MECHANICAL DESIGN AND ANALYSIS OF PMHBL MULTI PRODUCT CROSS COUNTRY PIPELINE

A thesis submitted in partial fulfilment of the requirements for the Degree of
Master of Technology
(Pipeline Engineering)

By

ALBY ABRAHAM ARACKAL
ROLL NO. R160206003

Under the guidance of

Prof. R. P. Shriwas
Senior Adjunct Professor
College of Engineering
University of Petroleum & Energy Studies

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UNIVERSITY OF PETROLEUM & ENERGY STUDIES
(ISO 9001:2000 Certified)

CERTIFICATE

This is to certify that the work contained in this thesis titled **"MECHANICAL DESIGN AND ANALYSIS OF PMHBL MULTI PRODUCT CROSS COUNTRY PIPELINE"** has been carried out by ALBY ABRAHAM ARACKAL (R160206003) under my supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

Petroleum and its products contribute to the energy requirements of a nation. The state of the country's development depends and is gauged by the fulfillment of the demand of petroleum products. Pipeline transportation is most suitable for bulk movement of liquid and gaseous consignments over long distances. The feasibility of pipelines for developing countries like India lies in its ability to traverse even the most, difficult terrain, to be practically unaffected by weather and to furnish transport of petroleum products at low unit cost (Chapter 1).

Pipeline as a capital intensive project requires careful study right from the conceptualization stage requiring a lot of man hours being put into it which makes it all the more tedious.

This report outlines the principles, for the mechanical design of the *Petronet Mangalore-Hassan- Mangalore* cross country product pipeline. For a number of reasons, design principles vary within the pipeline industry depending on fluid transported. The reasons are partly determined by the type of fluid, operating pressure and transport distance involved. Mechanical design of pipeline includes checking the selected pipeline thickness for different stresses (hoop and longitudinal stress), collapse and buckling. Design of pipeline also involves detailed survey of the route profile, which involves study of various obstructions, railway& road crossings, river crossings, elevation difference between two points along the pipeline route and soil chemistry etc., which provide a vital input for Process Design Basis as well as Engineering Design Basis. Correlation of all this factors enables optimum determination of steel grades and dimension of line pipe, pumps and pumping pressures, number of boosting stations (Chapter 3).

In this report we study the various design principles, methodology and procedures adopted for Petronet Mangalore-Hassan-Bangalore product pipeline; PMHBL is a joint venture

company promoted by Petronet India Ltd and Hindustan Petroleum Corporation Ltd, with 26% equity shares by each company. Petrol, Diesel, Kerosene, Naphtha and Aviation Turbine Fuel can be pumped through this pipeline. This report covers the aspects of internal and external stress analysis, loading by soil, hydraulic analysis and design of the pipeline (Chapter 4).

The final appropriate thickness which will help the pipeline operate safely during transportation of products, which will provide safe conditions during shutdown and installation and the maximum allowable combined stresses have been found out. Also the MAOP, SDH, appropriate grades have been found out which will prevent undue stresses on the pipeline during transportation (Chapter 5).

CHAPTER:-1

INTRODUCTION TO PIPELINES

1.1 INTRODUCTION:-

Petroleum and its products contribute to the energy requirements of a nation. The state of the country's development depends and is gauged by the fulfillment of the demand of petroleum products. Refining and marketing of Crude petroleum to produce required fuels is governed by availability of crude, the location of refineries and transportation to the major distribution centers.

CROSS-COUNTRY MOVEMENT OF OIL

OIL

Vital Source of Energy Essential for Domestic, Industry, Agriculture & Transport Sectors

CRUDE OIL

1. FROM WELLS TO GATHERING STATIONS
2. FROM GATHERING STATIONS TO REFINERIES
3. FROM PORTS TO REFINERIES

FINISHED PRODUCT

1. FROM REFINERIES TO CONSUMPTION CENTERS
2. FROM PORTS TO CONSUMPTION CENTERS

Road, rails and sea have always been the most common modes of transportation. With the growth of technology pipelines have become a popular mode of transportation. The term pipeline in broader sense means a facility used to transport commodities from point of receipt to the point of delivery.

Pipeline transportation is most suitable for bulk movement of liquid and gaseous consignments over long distances. Traditionally, pipelines have, proved to be the most convenient mode for transporting petroleum products. The feasibility of pipelines for developing countries like India lies in its ability to traverse even the most, difficult terrain, to be practically unaffected by weather and to furnish transport of petroleum products at low unit cost. Pipelines networks are always necessary to rationalize the surface transport system. They will go long way in relieving the overloaded surface transport system.

Pipelines also have the added advantage of being able to carry a number of commodities and also being the safest way of transporting inflammable goods.

1.2 HISTORY OF PIPELINE TRANSPORTATION:-

The pipeline system dates back to almost a hundred years. The first cross-country oil pipeline was laid in Pennsylvania in 1879 from Bradford to Allen town, about 109 miles long and 6" in diameter. The success of this pipeline prompted the United States to develop more pipelines in their country. The long distance pipeline transportation got a boost during World War II when coastal tanker traffic was disrupted. The pipelines were used as a foolproof way of transporting petroleum products. Later discoveries of giant oil fields in remote parts of the world led to planning and execution of correspondingly large pipeline networks. The main cause was that most of the oil fields were discovered in desert areas. Since road transportation was a very big problem, pipelines were developed. This concept caught on very fast and pipelines were built mainly from oil refineries to distributing centres. Thus, pipeline industry has grown in parallel with the development of world oil industry over the last one-century.

Most of the earlier refineries in India were installed at coastal locations, thus depending on coastal movement of crude oil. Further, the refining capacities being low, the products were either consumed locally or transported to the consumption centres by rail or road. After 1960, most of the refineries were installed in land-locked locations and crude and product pipelines were promptly laid. The first crude oil pipeline was laid from Digboi oil fields to Digboi refinery. Though this was a very small project it was a benchmark for further improvements in the Indian pipeline industry. During 1960-63, Oil India limited laid the first trunk crude oil pipeline, 1156 km long from Naharkatiya and Moran oil fields to the refineries at Guwahati and Barauni. The first cross-country product pipeline was laid during 1962-64 to transport products from Guwahati refinery to Siliguri. Subsequently, a number of product and crude oil pipelines were laid in the 60's, 70's and 80's, including sub-sea crude oil pipelines.

The pipelines laid during the 60's were designed, engineered and constructed by foreign companies. However, the exposure to this technology enabled Indian engineers to gain confidence, and the pipelines, which came up later, were designed and constructed with indigenous expertise. The country today has about 13,000 km of major crude oil and product pipelines. There are also a number of pipelines in the conceptualisation and building stage. Most of these pipelines are crude oil or product pipelines.

1.3 ADVANTAGES OF PIPELINE SYSTEM:-

Road, rails and sea have always been the most common modes of transportation. The main disadvantages of these systems are: -

- The time required for transportation is large.
- Safety hazards involved.
- Running these systems requires energy, which is again uneconomical.
- Additional energy is consumed for the transportation of dead weight containers.
- Losses due to evaporation, accounting and manual handling.

Therefore there is a need to develop such a mode of transportation, which is both safe and economic. The pipeline system of transportation is safe, economically viable and also environmentally friendly.

The main advantages of the pipeline system are: -

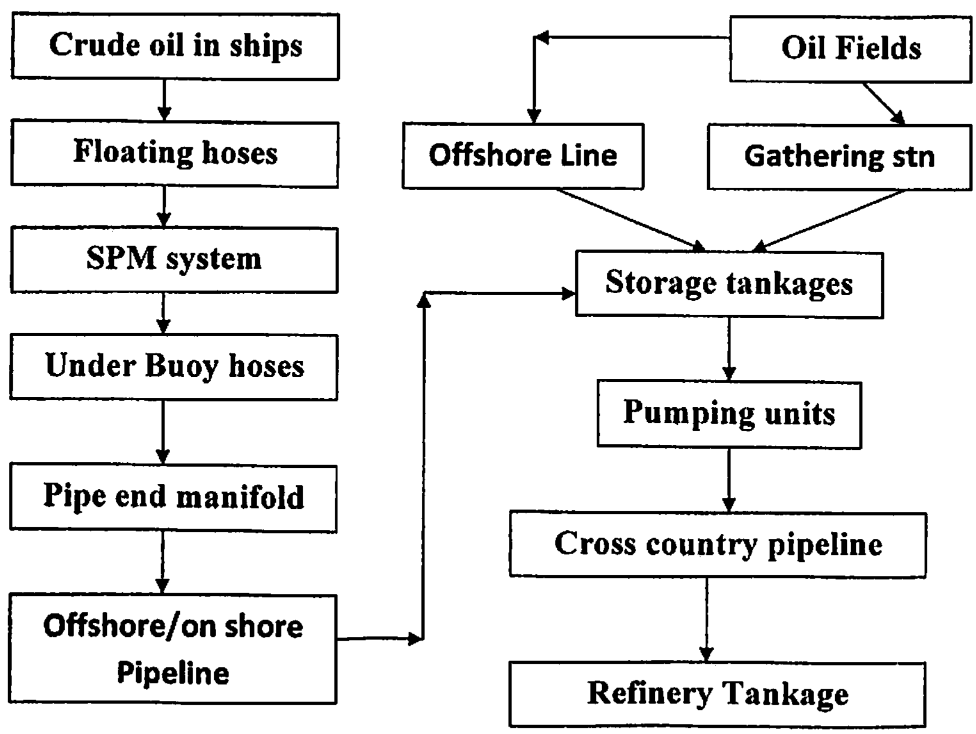
- They offer large scale economies in transportation.
- Transit losses are lower.
- Pipelines consume least energy.
- Reliable mode of transportation.
- Product handling is minimal hence enhancing safety.
- Impact on environment during construction, operation and maintenance is negligible and reversible making it environmentally friendly.
- Facility for multiple product handling.
- Flexibility in transport as the volume transported can be increased or decreased at a negligible cost.
- No consumption of energy for the transportation of dead weight containers.
- Pipelines can traverse difficult terrains. The land cost is also minimal since the pipeline can be buried underground and land can be restored back to other usage.
- Pipeline has the ability to maintain supplies even during floods, monsoons etc. and can provide massive relief movements required during drought situations.

The table below shows us the advantages of pipelines over road and rail transport.

Table 1.1 Comparison of Road, Rail& Pipeline Transport

HEAD	*ROAD*	*RAIL*	*PIPELINE*
ENERGY COST	VERY HIGH	HIGH	LOW
OPERATING COST	VERY HIGH	HIGH	LOW
POLLUTION	HIGH	LOW	NIL
MOVEMENT CONGESTION	HIGH	LOW	NIL
HANDLING LOSS	HIGH	LOW	NEGLIGIBLE
SAFETY HAZARDS	HIGH	LOW	NEGLIGIBLE
RELIABILITY	LOW	LOW	100%

The next fiure shows us the complete link between the various transport modes. From this table we also come to know that the piplines work in tandem with the various transport modes.



CHAPTER:- 2

LITERATURE REVIEW

2.1 BASIC DEFINITIONS:-

To discuss the basics of fluid flow in pipeline systems, it is necessary to first familiarize ourselves with how the key physical properties of fluids affect flow. The term "fluids" includes both liquids and gases. The effect of fluid properties on flow varies with the fluid type, i.e. Compressibility does not significantly affect the flow of liquids since liquids can, for the most part, be considered incompressible. Most of the following fluid properties and pipeline variables should be considered in modeling pipeline systems.

2.1.1 Density:-

Density or mass density of a fluid is defined as the ratio of the mass of a fluid to its volume. Thus mass per unit volume of a fluid is called density. The unit of mass density in SI unit is kg per cubic metre, *i.e.* kg/m^3. The density of liquids may be considered as constant while that of gases changes with the variation of pressure and temperature.

2.1.2 Specific Weight:-

Specific weight or weight density of a fluid is the ratio between the weight of a fluid to its volume. Thus weight per unit volume of a fluid is called weight density

2.1.3 Specific Volume:-

Specific volume of a fluid is defined as the volume of a fluid occupied by a unit mass or volume per unit mass of a fluid.

2.1.4 Specific Gravity:-

Specific gravity of a liquid is the density of the liquid divided by the density of water.

2.1.5 Viscosity:-

Viscosity is the property of a fluid that resists flow, or relative motion between adjacent parts of the fluid. It is an important term in calculating line size and pump horsepower requirements for liquid pipelines. Viscosity varies with temperature. Fluid viscosity will affect flow calculations.

2.1.6 Vapor Pressure:-

The pressure that holds a volatile liquid in equilibrium with its vapor at a given temperature is the vapor pressure. Vapor pressure is an especially important design criterion when handling volatile petroleum products, such as Liquefied Petroleum Gas (LPG). The minimum pressure in the pipeline must be high enough to maintain these fluids in a liquid state.

2.1.7 Pressure:-

Pressure can be defined as the force or thrust exerted over a surface divided by its area. In the context of pipelines, pressure can be thought of by the same definition. The source of the force applied to a fluid within the pipeline could come from the pumps, which transfer energy to the fluid via pistons or impellers, energy transferred from the reservoir within the earth, or the energy from gravity acting on a column of fluid due to elevation.

2.1.8 Hydraulic Gradient:-

The hydraulic gradient is a profile showing the pressure at any point along a pipeline. In the flow of liquid with a uniform velocity through a pipe of constant diameter, the hydraulic gradient is a straight line. This gradient represents only the pressure loss due to friction, which varies directly with the length of the pipe and the velocity of the fluid. The slope of the hydraulic gradient is proportional to the flow rate. Higher the flow rate, greater the slope of the hydraulic gradient.

2.1.9 Pipe Diameter:-

The larger the inside diameter of the pipeline, the more fluid can be moved through it, assuming that other variables are held constant.

