SYSTEM DESIGN OF MULTI PRODUCT PIPELINE

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SYSTEM DESIGN OF MULTI PRODUCT PIPELINE

A thesis submitted in partial fulfilment of the requirements for the Degree of

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CERTIFICATE

This is to certify that the work contained in this thesis titled "SYSTEM DESIGN OF MULTI PRODUCT PIPELINE" has been carried out by Balaji.R under my/our supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

This Project deals with the design of the pipeline transporting different petroleum products. It includes the calculation of diameter, thickness of the pipeline, MAOP, Pump location, Pump Sizing, Different stress acting over the pipeline. And also this Project validates the design by carrying out stress analysis and the stress developed is compared with the allowable stress. All the calculations are carried on the recommendation of ASME, API and OISD standards. The calculations are made manually. Here, a real time pipeline is taken into consideration, Petronet MHB Limited. All the above calculations are made and found that the design of pipeline is satisfactory and the stress level falls within the limits. This report also gives the ways and means, how to design for the extension of pipeline and also developing a new pipeline.

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TABLE OF CONTENTS

CHAPTER 1:

INTRODUCTION

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.

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.
- 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.
- 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.

CHAPTER 2:
LITERATURE REVIEW

2.1 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:

$$V = (Pg_c / 4\, \mu_E L)(r_w^2 - r^2) \qquad (2.1)$$

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 $R_e < 2000$, and continues until flow velocity reaches a certain a critical value that depends on pipe size and liquid properties causing $R_e >$ 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 R_e 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 R_e 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.

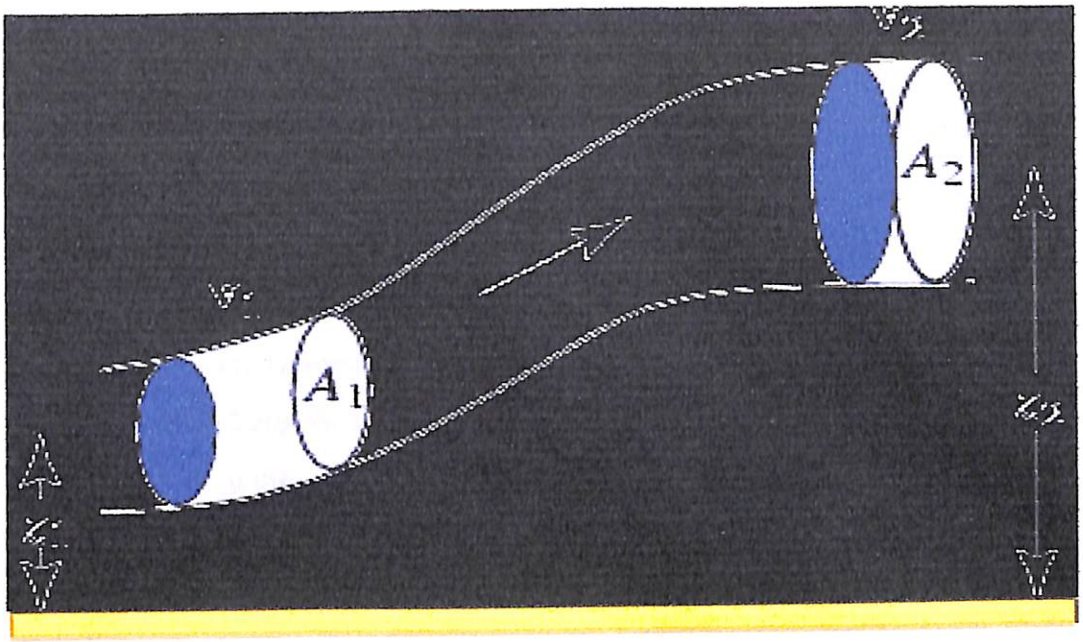
Pipelines are designed to have fluids flow in the turbulent pattern due to the operational advantages of turbulent flow. Since liquid particles are moving approximately at the same velocity across the cross section of the pipe, there is less mixing of the batches of various grades of fluids pumped in 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.

2.1.1 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 =$W\ (V^2A)/2g$

Where,

γ=Specific weight of the liquid

We can thus state that

$E = WZ_A+WP_A/\gamma+WV^2A/2g$ (2.2)

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

$H_A= Z_A+P_A/\gamma +V^2A/2g$ (2.3)

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

$H_B= Z_B+P_B/\gamma +V^2B/2g$ (2.4)

Due to conservation of energy

$H_A=H_B$

Therefore,

$Z_A+P_A/\gamma +V^2A/2g = Z_B+P_B/\gamma +V^2B/2g$ (2.5)

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:

$Z_A+P_A/\gamma+V^2A/2g = Z_B+P_B/\gamma+V^2B/2g+\sum h_L$(2.6)

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:

$Z_A+P_A/\gamma+V^2A/2g+H_P = Z_B+P_B/\gamma+V^2B/2g+\sum h_L$ (2.7)

H_P=pump head added to the liquid at point A

2.2 TELESCOPING PIPE WALL THICKNESS:-

On examining the typical hydraulic gradient, 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 under utilizing 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 for reduced pipeline pressures is referred to as telescoping pipe wall thickness.

2.3 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.

2.4 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 hydro test 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

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

$t_n = t + CA$ (3.2)

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:

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

$Pe = 2E(t/D)^3/(1-v^2), P\gamma = 2St/D, Pc = (P_y \times P_c)/\sqrt{(P_y^2 + P_e^2)}$

Where,

P_e= Elastic Collapse pressure (MPa)

P_γ= 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/mm2)

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. This approach is followed for both trench and embankment conditions.

