}}{14.73[0.979 \times 0.64 \times 528 \times 0.944]^{1/2}}$$

P_4=57.68 psia

* Eqn is not suitable for Medium Pr.
Polyflow eqn is used.

Calculating pressure P_{11}

$$10{,}000=\frac{18.063 \times 520\ [(58.23^2-p11^2)\ 8.625^{16/3}]^{1/2}}{14.73[0.979 \times 0.64 \times 528 \times 0.1189]^{1/2}}$$

P_{11}=58.229 psia

Calculating pressure P_{22}

$$20{,}000=\frac{18.063 \times 520\ [(57.68^2-p11^2)\ 8.625^{16/3}]^{1/2}}{14.73[0.979 \times 0.64 \times 528 \times 0.283]^{1/2}}$$

P_{22}=57.67 psia

Calculating pressure P_4

$$70{,}000=\frac{18.063 \times 520\ [(57.68^2-p11^2)\ 8.625^{16/3}]^{1/2}}{14.73[0.979 \times 0.64 \times 528 \times 0.866]^{1/2}}$$

P_4=57.37 psia

Calculating pressure P_{33}

$$30{,}000=\frac{18.063 \times 520\ [(57.37^2-p11^2)\ 8.625^{16/3}]^{1/2}}{14.73[0.979 \times 0.64 \times 528 \times 0.430]^{1/2}}$$

P_{33}=57.34 psia

Calculating pressure P_5

$$40{,}000=\frac{18.063 \times 520\ [(57.37^2-p11^2)\ 8.625^{16/3}]^{1/2}}{14.73[0.979 \times 0.64 \times 528 \times 0.765]^{1/2}}$$

P_5=57.28 psia

Calculating pressure P_{44}

$$20{,}000=\frac{18.063 \times 520\ [(57.28^2-p11^2)\ 8.625^{16/3}]^{1/2}}{14.73[0.979 \times 0.64 \times 528 \times 0.350]^{1/2}}$$

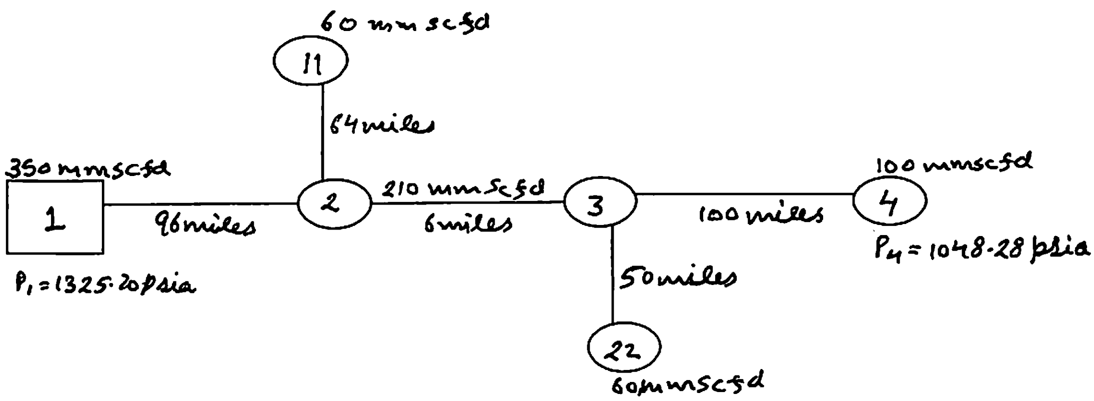
P_{44}=57.26 psia

Calculating pressure P_6

$$20{,}000=\frac{18.063 \times 520\ [(57.28^2-p11^2)\ 8.625^{16/3}]^{1/2}}{14.73[0.979 \times 0.64 \times 528 \times 0.750]^{1/2}}$$

P_6=57.258 psia

Problem2-Solve the following network for source node pressure 90bars (1325.70 psia). Total throughput being 350 mmscfh. Throughput is divided as shown in figure.