2.1.10 Pipe Length:-

The greater the length of a segment of pipe, greater the total pressure drop. Pressure drop can be the same per unit length for a given size and type of pipe, but the total pressure drop increases with length.

2.1.11 Reynolds number:-

This dimensionless number is used to describe the type of flow exhibited by a flowing fluid. In laminar flow, the molecules move parallel to the axis of flow. In turbulent flow, molecules move back and forth across the flow axis. Other types of flow are also possible, and the Reynolds number can be used to determine which type is likely to occur under specified conditions. In turn, the type of flow exhibited by a fluid affects pressure drop in the pipeline. The Reynolds number can be calculated for any given liquid and pipe size as follows:

$$Re = VD/\mu \qquad (2.1)$$

Where,

Re= Reynolds Number (dimensionless)

V = average velocity (ft/sec)

D = internal diameter (ft)

μ = viscosity of the liquid.

It has been shown that for values of Re less than approximately 2000, the flow is laminar. For values of Re above 4000 the flow is considered turbulent. Between these two values lies the "critical zone" where the flow is unpredictable. It is more practical to express the calculation of the Reynolds number in oil field units as follows:

$$\mathbf{Re = 2214\, Q/\, k\, D} \qquad (2.2)$$

Where,

Re = Reynolds Number (dimensionless)
Q = flow rate.
D = internal diameter (m)
k = kinematic viscosity (centistokes)

Or,

$$\mathbf{Re = 35.42\, dQ\, /\mu D} \qquad (2.3)$$

Where,

Re = Reynolds Number (dimensionless)

Q = flow rate

D = internal diameter (m)

d = density (kg/m^3)

μ= Absolute viscosity (centipoise)

2.1.12 Friction Factor:-

A variety of friction factors are used in pipeline equations. They are determined empirically and are related to the roughness of the inside pipe wall. For laminar flow conditions (Re < 2000), the friction factor (f) is a function of the Reynolds number (Re) and is given by:

$$f=64/Re$$

For turbulent flow conditions (Re > 4000), the friction factor (f) is a function, of the Reynolds number (Re) and the surface roughness of the pipe wall. The value of f is usually obtained from a chart developed by Moody. More correctly, friction factor depends on the relative roughness (e/D) rather than the absolute pipe roughness e.

Various correlations exist for calculating the friction factor f. These are based on experiments conducted by scientists and engineers over the last 60 years or more. A good all-purpose equation for the friction factor f in the turbulent region (i.e., where R>4000) is the Colebrook-White equation:

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

Where,

f=Darcy friction factor, dimensionless

D=Pipe internal diameter, in.

e=Absolute pipe roughness, in.

R=Reynolds number of flow, dimensionless

In SI units, the above equation for f remains the same as long as the absolute roughness 'e' and the pipe diameter D are both expressed in mm. All other terms in the equation are dimensionless.

It can be seen from the Equation that the calculation of 'f' is not easy, since it appears on both sides of the equation. A trial-and-error approach needs to be used. We assume a starting value of f (say, 0.02) and substitute it in the right-hand side of Equation. This will yield a second approximation for 'f', which can then be used to re-calculate a better value of 'f', by successive iteration. Generally, three to four iterations will yield a satisfactory result for 'f', correct to within 0.001.

2.2 THEORY OF FLUID FLOW:-

When pressure is applied to one end of a section of pipe filled with liquid, the liquid tends to move toward the end with a lower pressure. Due to the friction between the fluid and the pipe wall, the velocity of the fluid varies across the cross section of the pipe. The following equation expresses fluid velocity as a function of the square of the radius or distance from the pipe wall:

$$V = (P\, g_c / 4\, \mu_E\, L)\,(r_w^2 - r^2) \qquad (2.4)$$

Where,

V = velocity, m/sec

P = pressure difference, N/m^2

g_c = acceleration of gravity, (N/m^2)

μ_E = viscosity of the liquid, Ns/m^2

L = length of pipe, m

r_w = internal pipe radius, m

r = radius of interest, m

In general, the laminar flow of liquids occurs at $Re < 2000$, and continues until flow velocity reaches a certain a critical value that depends on pipe size and liquid properties causing Re > *2000.* The liquid velocity in laminar flow can be visualized as being divided into many concentric cylinders with friction resisting motion of one with respect to the other Liquid velocity is near zero at the pipe wall and increases to a maximum at the pipe center. This effect of one lamination or thin cylindrical sheet of liquid flowing inside another gives the name "laminar flow".

As liquid velocity increases, the laminations are subject to increasingly disruptive forces. At some critical velocity where *Re* becomes greater than 2000, the flow pattern begins to break down, and the liquid flow becomes unstable. The instability increases as velocity increases, until the liquid panicles move in random directions, all moving at about the same velocity within the pipe .As *Re* approaches *4000,* the flow is said to be turbulent. Individual particles of fluid move in a turbulent pattern, but as a whole the fluid volume moves at a constant average velocity in the direction of the flow. Between laminar and turbulent flow the liquid is said to be in the transition zone or critical zone. In this critical zone, the relationship of pressure loss and flow is variable and not subject to accurate measurement.

Pipelines are designed to have fluids flow in the turbulent pattern due to the operational advantages of turbulent flow. Since liquid particles are moving approximately at the same velocity across the cross section of the pipe, there is less mixing of the batches of various grades of fluids pumped in sequence. There is also less of a tendency for water or sediment to separate from the fluids, which would decrease the efficiency of the pipeline.

2.2.1 Bernoulli's Equation:-

The basic principle of conservation of energy applied to liquid hydraulics is embodied in Bernoulli's equation, which simply states that the total energy of the fluid contained in the pipeline at any point is a constant. Obviously, this is an extension of the principle of conservation of energy which states that energy is neither created nor destroyed, but transformed from one form to another.

Consider the pipeline shown in Figure 2.1 that depicts flow from point A to point B with the elevation of point A being Z_A and elevation at B being Z_B above some chosen datum. The pressure in the liquid at point A is P_A and that at B is P_B. Assuming a general case, where the pipe diameter at A may be different from that at B, we will designate the velocities at A and B to be V_A and V_B respectively. Consider a particle of the liquid of weight

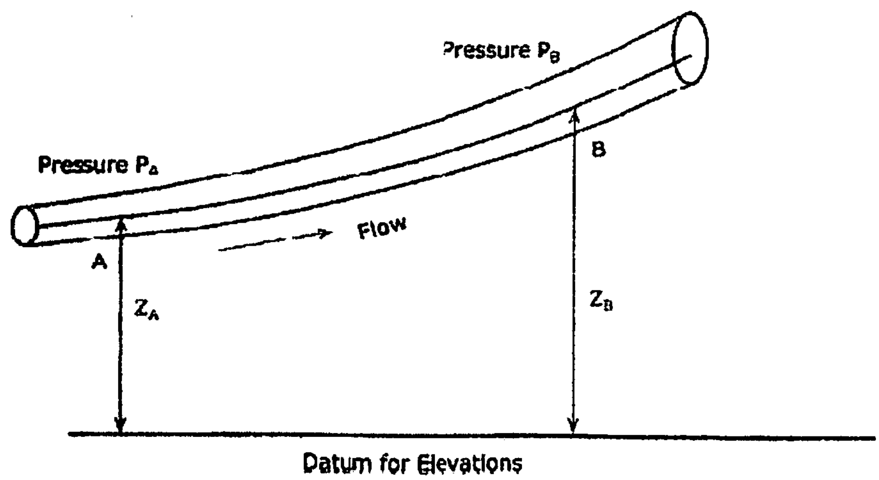


Figure 2.1 Energy of a liquid in pipe flow

'W' at point A in the pipeline. This liquid particle at A may be considered to possess a total energy E that consists of three components:

Energy due to position, or potential energy=WZ_A

Energy due to pressure, or pressure energy=WP_A/γ

Energy due to velocity, or kinetic energy =$W (V^2_A)/2g$

Where,

γ=Specific weight of the liquid

We can thus state that

$$E = WZ_A + WP_A/\gamma + WV^2_A/2g \quad (2.5)$$

Dividing by W throughout, we get the total energy per unit weight of liquid as

$$H_A = Z_A + P_A/\gamma + V^2_A/2g \quad (2.6)$$

Where,

H_A=total energy per unit weight at point A

Considering the same liquid particle as it arrives at point B, the total energy per unit weight at B is

$$H_B = Z_B + P_B/\gamma + V^2_B/2g \quad (2.7)$$

Due to conservation of energy

$$H_A = H_B$$

Therefore,

$$Z_A + P_A/\gamma + V^2_A/2g = Z_B + P_B/\gamma + V^2_B/2g \quad (2.8)$$

Equation (2.8) is one form of Bernoulli's equation for fluid flow.

In real-world pipeline transportation, there is energy loss between point A and point B, due to friction in the pipe. We include the energy loss due to friction by modifying Equation (2.4) as follows:

$$Z_A + P_A/\gamma + V^2_A/2g = Z_B + P_B/\gamma + V^2_B/2g + \sum h_L \quad (2.9)$$

Where,

Σh_L=all the head losses between points A and B, due to friction. In Bernoulli's equation (2.8), we must also include any energy added to the liquid, such as when there is a pump between points A and B. Thus the left-hand side of the equation will have a positive term added to it that will represent the energy generated by a pump. Equation (2.9) will be modified as follows to include a pump at point A that will add a certain amount of pump head to the liquid:

$$Z_A + P_A/\gamma + V^2_A/2g + H_P = Z_B + P_B/\gamma + V^2_B/2g + \sum h_L \quad (2.10)$$

Where,

H_P=pump head added to the liquid at point A

2.3 TELESCOPING PIPE WALL THICKNESS:-

On examining the typical hydraulic gradient shown in Figure 6.2, it is evident that under steady-state operating conditions the pipe pressure decreases from pump station to the terminus in the direction of flow. Thus, the pipeline segment immediately downstream of a pump station will be subject to higher pressures such as 1000 to 1200 psi while the tail end of that segment before the next pump station (or terminus) will be subject to lower pressures in the range of 50 to 300 psi. If we use the same wall thickness throughout the pipeline, we will be underutilizing the downstream portion of the piping. Therefore, a more efficient approach would be to reduce the pipe wall thickness as we move away from a pump station toward the suction side of the next pump station or the delivery terminus.

The higher pipe wall thickness immediately adjacent to the pump station will be able to withstand the higher discharge pressure and, as the pressure reduces down the line, the lower wall thickness would be designed to withstand the lower pressures as we approach the next pump station or delivery terminus. This process of varying the wall thickness to compensate

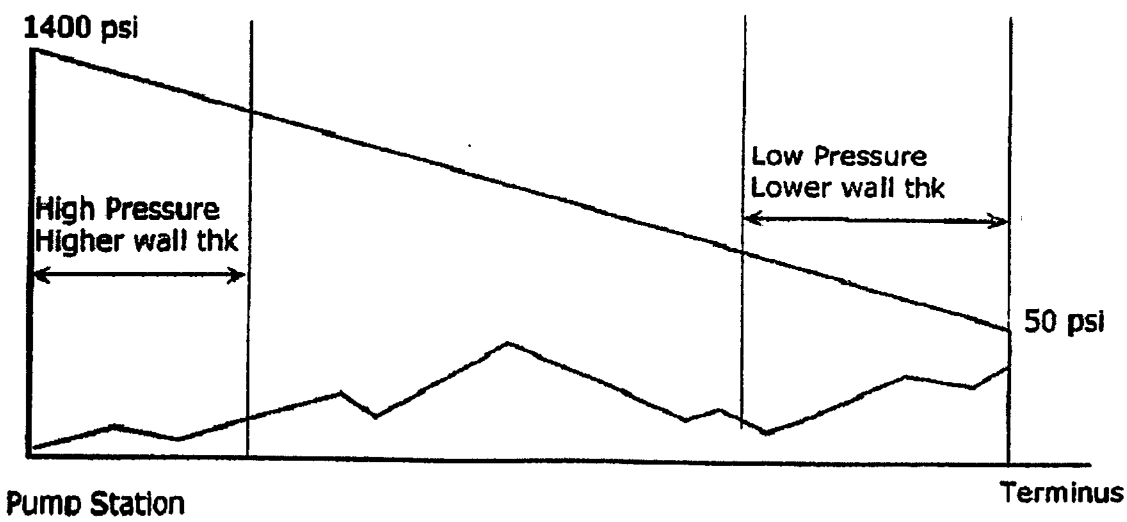


Figure 2.2 Telescoping pipe wall thickness

for reduced pipeline pressures is referred to as telescoping pipe wall thickness.

2.4 CHANGE OF PIPE GRADE: GRADE TAPERING:-

In the same way that pipe wall thickness can be varied to compensate for lower pressures as we approach the next pump station or delivery terminus, the pipe grade may also be varied. Thus the high-pressure sections may be constructed of X-52 grade steel whereas the lower-pressure section may be constructed of X-42 grade pipe material, thereby reducing the total cost. This process of varying the pipe grade is referred to as grade tapering. Sometimes a combination of telescoping and grade tapering is used to minimize pipe cost. It must be noted that such wall thickness variation and pipe grade reduction to match the requirements of steady-state pressures may not always work. Consideration must be given to increased pipeline pressures when intermediate pump stations shut-down and or under upset conditions such as pump start up, valve closure, etc. These transient conditions cause surge pressures in a pipeline and therefore must be taken into account when selecting optimum wall thickness and pipe grade.

2.5 TOTAL PRESSURE REQUIRED FOR TRANSPORT OF FLUID:-

The total pressure P_T required at the beginning of a pipeline to transport a given flow rate from point A to point B will depend on

- Pipe diameter, wall thickness, and roughness
- Pipe length
- Pipeline elevation changes from A to B
- Liquid specific gravity and viscosity
- Flow rate

If we increase the pipe diameter, keeping all other items above constant, we know that the frictional pressure drop will decrease and hence the total pressure P_T will also decrease. Increasing pipe wall thickness or pipe roughness will cause increased frictional pressure drop and thus increase the value of P_T. On the other hand, if only the pipe length is increased, the pressure drop for the entire length of the pipeline will increase and so will the total pressure P_T.

How does the pipeline elevation profile affect P_T? If the pipeline were laid in a flat terrain, with no appreciable elevation difference between the beginning of the pipeline A and the terminus B, the total pressure P_T will not be affected. But if the elevation difference between A and B were substantial, and B was at a higher elevation than A, P_T will be higher than that for the pipeline in flat terrain.

The higher the liquid specific gravity and viscosity, the higher will be the pressure drop due to friction and hence the larger the value of P_T. Finally, increasing the flow rate will result in a higher frictional pressure drop and therefore a higher value for P_T.

In general, the total pressure required can be divided into three main components as follows:

- Friction head
- Elevation head
- Delivery pressure at terminus

CHAPTER:-3

THEORETICAL DEVELOPMENT

3.1 PIPEWALL THICKNESS DESIGN:-

The onshore pipeline wall thickness is designed in accordance with ASME B31.4. The wall thickness design of the onshore pipeline is performed based on internal pressure containment under both operation and hydrotest conditions. External pressure due to soil overburden for the specified burial depth is assumed to be zero as it is negligible as compared to internal pressure. If the pipeline is backfilled immediately after installation, then there is the need to check for collapse due to overburden with zero pressure in the pipe.

In addition, the selected thickness for the onshore pipeline should be compatible with the expected installation method and practical pipe handling.

3.1.1 Design Criteria:-

The pipe wall thickness shall satisfy a design factor of 0.72 for Location Class 1, division 2, as extracted from design basis (Table 3.1).

3.1.2 Pressure Containment Design:-

Based on ASME B31.4, the wall thickness of the onshore pipeline shall satisfy the pressure requirement based on the following equation

$$t = PD/2S\,(FE) \quad (3.1)$$

$$t_n = t + CA \quad (3.2)$$

Where,

P= design pressure (MPa)

D= outside diameter of pipe (mm)

t_n= nominal wall thickness satisfying requirements for pressure and corrosion allowances (mm)

t = corroded pipe wall thickness (mm)

CA= corrosion allowance (mm)

F = design factor from Table 3.1

= 0.72

E = longitudinal joint factor from Table 3.2

= 1.0 (seamless pipe class)

S = specified minimum yield strength (MPa)

Table 3.1 Design Factor (F)

Class location	Design factor (*F*)
1	0.72
2	0.60
3	0.50
4	0.40

Table 3.2 Longitudinal joint factor (E)

Specification	Pipe class	Longitudinal joint factor(E)
ASTM A 53/A53M	Seamless	1.00
	Electric resistance welded	1.00
	Furnace butt welded	0.60
ASTM A 106	Seamless	1.00
ASTM A 333/A 333M	Seamless	1.00
	Electric resistance welded	1.00
ASTM A 381	Double submerged arc welded	1.00
ASTM A 671	Electric-fusion-welded	1.00
ASTM A 672	Electric-fusion-welded	1.00
ASTM A 691	Electric-fusion-welded	1.00
API 5 L	Seamless	1.00
	Electric resistance welded	1.00
	Electric flash welded	1.00
	Submerged arc welded	1.00
	Furnace butt welded	0.60
Other	Pipe over 4 inches (102 millimetres)	0.80
Other	Pipe 4 inches (102 millimetres) or less	0.60

3.1.3 Nominal Wall Thickness:-

The nominal pipe wall thickness of line pipe is the specified wall thickness taking into account manufacturing tolerance.

3.1.4 Corrosion Allowance:-

The external surface of pipelines is generally protected from corrosion with a combination of external coating and cathodic protection system. The internal surface, depending upon the service, may be subject to corrosion. This is accounted for by the addition of corrosion inhibitors or applying a corrosion allowance to the pipeline wall thickness. The corrosion allowance is calculated from the anticipated corrosion rate and the design life of the pipeline system.

3.1.5 Manufacturing Tolerance:-

Manufacturing or mill tolerances are specified acceptance limits for the line pipe wall thickness during manufacture. The tolerance will depend upon size of pipe and manufacturing process involved. A negative wall thickness tolerance should be taken into account when calculating wall thickness required for hoop stress criteria.

3.2 COLLAPSE DUE TO EXTERNAL PRESSURE:-

ASME B31.4 does not provide guidelines for pipeline collapse due to external pressure and therefore API RP 1111 methodology shall be used. The pipe wall thickness shall be designed to withstand collapse due to external pressure. During installation and shutdown, the external pressure due to backfill can cause collapse of the pipe. Therefore, the selected pipe wall thickness shall have adequate strength to prevent the collapse by taking into consideration physical properties, ovality and external loads.

In accordance with API RP 1111, Section 4.3.2, the characteristic capacity for external pressure (collapse) is given by:

$$(P_o - P_i) \leq f_o \times P_c \qquad (3.3)$$

$$P_e = \frac{2E\left(\frac{t}{D}\right)^3}{1-v^2} \qquad P_Y = \frac{2St}{D} \qquad P_c = \frac{(P_Y \times P_e)}{\sqrt{P_Y^2 + P_e^2}}$$

Where,

P_e= Elastic Collapse pressure (MPa)

P_Y= Yield pressure at collapse (MPa)

P_c= Collapse pressure of the pipe (MPa)

P_o= External pressure (MPa)

P_i = Internal pressure (MPa)

f_o= Collapse factor

= 0.7 for seamless or ERW pipe

= 0.6 for cold expanded pipe such as SAW

E = Young's modulus of steel (MPa)

ν = Poisson's ratio for steel.

D = Outside diameter of pipe (mm)

t = Corroded wall thickness of pipe (mm)

S = Specified minimum yield strength of pipe (N/mm^2)

The external pressure collapse checks are critical during installation due to maximum pressure difference and during operation shutdown when the pipe is fully corroded.

3.2.1 Vertical Earth Load (External Pressure, P_o):-

Vertical earth load is primarily a consideration for the non-operating conditions of buried steel pipe when the pipeline is under no internal pressure. Under most operating conditions, the external earth pressure can be neglected since it is insignificant in comparison to the internal pipe pressure. Vertical earth load is an important consideration when designing the pipe casing used for rail and road crossings.

For the purpose of calculating earth loads on a buried pipe, a steel pipe is considered flexible and design procedures for flexible pipes apply. For flexible pipes placed in a trench and covered with backfill, the earth dead load applied to the pipe is the weight of a prism of soil with a width equal to that of the pipe and a height equal to the depth of fill over the pipe, as shown in Figure 3.1. This approach is followed for both trench and embankment conditions.

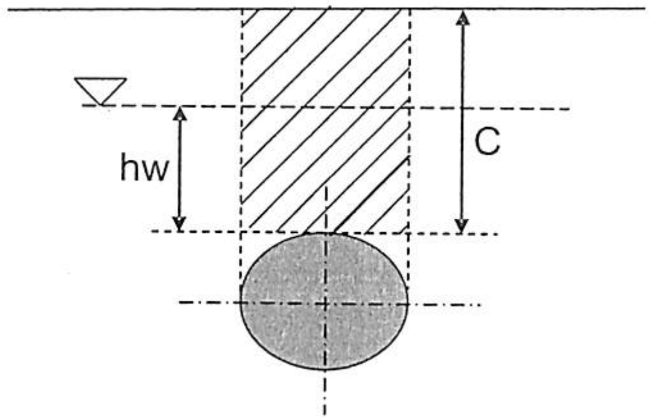


Figure 3.1 Soil prism above pipe

For conditions where the pipeline is above the water table, an upper-bound estimate of the pipe pressure resulting from earth dead load can be obtained using Equation 3.4,

$$P_o = \gamma C \qquad (3.4)$$

Where,

P_o = earth dead load pressure on the conduit.

γ = total dry unit weight of fill.

C = height of fill above top of pipe.

3.3 NEGATIVE BUOYANCY REQUIREMENT:-

3.3.1 General:-

Pipeline must achieve sufficient negative buoyancy to prevent floatation. It is more so for pipeline which are prone to seismic excitation. This is because accelerations due to seismic excitation will cause addition forces to act on the pipeline.

The criterion for establishing pipeline floatation is, generally, the specific gravity. Pipeline with specific gravity more than 1.1 will ensure the propensity of pipeline floatation is low.

The onshore pipeline is assumed to be lying across seismic zone. The design of the pipeline system will take into consideration the additional stress acting on the pipeline and determine if floatation occurs due to seismic effect during operation.

3.3.2 Flotation:-

Specific gravity of pipe: W_{sub}/V

Where,

W_{sub}= submerged weight of pipe

$= W_{pipe} + W_{cte} + W_{cc} - W_{buoy}$

V = volume of pipe (including coating)

W_{pipe} = weight of pipe material

W_{cte} = weight of coal tar enamel coating

W_{cc} = weight of concrete coating

W_{buoy}= buoyancy of pipe

Floatation check is carried out for buried pipeline in empty condition.

***NOTE:** In this project the water table is coming below the pipeline so the flotation check is not carried out.*

3.3.3 Pipe under Seismic Excitation:-

Under seismic excitation, the additional vertical forces on the pipeline may enable the pipeline to overcome the gravity load of self-weight and the soil cover and subsequently being exposed.

The following equations for lateral and vertical forces on the pipeline due to seismic effect are given for onshore pipeline:

$$F_{LS}=A_h W_p \quad (3.5)$$

$$F_{VS}=A_v W_p \quad (3.6)$$

Where,

F_{LS}= lateral force due to seismic effect on the pipe (N/m)

F_{VS}= vertical force due to seismic effect on the pipe (N/m)

W_p= weight of pipe (N/m)

A_h= design horizontal seismic coefficient

= 0.125

A_v= design vertical seismic coefficient

= 0.083

3.4 IN-PLACE STRESS ANALYSIS:-

3.4.1 General:-

Pipeline during operation condition is subjected to internal pressure, temperature differential, overburden loads, bending due to curvature etc., causing hoop, longitudinal and combined stresses in the pipeline. The stresses are to be kept within allowable limits to safeguard against pipe overstressing, which may lead to failure. If pipeline falls within seismic zone, additional lateral and horizontal forces as a result of seismic excitation must also be taken into consideration.

The in-place stress analysis for the pipeline is performed in accordance with ASME B31.4 and OISD 141. The most critical scenario, where the pipeline is in operating condition and under seismic excitation, is examined

3.4.2 Allowable stresses:-

The maximum allowable stresses, expressed as a percentage of the Specified Minimum Yield Strength (SMYS) of steel for the analysis are summarized in Table 3.3 below.

Table 3.3 Allowable Stresses

Description	ASME B31.4/OISD 141 Clause	Allowable Stress
Hoop Stress	ASME B 31.4 Cl. 841.1 14	0.72 SMYS
Longitudinal Stress	ASME B 31.4 Cl. 841.114 (Compression)	0.72 SMYS
	OISD 141 Cl. 12.3.3.2 (Tension)	0.90 SMYS
Combined Stress	ASME B 31.4 Cl. 833.4	1.00 SMYS

3.4.3 Analysis Methodology:-

The pipeline, during operation, is assumed to be in the restrained condition as it is to be buried and external pressure due to soil overburden is neglected. Both assumptions will lead to a conservative design for the pipeline system. The pertinent equations for this analysis are listed as follows:

Hoop Stress

The hoop stress is calculated using the equation below:

$$S_h = \frac{PD}{2t} \tag{3.7}$$

Where,

S_h = Hoop stress (MPa)

P = Net pressure (MPa)

$= P_i - P_e$

P_i = Internal design pressure (MPa)

P_e = External soil overburden pressure (MPa)

= 0

D = Pipeline outer diameter (mm)

t = Corroded pipe wall thickness (mm)

Longitudinal Stress

The longitudinal stress component for a restrained pipeline due to Poisson's effect, thermal and bending stresses is determined using the following equation:

$$S_L = \nu \times S_h - \alpha \times E \times \Delta T \pm S_B \tag{3.8}$$

Where,

S_L = Longitudinal Stress (MPa)

S_h = Hoop stress (MPa)

ν = Poisson's ratio of steel

= 0.3

E = Young's modulus of steel (MPa)

α = Co-efficient of thermal expansion (1/°C)

= 11.7×10^{-6} for steel

ΔT= Temperature difference between the product and surrounding air (°C)

S_B = Bending stress due to span bending and horizontal curve (MPa)

$= (\sigma_{BH}^2 + \sigma_{BV}^2)^{0.5}$

S_{BH}= Bending stress due to Horizontal component (MPa)

$= (F_H \times L^2 \times D) / (20 \times I)$

S_{BV}= Bending stress due to vertical component (MPa)

$= (F_V \times L^2 \times D) / (20 \times I) + (E \times D) / (2000 \times R_V)$

R_V= Horizontal bend radius, (m)

D = Outer diameter of steel pipe (m)

F_H = Horizontal loading (N/m)

$= F_{LS}$

F_V = Vertical loading (N/m)

$=F_{VS} + W_s$

F_{LS}= Lateral force due to seismic acceleration (N/m)

F_{VS}= Vertical force due to seismic acceleration (N/m)

W_s = Submerged Weight (N/m)

L = Allowable span, (m)

I = Moment inertia of the steel pipe (m^4)

Combined Stress

The Von-Mises equivalent stress is given by:

$$S_{eq} = (S_h^2 + S_L^2 - S_h S_L + 3S_t^2)^{0.5} \qquad (3.9)$$

Where,

S_{eq}= Von-Mises Equivalent Stress

S_h = Hoop stress

S_L = Longitudinal stress

S_t = Torsional stress

The torsional stress is negligible when compared to longitudinal stress or hoop stress. Thus, the torsional stress is ignored. The equation is approximated as:

$$S_{eq} = (S_h^2 + S_L^2 - S_h S_L)^{0.5} \qquad (3.10)$$

3.5 HYDRAULIC DESIGN:-

3.5.1 Pressure head losses:-

When fluid is transported in a conduit, the loss of head due to friction can be calculated with the help of the well know Darcy-Weisbach formula:

$$h_f=(\lambda \times L \times V^2)/(2D_i \times g) \qquad (3.11)$$

Where:

λ = friction co-efficient

h_f = friction head loss (m)

L = length of pipe (m)

D_i= Internal pipe diameter (m)

V = velocity of fluid inside conduit (m/s)

g = acceleration due to gravity (m/s^2)

The total friction head loss in the system is however a simulation of the following head losses.