Using Weymouth equation for high pressure network

$$Qn=\frac{18.063\ Tb\ [(p1^2-p2^2)\ D^{16/3}]^{1/2}}{Pb\ [\gamma_g\ Z\ T\ f\ L]^{1/2}}$$

Where,
Qn=flow (scfd)
$Tb=520^0R$
Pb=14.73 psia
Z=compressibility factor, 0.979 (assumed)
γ_g=gas gravity, 0.64(assumed)
p1=node pressure, psia
p2=node pressuer, psia
L=distance between two nodes, miles
D=diameter of pipeline, 36 inches(assumed)
f=friction factor, 0.01(assumed)
P_1=90 bar (assumed)

Calculating pressure P_2

$$350 \times 10^6=\frac{18.063 \times 520\ [(1325.7^2-p2^2)\ 36^{16/3}]^{1/2}}{14.73[0.979 \times 0.64 \times 528 \times 10 \times 96]^{1/2}}$$

P_2=1129.50 psia

Calculating pressure P_{11}

$$60 \times 10^6=\underline{18.063 \times 520\ [(1129.5^2-P_{11}^2)\ 36^{16/3}]^{1/2}}$$

$$14.73[0.979 \times 0.64 \times 528 \times 10 \times 64]^{1/2}$$

P_{11}=1124.83 psia

Calculating pressure P_3

$$210 \times 10^6 = \frac{18.063 \times 520\ [(1129.5^2 - P_3^2)\ 36^{16/3}]^{1/2}}{14.73[0.979 \times 0.64 \times 528 \times 10 \times 50]^{1/2}}$$

P3=1078.37 psia

Calculating pressure P_{22}

$$60 \times 10^6 = \frac{18.063 \times 520\ [(1078.37^2 - P_{22}^2)\ 36^{16/3}]^{1/2}}{14.73[0.979 \times 0.64 \times 528 \times 10 \times 50]^{1/2}}$$

P_{22}=1075.03 psia

Calculating pressure P_4

$$100 \times 10^6 = \frac{18.063 \times 520\ [(1078.37^2 - P_4^2)\ 36^{16/3}]^{1/2}}{14.73[0.979 \times 0.64 \times 528 \times 10 \times 160]^{1/2}}$$

P_4=1048.28 psia

RESULTS

FOR MEDIUM PRESSURE NETWORK

PIPELEG	LENGTH (MILES)	FLOW (SCFD)
1-2	0.798	100,000
2-3	0.944	90,000
3-4	0.866	70,000
4-5	0.765	40,000
5-6	0.750	20,000
2-11	0.11189	10,000
3-22	0.233	20,000
4-33	0.420	30,000
5-44	0.350	20,000

NODE	PRESSURE (PSIA)
1	58.8
2	58.23
3	57.68
4	57.37
5	57.28
6	57.258
11	57.229
22	57.671
33	55.34
44	55.269

HIGH PRESSURE NETWORK

PIPELEG	LENGTH (MILES)	FLOW (MMSCFD)
1-2	96	350
2-3	64	210
3-4	160	100
2-11	64	60
3-22	50	60

NODE	**PRESSURE (PSIA)**
1	1325.20
2	1129.50
3	1078.37
4	1048.28
11	1124.83
22	1075.03

Conclusion

From the two calculations we calculated the pressures at different nodes for two loop less networks. Medium pressure lines refer to lines in commercial or domestic area. It can be constructed either from MDPE.

High pressure lines are generally trunk lines which convey large amount of gas from one part of country to another. Very large industrial consumers can be directly connected to trunk line but for domestic and commercial consumers the pressure is needed to be reduced at city gate station which is further reduced at district regulating station.

From the results above, we can conclude that there are considerable pressure losses in high pressure system, whereas, losses can be ignored in medium/low pressure systems. Therefore it is more important in high pressure pipelines to take measures for minimizing the pressure losses. Few steps can be: to apply internal coating, to minimize bends and fitting in pipeline, to avoid sudden change in flow path.

Medium pressure system can be further extended to more complicated looped, medium or low pressure networks. There are many methods to solve them such as Newton nodal method, Newton loop method, Newton loop-node method etc.

Now many softwares have been developed modeling, simulation and network analysis of complex pipeline networks such as:

- TGNET,TLNET
- Pipeline simulator engine
- Pipeline studio
- Pipeline manager real time modeling
- Chem share

All these software use one or more equations according to the require and it has become very easy to solve looped networks than by tedious iterative methods

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