Entrance loss (h_e)

Bend losses (h_b)

Loss resulting from change of pipe diameter (h_c)

Loss in valves (h_v)

Exit loss (h_x)

Friction loss in pipe (h_f)

Therefore the total head loss is given by

$$H_T = V^2 ((\lambda_f \times L/D) + \lambda_e + \lambda_b + \lambda_c + \lambda_v + \lambda_x) / (2g)$$

3.5.1.1 Entrance losses (h_e):-

$$h_e = \lambda_e (V^2 / (2g)) \quad (3.12)$$

Where,

λ_e =co-efficient of entrance loss which is a function of the shape of the entrance to the pipe

= 0.35 to 0.45 (Sharp edged entrances)

= 0.25 to 0.30 (beveled entrances)

= 0.06 to 0.08 (round shaped entrances)

3.5.1.2 Loss due to sudden change in pipe diameter:-

$$h_c = \lambda_c (V_1^2 / (2g)) \quad (3.13)$$

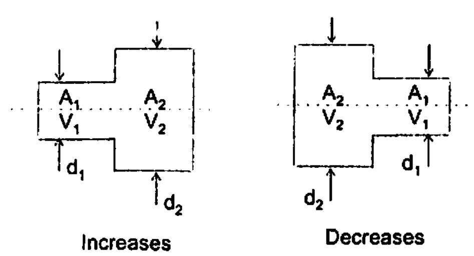
Where,

$\lambda_c = (1 - A_1/A_2)^2$ (Increase in area)

= 0.5 for sudden decreases

= 0.05 for beveled decreases

A_1 = C/S area in smaller pipe



A_2 = C/S area in Larger pipe

V_l = Flow velocity in smaller pipe

3.5.1.3 Exit losses:-

$$h_x = \lambda_x (V_l^2 / (2g)) \qquad (3.14)$$

Where,

λ_x = 0 for pipe discharging in air

= 1 for a pipe discharging in water (i.e., submerged)

3.5.2 Friction losses in the pipe itself:-

According to Reynolds, flow is laminar at wall & turbulence in the centre of the pipe, these direct causes of turbulence was the pipe wall roughness. This is contradicted by prandtl.

When flow takes place inside a pipe each annulus of fluid imports a shear force onto an inner neighboring concentric annulus. These shear force are proportional to the square of the difference in velocity.

In actual practice the flow is particularly always in the transition between rough and smooth pipe. Therefore Prandtl-Colebrook derived an equation which is valid for the transition area as well as for rough and smooth pipe.

$$1/\lambda^{0.5} = -2 \log (2.51 / Re \times \lambda^{0.5}) + (K/(3.71 \times D_i)) \qquad (3.15)$$

Where

K = Prandtl-Colebrook friction co-efficient

3.6 ECONOMIC ANALYSIS:-

In any pipeline investment project we must perform an economic analysis of the pipeline system to ensure that we have the right equipment and materials at the right cost to perform the necessary service and provide a profitable income for the venture. We analyze the cost implications and how to decide on the economic pipe size and pumping equipment required to provide the optimum rate of return on investment.

The major capital components of a pipeline system consist of the pipe, pump stations, storage tanks, valves, fittings, and meter stations. Once this capital is expended, and the pipeline has been installed and the pump station and other facilities built, annual operating and maintenance costs for these facilities will be incurred. Annual costs will also include general and administrative (G&A) costs including payroll costs, rental and lease costs, and other recurring costs necessary for the safe and efficient operation of the pipeline system. The revenue for this operation will be in the form of pipeline tariffs collected from companies that ship products through this pipeline. The capital necessary for building this pipeline system may be partly owner equity and partly borrowed money. An economic analysis must be performed for the project taking into account all these factors and a reasonable project life of 20 to 25 years, or more in some cases.

3.6.1 Capital Costs:-

The capital cost of a pipeline project consists of the following major components:

- Pipeline
- Pump stations
- Tanks and manifold piping
- Valves, fittings, etc.
- Meter stations
- SCADA and telecommunication
- Engineering and construction management
- Environmental and permitting
- Right-of-way acquisition cost
- Other project costs such as allowance for funds used during construction (AFUDC) and contingency

3.6.1.1 Pipeline Costs:-

The capital cost of a pipeline consists of material and labor for installation. To estimate the material cost we will use the following method:

Pipe material cost (PMC) = 28.1952 L (D-t) t (Cpt) (12.1) (3.16)

Where,

PMC=Pipe material cost, $

L=Pipe length, miles

D=Pipe outside diameter, in.

t=Pipe wall thickness, in.

Cpt=Pipe cost, $/ton

In SI units, Equation (3.16) can be written as

PMC=0.02463 L (D-t) t (Cpt) (3.17)

Where,

PMC=Pipe material cost, $

L=Pipe length, km

D=Pipe outside diameter, mm

t=Pipe wall thickness, mm

Cpt=Pipe cost, $/metric ton

Since the pipe will be coated, wrapped, and delivered to the site, we will have to increase the material cost by some factor to account for these items or add the actual cost of these items to the pipe material cost.

Pipe installation cost or labor cost is generally stated in $/ft or $/mile of pipe. It may also be stated based on an inch-diameter-mile of pipe. Construction contractors will estimate the labor cost of installing a given pipeline based on a detailed analysis of the terrain, construction conditions, difficulty of access, and other factors. A good approach is to express the labor cost in terms of $/inch diameter per mile of pipe. Thus we can say that a particular 16 in. pipeline can be installed at a cost of $15,000 per inch-diameter-mile. Therefore, for a 100 mile, 16 in. pipeline we can estimate the labor cost to be

Pipe labor cost=$15,000×16×100=$24 million

3.6.1.2 Pump Station:-

To estimate the pump station cost a detailed analysis would consist of preparing a material take-off from the pump station drawings and getting vendor quotes on major equipment such as pumps, drivers, switchgear, valves, instrumentation, etc., and estimating the station labor costs.

An approximate cost for pump stations can be estimated using a value for cost in dollars per installed horsepower. This is an all-inclusive number considering all facilities associated with the pump station. For example, we can use an installed cost of $1500 per HP and estimate that a pump station with 5000 HP will cost

$1500×5000=$7.5 million

In the above we used an all-inclusive number of $1500 per installed HP. This figure takes into account all material and equipment cost and construction labor. Such values of installed cost per HP can be obtained from historical data on recently constructed pump stations. Larger HP pump stations will have smaller $/HP costs while smaller pump stations with less HP will have a higher $/HP cost, reflecting economies of scale.

3.6.1.3 Tanks and Manifold Piping:-

Tanks and manifold piping can be estimated fairly accurately by detailed material take-offs from construction drawings and from vendor quotes.

Generally, tank vendors quote installed tank costs in $/bbl. Thus if we have a 50,000 bbl tank, it can be estimated at

50,000×$10/bbl=$500,000

based on an installed cost of $10/bbl.

We would of course increase the total tankage cost by a factor of 10– 20% to account for other ancillary piping and equipment.

As with installed HP costs, the unit cost for tanks decreases with tank size. For example, a 300,000 bbl tank may be based on $6/bbl or $8/bbl compared with the $10/bbl cost for the smaller, 50,000 bbl tank.

3.6.1.4 Valves and Fittings:-

Valves and fittings may also be estimated as a percentage of the total pipe cost. However, if there are several mainline block valve locations that can be estimated as a lump sum cost, we can estimate the total cost of valves and fittings as follows: A typical 16 in. mainline block valve installation may cost $100,000 per site including material and labor costs. If there are 10 such installations spaced 10 miles apart on a pipeline, we would estimate cost of valves and fittings to be $1.0 million.

3.6.1.5 Meter Stations:-

Meter stations may be estimated as a lump sum fixed price for a complete site. For example, a 10 in. meter station with meter, valves, and piping instrumentation may be priced at $250,000 per site including material and labor cost. If there are two such meter stations on the pipeline, we would estimate total meter costs at $500,000.

3.6.1.6 SCADA and Telecommunication System:-

This category covers costs associated with Supervisory Control and Data Acquisition (SCADA), telephone, microwave, etc. SCADA system costs include the facilities for remote monitoring, operation, and control of the pipeline from a central control center. Depending upon the length of the pipeline, number of pump stations, valve stations, etc., the cost of these facilities may range from $2 million to $5 million or more. An estimate based on the total project cost may range from 2% to 5%.

3.6.1.7 Engineering and Construction Management:-

Engineering and construction management consists of preliminary and detailed engineering design costs and personnel costs associated with management and inspection of the construction effort for pipelines, pump stations, and other facilities. This category usually ranges from 15% to 20% of total pipeline project costs.

3.6.1.8 Environmental and Permitting:-

In the past, environmental and permitting costs used to be a small percentage of the total pipeline system costs. In recent times, due to stricter environmental and regulatory requirements, this category now includes items such as an environmental impacts report, environmental studies pertaining to the flora and fauna, fish and game, endangered species, and allowance for habitat mitigation. The latter cost includes the acquisition of new acreage to compensate for areas disturbed by the pipeline route. This new acreage will then be allocated for parks, wildlife preserves, etc.

Permitting costs would include pipeline construction permits such as road crossings, railroad crossings, river and stream crossings, and permitting for antipollution devices for pump stations and tank farms. Environmental and permitting costs may be as high as 10% to 15% of the total project costs.

3.6.1.9 Right-of-Way Acquisitions:-

Right of way (ROW) must be acquired for building a pipeline along private lands, farms, public roads, and railroads. In addition to initial acquisition costs there may be annual lease costs that the pipeline company will have to pay railroads, agencies, and private parties for pipeline easement and maintenance. The annual ROW costs would be considered an expense and would be included in the operating costs of the pipeline.

3.6.1.10 Other Project Costs:-

Other project costs would include allowance for funds used during construction (AFUDC), legal and regulatory costs, and contingency costs. Contingency costs cover unforeseen circumstances and design changes including pipeline rerouting to bypass sensitive areas, pump stations and facilities modifications not originally anticipated at the start of the project. AFUDC and contingency costs will range between 15% and 20% of the total project cost.

3.6.2 Operating Costs:-

The annual operating cost of a pipeline consists mainly of the following:

- Pump station energy cost (electricity or natural gas)
- Pump station equipment maintenance costs (equipment overhaul, repairs, etc.)
- Pipeline maintenance cost including line rider, aerial patrol, pipe replacements, relocations, etc.
- SCADA and telecommunication costs
- Valve and meter station maintenance
- Tank farm operation and maintenance
- Utility costs: water, natural gas, etc.
- Ongoing environmental and permitting costs
- Right-of-way lease costs
- Rentals and lease costs
- General and administrative costs including payroll

3.6.3 Feasibility Studies and Economic Pipe Size:-

In many instances we have to investigate the technical and economic feasibility of building a new pipeline system to provide transportation services for liquids from a storage facility to a refinery or from a refinery to a tank farm. Other types of studies may include technical and economic feasibility studies for expanding the capacity of an existing pipeline system to handle additional throughput volumes due to increased market demand or refinery expansion.

Grass roots pipeline projects, where a brand new pipeline system needs to be designed from scratch, involve analysis of the best pipeline route, optimum pipe size, and pumping equipment required to transport a given volume of liquid. In this project we will learn how an economic pipe size is determined for a pipeline system, based on an analysis of capital and operating costs. To determine the optimum pipe size required, we must analyze the capital costs and the annual operating costs to determine the scenario that gives us the least total cost, taking into account a reasonable project life. We would perform these calculations considering the time value of money, and select the option that results in the lowest present value (PV) of investment.

Generally, in any situation we must evaluate at least three or four different pipe diameters and calculate the total capital costs and operating costs for each pipe size.

CHAPTER:-4

PIPELINE SYSTEM DESIGN

CHAPTER:-4

PIPELINE SYSTEM DESIGN

4.1 PETRONET MHB LIMITED:-

Petronet Mangalore-Hassan-Bangalore Ltd was incorporated as company on 31-07-1998 on common carrier principle (provide product transportation service to any I all shippers upon reasonable request). PMHBL is a joint venture company promoted by Petronet India Ltd and Hindustan Petroleum Corporation Ltd, with 26% equity shares by each company. Oil & Natural Gas Corporation Ltd has joined as a strategic partner in the company by taking 23 % equity. The total cost of the project is Rs.667 crores with debt equity ratio of 3:1 and project has been completed within the approved cost. This pipeline will evacuate the petroleum products from Mangalore Refinery and bring to Hassan and Devangonthi at Oil Marketing Co. Terminals. Petrol, Diesel, Kerosene, Naphtha, and Aviation Turbine Fuel can be pumped through, this pipeline and this pipeline will meet the needs of Hassan, Mysore, Mandya, Tumkur, Chikmagalur, Chitradurga, Shimoga, Kolar, Bellary, Riachur, Bangalore Rural & Bangalore Urban districts of Karnataka State.

The Mangalore-Hassan-Bangalore pipeline project owned by Petronet MHB Ltd is a 362 km long cross country multi product pipeline laid for transporting POL products like High Speed Diesel, Motor Spirit, Superior Kerosene Oil, Naphtha and Aviation Turbine Fuel from the Mangalore Refinery & Petrochemicals at Mangalore to Bangalore via Hassan town.

4.2 ROUTE SELECTED:-

The pipeline takes off from Mangalore Refinery located in Dakshina Kannada District, Karnataka State with Geographical location as Latitude 12° 58 min and Longitude 74^0 51 min. The pipeline passes through the fields of more than 5515 landowners in 237 villages & 17 Taluks under administrative jurisdiction of Dakshina Kannada, Chikmagalur, Hassan, Mandya, Tumkur and Bangalore rural & Bangalore urban Districts of Karnataka State.

The entire pipeline route is made up of diversified landscape and is characterized by undulated profile with the presence of hill ranges, rocky areas, plains, streams and valleys. The pipeline from Mangalore runs by the shortest route through the coastal plains and travels through the Western Ghats of Dharmastala - Neriya- Devaramane sector. The elevation pattern varies from 4.39 meters at Mangalore take off point with, respect to Mean Sea Level (MSL) and goes down to 0.4 meters, at the lowest point and then rises gradually up to 125 meters at Neriya Pump Station over a distance of 79.2 Km. Pipeline then enters Charmadi Ghat of Western Ghats and further steeply rises within 14.399 Km to 914.61 meter at 93.349 Km Chainage and then goes down to 769.61 meter at 96.77 Km Chainage at Hulukamale halla river and further steeply rises within 2.13 Km to 1127.53 meter at 98.90 Km Chainage i.e. at Gutti saddle. The slopes are up to 70^0 and even 60 long radius bends have been used within 1 Km. Then the pipeline descends and traverses Coffee Estates towards Hassan pumping and delivery station at 165 Km having an elevation of 951 mtr. From Hassan the pipeline covers a distance of 197.3 Km to reach Bangalore Receipt station. Finally the pipeline terminates at Devangonthi Terminal station, having an elevation of 890.66 mtr at Bangalore City. The Geographic Location of Devangonthi Station is 12° 59 min latitude and 77° 51 min longitude. PMHBL is the first pipeline laid in such a difficult terrain in this country, & probably in the world. The pipeline traverses through 4.85 Kms of Reserve Forest area, 3.35 Kms of State Forest area, 24 Kms of Ghat section, 15 Kms of coffee plantation area, 4.5 Kms of cashew nut plantation, 7.4 Kms of Areca nut plantation, 34.1 Kms of barren land and balance crop and mixed plantation area. In the entire route, the pipeline crosses 8 major rivers viz Gurupur, Netravathi, Apiyur, Japavathi, Hemavathi, Shimsa and Akavathi. It also crosses about 338 different roads (including 5 National Highways) and 8 Major railway lines where the horizontal boring method had been used for pipe laying, so that normal traffic of major highways and railways were not affected.

4.3 SYSTEM DESIGN BASIS:-

The major steps involved in the pipeline system design are:-

- Determination of major parameters for the pipeline.
- Selection of probable sizes.
- Determination of hydraulics, system configuration and value.
- Selection of sizes with least present value.

The major considerations taken while designing are:-

- Route survey.
- Volume of flow considerations for 10-15 years.
- Length of the pipeline.
- Elevation profile and terrain.
- Residual head required at receipt terminal.

- Fluid characteristics like specific gravity, density, viscosity, pour point, yield stress and friction.
- Type of prime movers.
- Location of stations.

The Physical characteristics and total demand of each product as envisaged for Phase I, 2006-07, and Phase II 2013-14, which is the design basis for of the project are as below:-

Table 4.1 Product Characteristics& Demand

Product	Sp Gravity @15° C	Viscosity CST	Vapor Pr Kg / cm²	Phase I Tonnes / Yr	Phase II Tonnes / Yr
MS	0.7289	0.51 @ 38°C	0.7	496000	839000
HSD	0.8359	0.5 @ 37°C	0.1	3397000	5784000
SKO	0.8105	1.18 @ 37°C	--	617000	759000
ATF	0.8105	1.18 @ 37°C	--	56000	79000
NAPTHA	0.6959	0.45@ 37.8°C		1000000	1000000

Total requirement is 5.6 MMTPA in Phase I and 8.5 MMTPA in Phase II. Pipeline has been designed for the final throughput as envisaged for the year 2013-14. However, other facilities like pumping system, storage tanks, loading facilities etc, are designed for the throughput as envisaged in the year 2006-07.

4.4 STEPS TO BE FOLLOWED:-

4.4.1 Flow rate (Q):-

The flow rate required for the pipeline is set by considering the initial throughput, demand and consumption centers.

4.4.2 Velocity (V):-

The velocity is calculated by the continuity equation.

$$Q = V*A \qquad (4.1)$$

Where,

A= Cross section area of the pipeline.

4.4.3 Reynolds number (R_e):-

The Reynolds number is calculated by the relation:

$$R_e = v * D / Z \quad (4.2)$$

Where,

v = Fluid viscosity (m/sec)

D= Inside diameter of pipe (m)

Z= Kinematic viscosity (m^2/sec)

The R_e has to be greater than 4000 for turbulent flow which is necessary in pipelines.

4.4.4 Friction factor (f):-

It is calculated by Colebrook Formula. It is usually taken as a constant value.

$$1/f^{(1/2)} = 1.14 + 2\log_{10} D/E - 2\log_{10} [1+9.28/(Re*(E/D)*f^{(1/2)}] \quad (4.3)$$

Where,

E= Absolute roughness (mm)

4.4.5 Pressure loss (P):-

It is the amount of head lost per km of the pipeline due to friction. It is calculated in kg/cm^2 and converted into MCL (Meters of Liquid Column).

$$P = (6.38 * 10^8 * Q^2 * f * s) / D^5 \quad (4.4)$$

Where,

s = specific gravity of the liquid

4.4.6 Station Discharge Head (SDH):-

It is the head that is required to be discharged at the pumping station for the product to reach the next station, with the required residual head. The SDH is calculated by taking into consideration the friction loss elevation difference and the distance. The ground profile is assumed to be uniform.

$$SDH = f * L + (H'' - H') + h \quad (4.5)$$

Where,

L = Distance (kms)

H"-H' = Elevation difference (m)

H = Residual head (MCL)

4.4.7 Maximum Allowable Operating Pressure (MAOP):-

It is the maximum pressure the pipeline allowable in the pipeline based on the pipe material.

$$MAOP = (S * 2T * S.F) / D \qquad (4.6)$$

Where,

S = Yield strength (psi)

T = Wall thickness (inches)

S.F = Factor of Safety

4.4.8 Horsepower Required:-

$$BHP = \frac{Q * H * S * 1000}{75 * n_1 * n_2} \qquad (4.7)$$

Where,

H = Head in metres

S = Specific gravity

n_1= Pump efficiency

n_2= Transmission efficiency (gear box)

4.4.9 Situation Of Pumping Stations:-

The steps followed in deciding the location of the pumping stations are:-

- Calculate SDH required as per energy equation.
- SDH required > MAOP, more than One station necessary based on the following conditions:-

  Case I: SDH < or = MAOP one station.

  Case II: SDH > MAOP & < 2 MAOP i.e. SDH/MAOP between 1 & 2 stations.

  Case III: SDH > 2 MAOP & < 3 MAOP i.e. SDH/MAOP between 2 & 3 stations.

- Depending on value of SDH / MAOP, determine number of stations.

Sometimes the ground profile may not be uniform there may be peaks in the route of the pipeline and, the selected hydraulic gradient between end points may not cross the in-between peaks. Hence it will be necessary to add more stations. Minor variations could be corrected by using higher SDH in the same system with higher wall thickness and higher-grade pipes. Major variations may require addition of pump station. It will also be necessary to adjust the location of stations according to the tap off points and place.

4.5 DESIGN PROCEDURE:-

The pipeline design has a number of design calculations to be done. The steps followed in the procedure are:-

4.5.1 Line Size Optimization:-

This is the procedure of selecting the pipe for the pipeline. It is based on projected throughput, different line sizes are selected for detailed analysis. The line size is specified by three parameters, diameter, thickness and grade (API) - API 5L X (SMYS).

There are 12 to 27 options of line sizes available to select from. The short-listing is done by elimination. For each size, the following are worked out:-

- Hydraulics & System Configuration
- Capital Cost
- Operating Cost
- Phasing of capital cost
- Other costs like tankage
- Present Value of costs for 35 years of operation

Pipeline size having least Present Value of costs is considered as the optimum size. The pipeline has been designed in Phase I for a flow rate of 873 m3/hr in Mangalore-Hassan section and 700 m3/hr in Hassan-Bangalore section. In phase-II design flow rates are 1317 m3/hr and 1030 m3/hr respectively at 8000 working hours per annum. Accordingly system optimization analysis was carried out and a number of alternatives were considered for deciding the pipeline size and number of pumping units & their capacities. The wall thickness for the pipeline has been adopted based on the design code and minimum wall thickness requirement. Thus the most economical option of pipeline diameter worked out as:-

Table 4.2 Pipeline Features

Yield Stress Psi	Length KM	Pipe Size And Grade	Design Pr Kg / cm^2
Mangalore-Nerriya	82	20"AP15L Gr.X-52	68.0
Nerriya- Hassan	86	24"AP15L Gr.X-70	99.8
Hassan-Bangalore	196	20"AP15L Gr.X-60	70.6

4.5.2 Design Format:-

The pipeline has been designed in three sections:-

- Mangalore to Nerriya
- Nerriya to Hassan
- Hassan to Bangalore

The dispatch terminal was situated at Mangalore at a height of 4.39m above mean sea level. There is a pumping station at Mangalore. The next pumping station was situated at Nerriya at a distance of 82kms from Mangalore and a height of 125m above mean sea level. The main reason for having a pumping station at Nerriya was due to a presence of a peak of height 1128m above mean sea level at a distance of 110kms from Mangalore dispatch station. The power to be generated at Mangalore pump station would need to be very large if the peak had to be crossed directly. Hence it was decided to have a pumping station at Nerriya. The next station is situated at Hassan, which is also a tap of point. Hassan station is situated at a distance of 168kms from Mangalore and at a height of 919m above mean sea level. The Bangalore receipt terminal is situated at a distance of 364kms and a height of 902m above mean sea level.

All the calculations are done considering a throughput of 873m^3/h and a residual head of 50m.

4.5.3 Location of Pumping Stations:-

The main factor behind the situation of pumping stations is the hydraulic gradient. The hydraulic gradient is very useful in the solution of pipeline hydraulics graphically. By combining the hydraulic gradient of the pipeline with the elevation profile we can determine where to place pump stations along the pipe to maintain a positive head throughout the system.

The intersection of the hydraulic gradient with the elevation profile gives the theoretical location of each pump station. Since it is necessary to maintain a positive pressure on the pump suction, the actual location of each station must be moved upstream from the theoretical locations to provide this suction head. Any other head requirements must also be considered; for example, pressure to overcome the static head represented by the height of a storage tank. The location of the pump stations is sometimes fixed by other considerations, such as maximum operating pressure (MOP) of the pipe and land restrictions. Based on the profile the various pumping stations and sub stations have been constructed.

- **Mangalore Dispatch Station:-**

  PMHBL initial pumping station is located at village Bala at Mangalore, near Mangalore Refinery & Petro-chemicals Ltd. The latitude is 12°58 min. and the longitude is 74° 51 min. and an elevation of 4.39m.

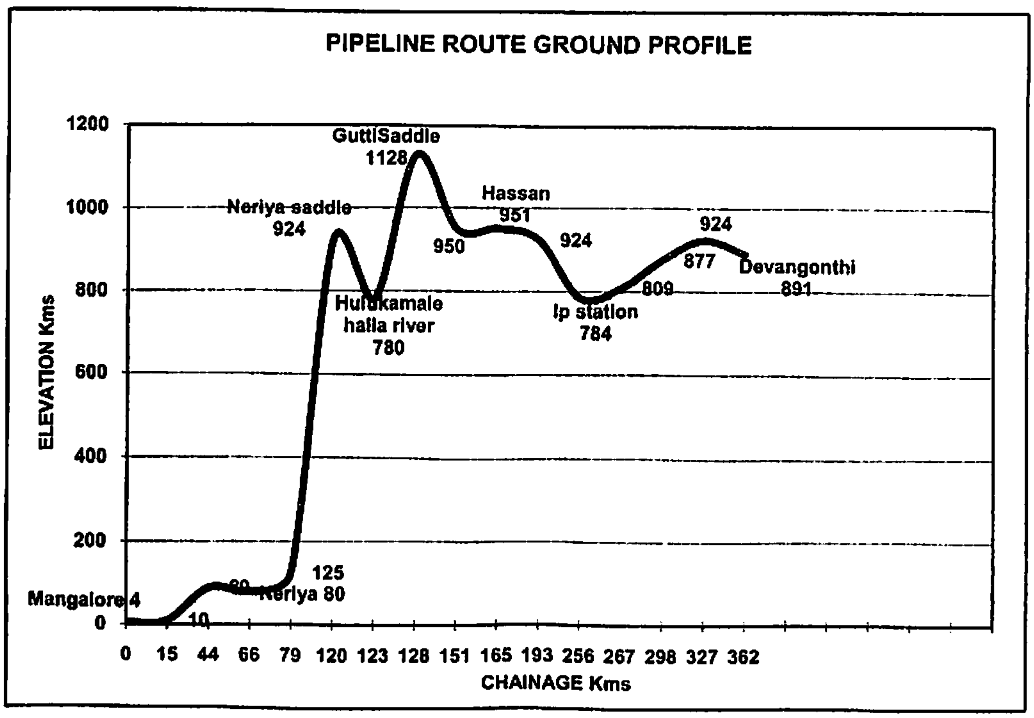


Figure 4.1 Elevation Profile

- **Nerriya Pump Station:-**

  The intermediate pumping station of PMHBL is at the foot hills of Charmadi Ghats is located at village Nerriya, Belthangady Taluk, District Dakshina Kannada and is about79.2Kms from Mangalore city. The latitude is 12°59 min. And the longitude is 74°27 min and an elevation of 125m.

- **Hassan, Pump Station and Tap-off Terminal:-**

  The Intermediate, Pumping & Delivery station of PMHBL is located at KIADB, Bommanaikana village at Hassan and is about 165kms from Mangalore city. The latitude is 13°02 min. and the longitude is 76°06 min. and an elevation of 951m.

- **Devanagonthi Receipt Terminal:-**

  The Receipt Terminal of PMHBL is located near Devangonthi Railway station, Tarabahalli village, Hoskote Taluk, Bangalore and the latitude is 12° 59 min and the longitude is 77° 51 min. At an elevation of 890.66m and is about 45Km from Bangalore city.

CHAPTER:-5

COMPUTATIONS & DISCUSSIONS

5.1 WALL THICKNESS CALCULATIONS:-

Based on Section 3.1.2

$$t= PD/2S\ (FE)$$

$$t_n = t+ CA$$

The calculated wall thickness is added to the corrosion allowance to get the technically viable wall thickness. The wall thickness is compared with commercially available standard pipe wall thickness and higher of the two wall thicknesses is finally selected for operation.

Mangalore- Nerriya

P=68 kg/cm^2 =6.67 MPa

D=20 in =508mm

F=0.72

E=1

S=52000psia =358.53MPa

$$6.67*508/2*358.53\ (0.72*1)$$

$$= 6.56\text{mm}$$

$$t_n= 6.56+0.5= 7.06$$

= 7.13mm (commercially available)

The calculated value of 7.06mm is compared with the commercially viable thicknesses and the higher of the two values 7.13mm was chosen to withstand the design pressure.

Nerriya- Hassan

P=99.8 kg/cm^2 =9.8MPa

D=24 in =609.6mm

F=0.72

E=1

S=70000psia =482.63MPa

t=9.8*609.6/2*482.63 (0.72*1)

=8.6

t_n=8.6+0.5 =9.1

=9.5mm (commercially available)

The calculated value of 9.1mm is compared with the commercially viable thicknesses and the higher of the two values 9.5mm was chosen to withstand the design pressure.

Hassan- Bangalore

P=70.6 kg/cm^2 =6.92MPa

D=20 in =508mm

F=0.72

E=1

S=60000psia =413.68MPa

t=6.92*508/2*413.68 (0.72*1)

=5.8

t_n=5.8+0.5 =6.3

=6.4mm (commercially available)

The calculated value of 9.1mm is compared with the commercially viable thicknesses and the higher of the two values 9.5mm was chosen to withstand the design pressure.

5.2 COLLAPSE DUE TO EXTERNAL PRESSURE:-

5.2.1 Shutdown and Installation:-

Based on Section 3.2 and Equations 3.1 and 3.2, we have

$$(P_o - P_i) \leq f_o \times P_c$$

and

$$P_o = \gamma C$$

Mangalore- Nerriya

γ=1800kg/m^3

C=1.2m

P_o=1800*1.2

=2160kg/m^2=0.216kg/cm^2

=0.0213MPa

$$P_e = \frac{2E\left(\frac{t}{D}\right)^3}{1-\nu^2} \qquad P_Y = \frac{2St}{D} \qquad P_C = \frac{(P_Y \times P_e)}{\sqrt{P_Y^2 + P_e^2}}$$

P_e=2*2*10^5*(6.56/508)^3/ (1-0.3^2)

=0.94MPa

P_γ=2*358.53*6.56/508

=9.25MPa

P_c=0.9352

f_o=0.7

f_o*P_c =0.6546

Since the condition of Eqn.3.1 is satisfied, there is no chance of collapse due to external pressure during shutdown and installation conditions.

Nerriya- Hassan

P_o=0.0213MPa

$P_e=2*2*10^5*(8.6/609.6)^3/(1-0.3^2)$

=1.23MPa

$P\gamma$=2*482.63*8.6/609.6

=13.62MPa

P_c=1.225MPa

f_o*P_c=0.8575

Since the condition of Eqn.3.1 is satisfied, there is no chance of collapse due to external pressure during shutdown and installation conditions.

Hassan- Bangalore

P_o=0.0213MPa

$P_e=2*2*10^5*(5.8/508)^3/(1-0.3^2)$

=0.654MPa

$P\gamma$=2*413.68*5.8/508

=9.44MPa

P_c=0.652MPa

f_o*P_c=0.4564

Since the condition of Eqn.3.1 is satisfied, there is no chance of collapse due to external pressure during shutdown and installation conditions.

5.3 NEGATIVE BUOYANCY REQUIREMENTS:-

5.3.1 Pipe under Seismic Excitation:-

Based on Section 3.3.3 and Eqns.3.3 and 3.4,

$W_p = W_1 + W_2$

W_1 = steel pipe weight (kgf/m)

W_2 = polyethylene coating weight (kgf/m)

$\rho_{steel} = 7850 kg/m^3$

$\rho_{PE} = 950 kg/m^3$

$W_1 = (\pi*((D_o*0.001)^2-(D_i*0.001)^2)/4)*\rho_{steel}$ (5.1)

D_o = outside diameter of pipe (mm)

D_i = inner diameter of pipe (mm)

$W_2 = (\pi*(((D_o+2T_c)*0.001)^2-(D_o*0.001)^2)/4)*\rho_{PE}$ (5.2)

T_c = coating thickness (mm)

= 2.2 mm

Mangalore- Nerriya

$W_1 = (\pi*((508*0.001)^2-(493.74*0.001)^2)/4)*7850$

= 88.07kgf/m

$W_2 = (\pi*(((508+2*2.2)*0.001)^2-(508*0.001)^2)/4)*950$

= 3.35kgf/m

W_p= 88.07+3.35= 91.42kgf/m

= 896.83N/m

F_{LS}= 0.125*896.83= 112.04N/m

F_{VS}= 0.083*896.83= 74.44N/m

Nerriya- Hassan

D_o= 609.6mm D_i= 590.6mm t_n= 9.5mm

W_1= 140.6kgf/m

W_2= 4.02kgf/m

W_p=144.62kgf/m=1418.72N/m

F_{LS}= 0.125*1418.72= 177.34N/m

F_{VS}= 0.083*1418.72= 117.75N/m

Hassan- Bangalore

D_o= 508mm D_i= 495.2mm t_n= 6.4mm

W_1= 79.2kgf/m

W_2= 3.35kgf/m

W_p= 82.55kgf/m= 808.99N/m

F_{LS}= 0.125*808.99= 101.12N/m

F_{VS}= 0.083*808.99= 67.15N/m

5.4 STRESS ANALYSIS:-

Based on Section3.4 and Eqns.3.5, 3.6 and 3.8,

$$S_h = \frac{PD}{2t}$$

$$S_L = \nu \times S_h - \alpha \times E \times \Delta T \pm S_B$$

$$S_{eq} = (S_h^2 + S_L^2 - S_h S_L)^{0.5}$$

Mangalore- Nerriya

D= 508mm

t = 6.56mm(corroded pipe wall thickness)

P = P_i= 68 kg/cm^2= 6.67 MPa

S_h= 6.67*508/2*6.56

= 258.26 MPa

Design temperature= 43.3^{0}c

Air temperature (surface) = 11.1^{0}c

ΔT= 43.3-11.1= 32.2^{0}c

ν = 0.3

E = 2*10^5 MPa

α = 11.7*10^{-6} /^{0}c for steel

L = Allowable span= 0 *(As pipeline is supported by soil from all sides, i.e. no free span)*

i.e. S_{BH}= 0 and

S_{BV}= ED/2000R_V (since L=0, first term of S_{BV} is becoming zero)

R_V= 140m (Horizontal Bend Radius)

S_{BV}= 2*10^5*0.508/2000*140

= 0.363 MPa

S_B = 0.363 MPa

S_L = 0.3*258.26-2*10^5*11.7*10^{-6}*32.2±0.363

= 76.724

= 76.361

S_{eq} = (258.26^2+76.724^2-258.26*76.724)$^{0.5}$

= 229.72 MPa

Allowable combined= 1*SMYS

= 358.53 MPa

Here it is seen that the equivalent stress < allowable combined as specified in the theory. Therefore pipeline will work safely during operation, i.e. transportation of products through the pipeline.

<u>Nerriya- Hassan</u>

D= 609.6 MPa

t = 8.6mm (corroded pipe wall thickness)

$P = P_i = 9.8$ MPa

$S_h = 9.8*609.6/2*8.6$

= <u>347.33</u> MPa

Design temperature= 43.3^0c

Air temperature (surface) = 11.1^0c (extreme)

$\Delta T = 32.2^0$c

$\nu = 0.3$

$E = 2*10^5$ MPa

$\alpha = 11.7*10^{-6}$ /^{0}c for steel

L = Allowable span= 0 *(As pipeline is supported by soil from all sides, i.e. no free span)*

i.e. $S_{BH} = 0$ and

$S_{BV} = ED/2000R_V$ (since L=0, first term of S_{BV} is becoming zero)

$R_V = 140$m (Horizontal Bend Radius)

$S_{BV} = 2*10^5*0.6096/2000*140$

= 0.435 MPa

$S_B = 0.435$ MPa

$S_L = 0.3*347.33-2*10^5*11.7*10^{-6}*32.2\pm0.435$

= 29.286

= 28.416

S_{eq} = $(347.33^2+29.286^2-347.33*29.286)^{0.5}$

= 333.65 MPa

Allowable combined= 1*SMYS

= 482.63 MPa

Here it is seen that the equivalent stress < allowable combined as specified in the theory. Therefore pipeline will work safely during operation, i.e. transportation of products through the pipeline.

Hassan- Bangalore

D= 508mm

t = 5.8mm (corroded pipe wall thickness)

P = P_i= 6.92 MPa

S_h= 6.92*508/2*5.8

= 303.05 MPa

Design temperature= 43.3^{0}c

Air temperature (surface) = 11.1^{0}c

ΔT= 43.3-11.1= 32.2^{0}c

v = 0.3

E = 2*10^5 MPa

α = 11.7*10^{-6} /^{0}c for steel

L = Allowable span= 0 *(As pipeline is supported by soil from all sides, i.e. no free span)*

i.e. S_{BH}= 0 and

S_{BV}= ED/2000R_V (since L=0, first term of S_{BV} is becoming zero)

R_V= 140m (Horizontal Bend Radius)

S_{BV}= $2*10^5*0.508/2000*140$

= 0.363 MPa

S_B = 0.363 MPa

S_L = $0.3*303.05-2*10^5*11.7*10^{-6}*32.2\pm0.363$

= 15.93

= 15.567

S_{eq} = $(303.05^2+15.93^2-303.05*15.93)^{0.5}$

= 295.41 MPa

Allowable combined= 1*SMYS

= 413.68 MPa

Here it is seen that the equivalent stress < allowable combined as specified in the theory. Therefore pipeline will work safely during operation, i.e. transportation of products through the pipeline.

5.5 HYDRAULIC ANALYSIS AND DESIGN OF PIPELINE SYSTEM:-

Based on Sections 4.1, 4.2 and 4.3, further calculations have been done. Pipeline has been designed with HSD specifications since it is the heaviest among the products transported by the pipeline and its demand is also the highest. Design with HSD specification will satisfy the design requirements for the other products. First we consider Mangalore-Hassan section.

Mangalore- Hassan (20 in. pipe, Grade X52, 168 km)

A) Flow rate:-

Q = 5.6 MMTPA

= $5.6 * 10^6$ ton/a

$= 5.6 * 10^9$ kg/a

In a year we have 8760hrs. Let us consider 8000hrs, with the rest for repairs.

$$Q = \frac{5.6 * 10^9}{8000} \text{ kg/hr}$$

$$= \frac{5.6 * 10^9}{8000 * 0.8359 * 10^3} \text{ m}^3\text{/hr}$$

$$= \underline{873} \text{ m}^3\text{/hr}$$

B) Cross sectional area of the pipe:-

I.D. of the pipe = (508 – 2*7.13) =493.74mm

= 0.49374 m

$$\text{Area} = \frac{\pi * D^2}{4}$$

$$= \frac{\pi * 0.49374^2}{4}$$

$$= 0.1915 \text{ m}^2$$

C) Velocity of flow:-

$$V = Q/A$$

$$= \frac{8.73*10^2}{0.1915}$$

$$= 4558.75 \text{ m/hr}$$

$$= 1.27 \text{ m/sec}$$

D) Reynolds number:-

$$R_e = V\,D / \nu$$

$$= \frac{1.27 * 0.49374}{1 * 10^{-6}}$$

$$= 627049.8 > 4000$$

Thus the flow is turbulent.

E) Friction factor:-

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

e = 0.002 in (roughness)

= 0.000051 m

$$\frac{1}{\sqrt{f}} = -2\log\left[\frac{0.000051}{3.7*0.49374} + \frac{2.51}{627049.8\sqrt{0.02}}\right]$$

Assuming initial value of 'f' on right side as 0.02, by iteration

f = 0.0141

F) Head loss due to friction (Darcy Weisbach):-

$$h_f = \frac{f\ L\ V^2}{2\ g\ d}$$

$$= \frac{0.0141 * (82000+86000) * 1.27^2}{2 * 9.8 * 0.49374}$$

= 394.8 m

G) Station discharge head:-

SDH = h_f + (H"-H') + H

= 394.8 + (1128-4.39) + 50

= 394.8 + 1123.61 + 50

= 1568.41 m

H) Maximum allowable operating pressure:-

$$MAOP = \frac{S * 2T * S.F}{D}$$

$$= \frac{52000 * 2 * (0.281) * 0.72}{20}$$

= 1052.06 psi

= 73.98 kg /cm^2

$$= \frac{73.98*10^4}{835.9}$$

$$= \underline{885.03}\ m$$

Here it is seen that SDH > MAOP, hence more than one station is required between Mangalore and Nerriya. Therefore using elevation profile and hydraulic gradient it is decided to design the pipeline in 2 sections, i.e. from Mangalore- Nerriya and Nerriya-Hassan (to counter the peak at Gutti Saddle-1128m) and to place pump stations at Mangalore and Nerriya.

Mangalore- Nerriya (20 in. pipe, Grade X52, 82km)

A) Flow rate:-

$$Q = 5.6\ MMTPA$$

$$= 5.6 * 10^6\ ton/a$$

$$= 5.6 * 10^9\ kg/a$$

In a year we have 8760hrs. Let us consider 8000hrs, with the rest for repairs.

$$Q = \frac{5.6 * 10^9}{8000}\ kg/hr$$

$$= \frac{5.6 * 10^9}{8000 * 0.8359 * 10^3}\ m^3/hr$$

$$= \underline{873}\ m^3/hr$$

B) Cross sectional area of the pipe:-

I.D. of the pipe = (508 – 2*7.13) =493.74mm

= 0.49374 m

$$Area = \frac{\pi * D^2}{4}$$

$$= \frac{\pi * 0.49374^2}{4}$$

$$= 0.1915\ m^2$$

C) Velocity of flow:-

$$V = Q/A$$

$$= \frac{8.73*10^2}{0.1915}$$

$$= 4558.75 \text{ m/hr}$$

$$= 1.27 \text{ m/sec}$$

D) Reynolds number:-

$$R_e = V\,D\,/\,v$$

$$= \frac{1.27 * 0.49374}{1 * 10^{-6}}$$

$$= 627049.8 > 4000$$

Thus the flow is turbulent.

E) Friction factor:-

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

e = 0.002 in (roughness)

= 0.000051 m

$$\frac{1}{\sqrt{f}} = -2\log\left[\frac{0.000051}{3.7*0.49374} + \frac{2.51}{627049.8\sqrt{0.02}}\right]$$

Assuming initial value of 'f' on right side as 0.02, by iteration

f = 0.0141

F) Head loss due to friction (Darcy Weisbach):-

$$h_f = \frac{f\,L\,V^2}{2\,g\,d}$$

$$= \frac{0.0141 * 82000 * 1.27^2}{2 * 9.8 * 0.49374}$$

$$= 192.7 \text{ m}$$

G) Station discharge head:-

$$SDH = h_f + (H''-H') + H$$
$$= 192.7 + (125-4.39) + 50$$
$$= 192.7 + 120.61 + 50$$
$$= \underline{363.31}\ m$$

H) Maximum allowable operating pressure:-

$$MAOP = \frac{S * 2T * S.F}{D}$$
$$= \frac{52000 * 2 * (0.281) * 0.72}{20}$$
$$= 1052.06\ psi$$
$$= 73.98\ kg/cm^2$$
$$= \frac{73.98*10^4}{835.9}$$
$$= \underline{885.03}\ m$$

Here it is seen that SDH < MAOP hence only one station is required between Mangalore and Nerriya.

I) Horsepower Required:-

$$BHP = \frac{Q * H * S * 1000}{75 * n_1 * n_2}$$
$$= \frac{873 * 363.31 * 0.8359 * 1000}{75 * 0.8 * 0.9 * 3600}$$
$$= \underline{1363.8}\ HP$$

Installed hp = 1.1 * BHP

= 1500.18 HP

= <u>1119.13</u> KW

Since only 1 pump station will be present power required at that pump station will be 1119.13KW. Next we design the section from Nerriya- Hassan using the same 20 in. pipe of Grade X52.

Nerriya- Hassan (20 in. pipe, Grade X52, 86km)

A) Flow rate:-

$$Q = 5.6 \text{ MMTPA}$$

$$= 5.6 * 10^6 \text{ ton/a}$$

$$= 5.6 * 10^9 \text{ kg/a}$$

In a year we have 8760hrs. Let us consider 8000hrs, with the rest for repairs.

$$Q = \frac{5.6 * 10^9}{8000} \text{ kg/hr}$$

$$= \frac{5.6 * 10^9}{8000 * 0.8359 * 10^3} \text{ m}^3\text{/hr}$$

$$= \underline{873} \text{ m}^3\text{/hr}$$

B) Cross sectional area of the pipe:-

I.D. of the pipe = (508 – 2*7.13) =493.74mm

= 0.49374 m

$$\text{Area} = \frac{\pi * D^2}{4}$$

$$= \frac{\pi * 0.49374^2}{4}$$

$$= 0.1915 \text{ m}^2$$

C) Velocity of flow:-

$$V = Q/A$$

$$= \frac{8.73*10^2}{0.1915}$$

$$= 4558.75 \text{ m/hr}$$

$$= 1.27 \text{ m/sec}$$

D) Reynolds number:-

$$R_e = V\,D / \nu$$

$$= \frac{1.27 * 0.49374}{1 * 10^{-6}}$$

= 627049.8 > 4000

Thus the flow is turbulent.

E) Friction factor:-

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

e = 0.002 in (roughness)

= 0.000051 m

$$\frac{1}{\sqrt{f}} = -2\log\left[\frac{0.000051}{3.7 \cdot 0.49374} + \frac{2.51}{627049.8\sqrt{0.02}}\right]$$

Assuming initial value of 'f' on right side as 0.02, by iteration

f = 0.0141

F) Head loss due to friction (Darcy Weisbach):-

$$h_f = \frac{f\ L\ V^2}{2\ g\ d}$$

$$= \frac{0.0141 * 86000 * 1.27^2}{2 * 9.8 * 0.49374}$$

= 202.10 m

G) Station discharge head:-

SDH = h_f + (H"-H') + H

= 202.10 + (1128-125) + 50

= 192.7 + 1003 + 50

= 1255.1 m

H) Maximum allowable operating pressure:-

$$MAOP = \frac{S * 2T * S.F}{D}$$

$$= \frac{52000 * 2 * (0.281) * 0.72}{20}$$

= 1052.06 psi

= 73.98 kg /cm^2

$$= \frac{73.98*10^4}{835.9}$$

= 885.03 m

Design was done using the same material X52 with diameter 20inch as in the first section from Mangalore- Nerriya. Here we see that SDH > MAOP, hence more than one station is required between Mangalore and Nerriya. Therefore to prevent the additional expenses incurred with one more pumping station and to reduce the pumping cost of the single pumping station in Nerriya it has been decided to increase the diameter of the pipe from 20 in. to 24 inch (reduced frictional losses) by iteration and also the MAOP in this case is much lower than design pressure for this section, thus to accommodate for the increased pressure the grade has been increased to X70 and also adequate increase in thickness is calculated as shown before in the first section of this chapter.

Nerriya- Hassan (24 in. pipe, Grade X70, 86km)

A) Flow rate:-

Q = 5.6 MMTPA

= 5.6 * 10^6 ton/a

= 5.6 * 10^9 kg/a

In a year, we have 8760hrs. Let us consider 8000hrs, with the rest for repairs.

$$Q = \frac{5.6 * 10^9}{8000} \text{ kg/hr}$$

$$= \frac{5.6 * 10^9}{8000 * 0.8359 * 10^3} \text{ m}^3\text{/hr}$$

= 873 m^3/hr

B) Cross sectional area of the pipe:-

I.D. of the pipe = (609.16 – 2*9.5) =590.6mm

= 0.5906 m

$$\text{Area} = \frac{\pi * D^2}{4}$$

$$= \frac{\pi * 0.5906^2}{4}$$

$$= 0.274 \text{ m}^2$$

C) Velocity of flow:-

$$V = Q/A$$

$$= \frac{8.73*10^2}{0.274}$$

$$= 3186.13 \text{ m/hr}$$

$$= 0.885 \text{ m/sec}$$

D) Reynolds number:-

$$R_e = V\,D\,/\,v$$

$$= \frac{0.885 * 0.5906}{1 * 10^{-6}}$$

$$= 522681 > 4000$$

Thus the flow is turbulent.

E) Friction factor:-

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

e = 0.002 in (roughness)

= 0.000051 m

$$\frac{1}{\sqrt{f}} = -2\log\left[\frac{0.000051}{3.7*0.5906} + \frac{2.51}{522681\sqrt{0.02}}\right]$$

Assuming initial value of 'f' on right side as 0.02, by iteration

f = 0.0138

F) Head loss due to friction (Darcy Weisbach):-

$$h_f = \frac{f\ L\ V^2}{2\ g\ d}$$

$$= \frac{0.0138 * 86000 * 0.885^2}{2 * 9.8 * 0.5906}$$

$$= 80.3\ m$$

Based on Section 3.5.1.2,

Friction loss in Enlarger from 20 in to 24 in

$$\lambda_c = (1 - (0.191/0.274))^2$$

$$= 0.092$$

$$h_c = 0.092 * 1.27^2/2 * 9.8$$

$$= 0.0075m$$

G) Station discharge head:-

$$SDH = h_f + (H'' - H') + H + \text{friction loss in enlarger}$$

$$= 80.3 + (1128 - 125) + 50 + 0.0075$$

$$= 80.3 + 1003 + 50 + 0.0075$$

$$= \underline{1130.31}\ m$$

H) Maximum allowable operating pressure:-

$$MAOP = \frac{S * 2T * S.F}{D}$$

$$= \frac{52000 * 2 * (0.374) * 0.72}{24}$$

$$= 1571\ psi$$

$$= 110.5\ kg/cm^2$$

$$= \frac{110.5 * 10^4}{835.9}$$

$$= \underline{1322}\ m$$

Here we see that SDH < MAOP hence only one station is required between Mangalore and Nerriya and also the increased diameter and grade has helped in reducing the frictional losses which will help in reduction of pumping cost from Nerriya station.

I) Horsepower Required:-

$$BHP = \frac{Q * H * S * 1000}{75 * n_1 * n_2}$$

$$= \frac{873 * 1130.31 * 0.8359 * 1000}{75 * 0.8 * 0.9 * 3600}$$

$$= \underline{4243}\ HP$$

Installed hp = 1.1 * BHP

= 4667.3 HP

= 3481.81 KW

Since only 1 pump station will be present, power required at that pump station will be 3481.81KW. Now we look at the Hassan-Bangalore section.

Hassan- Bangalore (20 in. pipe, Grade X60, 196km)

A) Flow rate:-

$Q = 700\ m^3/h$

B) Cross sectional area of the pipe:-

I.D. of the pipe = (508 – 2*6.4) = 495.2mm

= 0.4952 m

$$Area = \frac{\pi * D^2}{4}$$

$$= \frac{\pi * 0.4952^2}{4}$$

$$= 0.1926\ m^2$$

C) Velocity of flow:-

V = Q/A

$$= \frac{7*10^2}{0.1926}$$

= 3634.5 m/hr

= 1.01 m/sec

D) Reynolds number:-

$R_e = V\,D\,/\,v$

$= \frac{1.01 * 0.4952}{1 * 10^{-6}}$

= 500152 > 4000, thus flow is turbulent.

E) Friction factor:-

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

e = 0.002 in (roughness)

= 0.000051 m

$\frac{1}{\sqrt{f}} = -2\log\left[\frac{0.000051}{3.7 * 0.4952} + \frac{2.51}{500152\sqrt{0.02}}\right]$

Assuming initial value of 'f' on right side as 0.02, by iteration

f = 0.0142

F) Head loss due to friction (Darcy Weisbach):-

$h_f = \frac{f\,L\,V^2}{2\,g\,d}$

$= \frac{0.0142 * 196000 * 1.01^2}{2 * 9.8 * 0.4952}$

= 292.52 m

Based on Section 3.5.1.2,

Friction loss due to sudden change in diameter from 24 in to 20 in

$\lambda_c = 0.05$

$h_c = 0.05 * 1.01^2 / 2 * 9.8$

= 0.0026m

G) Station discharge head:-

SDH = h_f + (H"-H') + H +friction loss due to change in diameter

= 292.52 + (951-784) + 50 + 0.0026

= 192.7 + 167 + 50 + 0.0026

= 509.52 m

H) Maximum allowable operating pressure:-

$$MAOP = \frac{S * 2T * S.F}{D}$$

$$= \frac{60000 * 2 * (0.252) * 0.72}{20}$$

$$= 1088.64 \text{ psi}$$

$$= 76.56 \text{ kg /cm}^2$$

$$= \frac{76.56*10^4}{835.9}$$

$$= \underline{915.9} \text{ m}$$

Here we see that SDH < MAOP hence only one station is required between Mangalore and Nerriya. Even grade X52 is satisfying the safe requirements, but keeping in mind the capacity augmentation which will be done, we have used the grade X60 keeping in mind the increased pressure and flow years later.

I) Horsepower Required:-

$$BHP = \frac{Q * H * S * 1000}{75 * n_1 * n_2}$$

$$= \frac{700 * 509.52 * 0.8359 * 1000}{75 * 0.8 * 0.9 * 3600}$$

$$= \underline{1533.62} \text{ HP}$$

$$\text{Installed hp} = 1.1 * BHP$$

$$= 1686.98 \text{ HP}$$

$$= \underline{1258.49} \text{ KW}$$

Since only 1 pump station will be present, power required at that pump station will be 258.49KW.

5.6 ECONOMIC ANALYSIS:-

Based on Section 3.6, cost analysis will be done to determine the optimum pipe size required, by analyzing the capital costs and the annual operating costs to in the section ***Nerriya- Hassan (86 km, X70).*** We would perform these calculations considering the time value of money, and select the option that results in the lowest present value (PV) of investment.

Evaluation of 20 in., 22 in. and 24 in. will be done and the total capital costs and operating costs for each pipe size calculated.

First we have to bracket the pipe diameter range. If we consider 20 in. diameter pipe, 0.300 in. wall thickness, the average velocity using Eq. 4.1 will be

$$V=873/(0.191*3600)=1.27\ m/s$$
$$=4.2\ ft/s$$

We will compare this with two other pipe sizes: 22 in. and 24 in. nominal diameter. Initially, we will assume 0.350 in. pipe wall thickness for the 22 in. and 24 in. pipes. Later we will calculate the actual required wall thickness for the given MAOP. Using ratios, the velocity in the 22 in. pipe will be

$$4.2\times(19.4/21.3)^2 \text{ or } 3.5\ ft/s$$

and the velocity in the 24 in. pipe will be

$$4.2\times(19.4/23.3)^2 \text{ or } 2.9\ ft/s$$

Next we need to choose a suitable wall thickness for each pipe size to limit the operating pressure to 1571 psi. Using the internal design pressure Equation (3.1), we calculate the pipe wall thickness required as follows:

For 20 in. pipe, the wall thickness is

$$T=1571\times20/(2\times70{,}000\times0.72)=0.312\ in.$$

Similarly for the other two pipe sizes we calculate:

For 22 inch pipe, the wall thickness is

$$T=1571\times22/(2\times70{,}000\times0.72)=0.343\ in.$$

For 24 in. pipe, the wall thickness is

$$T=1571\times24/(2\times70{,}000\times0.72)=0.374\ in.$$

Using the closest commercially available pipe wall thicknesses, we choose the following three sizes:

20 in., 0.312 in. wall thickness (MAOP=1573 psi)

22 in., 0.344 in. wall thickness (MAOP=1576 psi)

24 in., 0.375 in. wall thickness (MAOP=1575 psi)

The revised MAOP values for each pipe size, with the slightly higher than required minimum wall thickness, were calculated as shown within parentheses above.

Next, we calculate the pressure drop due to friction in each pipe size at the given flow rate of 873 m^3/h, using the Darcy Weishbach equation from Equation (4.4) and also Eqns. 4.2 and 4.3 for the 20 in. pipeline

$$h_f = \frac{f\ L\ V^2}{2\ g\ d}$$

$$= \frac{0.0141 * 86000 * 1.27^2}{2 * 9.8 * 0.493776}$$

$$= 202.1\ m$$

Similarly, we get the following for the pressure drop in the 22 in. and 24 in. pipelines:

$h_f = 136.74m$ for the 22 in. pipe

$h_f = 26.39$ m for the 24 in. pipe

We can now calculate the total pressure required for each pipe size, taking into account the friction drop in the 86 km pipeline and the elevation head of 1003 m along with a minimum delivery pressure of 50m at the next terminus.

Total pressure required at the origin pump station is:

202.1+ (1128-125) +50=1492.11 psi for the 20 in. pipe

136.74+ (1128-125) +50=1414.52 psi for the 22 in. pipe

82.23+ (1128-125) +50=1349.7 psi for the 24 in. pipe

The total BHP required for each case will be calculated from the above total pressure and the flow rate of 873m^3/h using Equation (4.7).

$$BHP = \frac{Q * H * S * 1000}{75 * n_1 * n_2}$$

$$= \frac{873 * 1255 * 0.8359 * 1000}{75 * 0.8 * 0.9 * 3600}$$

$= \underline{4711.03}$ HP for 20 in.

$$BHP = \frac{Q * H * S * 1000}{75 * n_1 * n_2}$$

$$= \frac{873 * 1189.74 * 0.8359 * 1000}{75 * 0.8 * 0.9 * 3600}$$

$$= \underline{4466.06}\ HP \qquad \text{for 22 in.}$$

$$BHP = \frac{Q * H * S * 1000}{75 * n_1 * n_2}$$

$$= \frac{873 * 1135.23 * 0.8359 * 1000}{75 * 0.8 * 0.9 * 3600}$$

$$= \underline{3621.44}\ HP \qquad \text{for 24 in.}$$

Increasing the BHP values above by 10% for installed HP and choosing the nearest motor size, we will use 6000 HP for the 20 in. pipeline system, 5000 HP for the 22 in. system, and 4000 HP for the 24 in. pipeline system.

To calculate the ***capital*** cost of facilities, we will use $700 per ton for steel pipe, delivered to the construction site. The labor cost for installing the pipe will be based on $20,000 per inch-diameter-mile.

The installed cost for pump stations will be assumed to be $1500/HP. To account for other cost items discussed earlier in previous chapter, we will add 25% to the subtotal of pipeline and pump station cost.

The estimated capital costs for the three pipe sizes are summarized in Table 5.1. Based on total capital costs alone, it can be seen that the 24 in. system is not the best. Therefore, we will have to look at the operating costs as well, before making a decision on the optimum pipe size.

Table 5.1 Capital Costs for Varying Pipe Sizes

Capital Cost (Crores Rs.)	**20 in.**	**22 in.**	**24 in.**
Pipeline (PMC&Installation)	87.32	94.52	101.8
Pump stations	36	30	24
Other (25%)	30.83	31.13	31.45
Total	154.15	155	157.25

Next, we calculate the ***operating*** cost for each scenario, using electrical energy costs for pumping. As discussed earlier in previous chapter, many other items enter into the calculation of annual operating costs, such as O&M, G&A costs, etc. For simplicity, we will increase the electrical cost of the pump stations by a factor to account for all other operating costs.

Using the BHP calculated at each pump station for the three cases and Rs.4.82/kWh for electricity cost, we find that the annual operating cost for 24 hr operation per day, 333 days per year the annual costs are:

4711×0.746×24×333×4.82=Rs.13.54 crores/yr for 20 in.

4466×0.746×24×333×4.82=Rs.12.83 crores/yr for 22 in.

3621×0.746×24×333×4.82=Rs.10.41 crores/yr for 24 in.

Increasing above numbers by a 50% factor to account for other operating costs such as O&M, G&A, etc., we get the following for total annual costs for each scenario:

Rs.20.31 crores/yr for 20 in.

Rs.19.245 crores/yr for 22 in.

Rs.15.615 crores/yr for 24 in.

Next, we use a project life of 25 years and interest rate of 8% to perform a discounted cash flow (DCF) analysis, to obtain the present value of these annual operating costs. Then the total capital cost calculated earlier and listed in Table 5.1 will be added to the present values of the annual operating costs. The present value (PV) will then be obtained for each of the three scenarios.

The equation relating the present value of a series of annual payments over a no. of years at a specified interest rate is as follows:

$$PV = \frac{R}{i}\left(1 - \frac{1}{(1+i)^{\wedge}n}\right)$$

Where,

PV = present value

R = series of cash flows

i = interest rate, decimal value

n = no. of periods, years

PV of 20 in. system=Rs.154.15+present value of Rs.20.31 crores/yr at 8% for 25 years

Or

PV_{20}=154.15+216.8=Rs.371 crores

Similarly, for the 22 in. and 24 in. systems, we get

PV_{22}=155+205=Rs.360 crores

PV_{24}=157.25+166.75=Rs.324 crores

Thus, based on the net present value of investment, we can conclude that the 24 in. pipeline system with one 4000 HP pump station is the preferred choice.

In the preceding calculations we made several assumptions for the sake of simplicity. We considered major cost components, such as pipeline and pump station costs, and added a percentage of the subtotal to account for other costs. Also, in calculating the PV of the annual costs we used constant numbers for each year. A more rigorous approach would require the annual costs be inflated by some percentage every year to account for inflation and cost of living adjustments.

CHAPTER:-6

CONCLUSION

6.1 CONCLUSION:-

Mechanical design and analysis in this project has provided us with the right values which should be used for both manufacturing and operation of the pipeline in the safe mode which otherwise can be both destructive for humans and the pipeline. The appropriate thickness values which should be used in each section were found out to be ***7.13mm, 9.5mm and 6.4mm*** respectively. These values were decided upon after providing corrosion allowance and then comparing with the commercially available values. ***External collapse pressure*** checks due to soil overburden pressure during shutdown and installation was done to see whether these calculated thickness values were enough, and these values has been found satisfying the necessary Eqns. Internal stresses like ***hoop stress and longitudinal stress*** which can affect the pipeline during its operation leading to its buckling or collapse were found out, to see whether these were coming within the allowable maximum values range and it was found that there was perfect compliance. The seismic forces which can affect the pipeline were found out. ***Hydraulic analysis and design*** was also done to find out the MAOP, SDH, the no. of pump stations and the power required at the pump stations. In the first case as shown in section 5.5, SDH was greater than MAOP; therefore there was the need for two pumping stations at Mangalore and Nerriya. Now it was decided to separate the pipeline as two sections, i.e. Mangalore-Nerriya and Nerriya- Hassan. In the first section we used 20inch, X52 pipe which was found suitable and the necessary power required at the Mangalore pump station was found out. In the next section we again used the same dimensions which led to SDH being greater than MAOP, the end result of which was need of two pump stations. Now to prevent the additional expenses incurred with one more pumping station and to reduce the pumping cost of the single pumping station in Nerriya it was decided to increase the diameter of the pipe from 20 in. to 24 inch (reduced frictional losses) by iteration and also the MAOP in this case was much lower than design pressure for this section, thus to accommodate for the increased pressure the grade has been increased to X70. This led to appropriate results for this section. In the last section X52 grade was appropriate but due to plans for augmentation after some years, to be on the safe side the grade was decided upon X60 to accommodate for the increased flow rate and pressure years later.

Cost analysis done for Nerriya- Mangalore section proved that 24 in. pipeline with 4000hp motor was the most feasible compared with 22 in. and 20 in.

This report can be used for design and stability check (stress analysis) of other product pipelines, but the sheer amount of exertion involved in manual calculations (iteration works) recommends use of a software. Also having some data (diameter, grade) at the beginning helps ease out the design calculations otherwise which will make the design work very tedious.

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APPENDIX:-

Laminar Flow and Turbulent Flow of Fluids

Resistance to flow in a pipe

When a fluid flows through a pipe the internal roughness (e) of the pipe wall can create local eddy currents within the fluid adding a resistance to flow of the fluid. Pipes with smooth walls such as glass, copper, brass and polyethylene have only a small effect on the frictional resistance. Pipes with less smooth walls such as concrete, cast iron and steel will create larger eddy currents which will sometimes have a significant effect on the frictional resistance.

The velocity profile in a pipe will show that the fluid at the centre of the stream will move more quickly than the fluid towards the edge of the stream. Therefore friction will occur between layers within the fluid.

Fluids with a high viscosity will flow more slowly and will generally not support eddy currents and therefore the internal roughness of the pipe will have no effect on the frictional resistance. This condition is known as laminar flow.

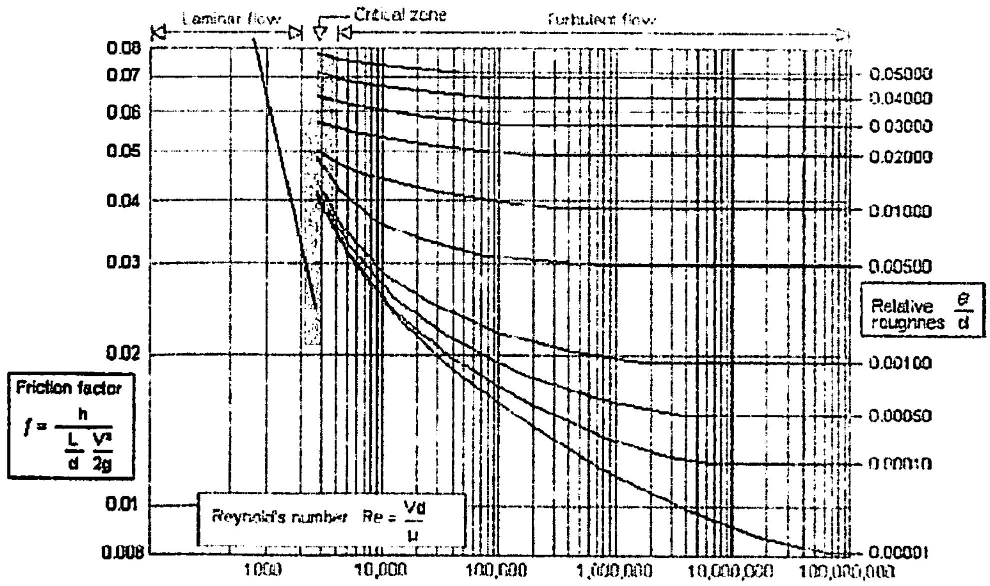
Laminar Flow

Where the Reynolds number is less than 2300 laminar flow will occur and the resistance to flow will be independent of the pipe wall roughness.

The friction factor for laminar flow can be calculated from 64 / Re.

Turbulent Flow

Turbulent flow occurs when the Reynolds number exceeds 4000.



Eddy currents are present within the flow and the ratio of the internal roughness of the pipe to the internal diameter of the pipe needs to be considered to be able to determine the friction factor. In large diameter pipes the overall effect of the eddy currents is less significant. In small diameter pipes the internal roughness can have a major influence on the friction factor.

The 'relative roughness' of the pipe and the Reynolds number can be used to plot the friction factor on a friction factor chart.

The friction factor can be used with the **Darcy-Weisbach formula** to calculate the frictional resistance in the pipe.

Between the Laminar and Turbulent flow conditions (Re 2300 to Re 4000) the flow condition is known as critical. The flow is neither wholly laminar nor wholly turbulent.

It may be considered as a combination of the two flow conditions.

Internal roughness (e) of common pipe materials.

Cast iron (Asphalt dipped)	0.1220 mm	0.004800"
Cast iron	0.4000 mm	0.001575"
Concrete	0.3000 mm	0.011811"
Copper	0.0015 mm	0.000059"
PVC	0.0050 mm	0.000197"
Steel	0.0450 mm	0.001811"
Steel (Galvanized)	0.1500 mm	0.005906"