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:

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

$F_{VS}=A_v W_p$ (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 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
	OISD141 C1.12.3.3.2 (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:

$$S_h = PD/2t \qquad (3.7)$$

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)

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

$$S_L = v \times S_h - \alpha \times E \times \Delta T \pm S_B \qquad (3.8)$$

Where,

S_L= Longitudinal Stress (MPa)

S_h= Hoop stress (MPa)

v = Poisson's ratio of steel

= 0.3

E = Young's modulus of steel (MPa)

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

$= 11.7 \times 10^{-6}$ 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)

$=F_{VS} + Ws$

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

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

Ws = 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:

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

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:

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

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:

$h_f = (\lambda \times L \times V^2)/(2D_i \times g)$ (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):-

$h_e = \lambda_e (V^2 / (2g))$ (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:-

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

Where,

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

= 0.5 for sudden decreases

= 0.05 for bevelled decreases

A_1 = C/S area in smaller pipe

A_2 = C/S area in Larger pipe

V_1 = Flow velocity in smaller pipe

3.5.1.3 Exit losses:-

$h_x = \lambda_x (V_1^2 / (2g))$ (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 neighbouring 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.

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

Where

K = Prandtl-Colebrook friction co-efficient

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 l 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 700 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 and Demand

Product	Sp. Gravity @ 15°C	Viscosity CST	Vapor Pressure,Kg/ cm^2	Phase I Tonnes/Year	Phase II Tonnes/Year
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 centres.

4.4.2 Velocity (V):-

The velocity is calculated by the continuity equation.

$Q = V*A$ (4.1)

A= Cross section area of the pipeline.

4.4.3 Reynolds number (Re):-

The Reynolds number is calculated by the relation:

$Re = v * D/ Z$ (4.2)

Where,

v = Fluid viscosity (m/sec)

D= Inside diameter of pipe (m)

Z= Kinematic viscosity (m^2/sec)

The Re 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.

$1/f^{(1/2)} = 1.14 + 2\log10\ D/E - 2\log10\ [1+9.28/ (R_e*(E/D)*f\,(1/2)]$ (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/cm2 and converted into MCL (Meters of Liquid Column).

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

$SDH = f * L + (H'' - H') + h$ (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 (4.6)

Where,

S = Yield strength (psi)

T = Wall thickness (inches)

S.F = Factor of Safety

4.4.8 Horsepower Required:-

$BHP = Q * H * S * 1000 / (75 * n_1 * n_2)$ (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 Optimisation:-

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). The pipeline has been designed in Phase I for a flow rate of 873 m^3/hr in Mangalore- Hassan section and 700 m^3/hr in Hassan-Bangalore section. In phase-II design flow rates are 1317 m^3/hr and 1030 m^3/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 Pressure,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, nearby Mangalore Refinery & Petro-chemicals Ltd. The latitude is 12°58 min. and the longitude is 74° 51 min. and an elevation of 4.39m.

Location of Different Stations:

Station	Elevation(m)	Kilometer(Km)
Mangalore	4.39	0.00
SV-I	9.53	15.497
SV-II	89.12	44.201
SV-III	80.27	66.036
Nerriya	125	79.5
SV-IV	910	119.558
SV-V	961	150.854
Hassan	951	165.5
SV-VI	923.82	192.852
SV-VII	852.09	220.308
SV-VIII	784.82	256.379
IPS	808.67	266.757
SV-IX	876.87	297.504
SV-X	923.99	327.340
Bangalore	890.66	362.373

•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 AND 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)

= 6.56mm

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

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

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

$P_e = 2E(t/D)^3/(1-v^2)$

$P_\gamma = 2St/D$

$P_c = (Py \times Pc)/\sqrt{(P_y^2 + P_e^2)}$

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

=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/ (1-0.32)

=1.23MPa

P_γ=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/ (1-0.32)

=0.654MPa

P_γ=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)

ρ_{steel}= 7850kg/m^3

ρ_{PE} = 950kg/m^3

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

D_o = outside diameter of pipe (mm)

D_i= inner diameter of pipe (mm)

$W_2 = (\pi*(((Do+2Tc)*0.001)^2-(Do*0.001)^2)/4)* \rho_{PE}$ (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,

$S_h = PD/2t$

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

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

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

$\Delta T = 43.3 - 11.1 = 32.2^0c$

$v = 0.3$

$E = 2*10^5$ MPa

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

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

$= 0.363$ MPa

$S_B = 0.363$ MPa

$S_L = 0.3*258.26-2*10^5*11.7*10^{-6}*32.2\pm0.363$

$= 76.724$

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

$= 229.72$ 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.

Nerriya- Hassan:-

D= 609.6 MPa

t = 8.6mm (corroded pipe wall thickness)

$P = P_i = 9.8$ MPa

$S_h = 9.8*609.6/2*8.6$

$= 347.33$ MPa

Design temperature= 43.3^0c

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

$\Delta T = 32.2^0c$

$v = 0.3$

$E = 2*10^5$ 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= 140m (Horizontal Bend Radius)

S_{BV}= 2*105*0.6096/2000*140

= 0.435 MPa

S_B = 0.435 MPa

S_L = 0.3*347.33-2*105*11.7*10-6*32.2 ± 0.435

= 29.286

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

= 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

ν = 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= 140m (Horizontal Bend Radius)

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

= 0.363 MPa

S_B = 0.363 MPa

$S_L = 0.3*303.05-2*10^5*11.7*10^{-6}*32.2 \pm 0.363$

= 15.93

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

= 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 = $(5.6 * 10^9)/8000$ kg/hr

=$5.6 * 10^9 / (8000 * 0.8359 *10^{3)}$

= 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 = $\pi * D^2/4$

= $\pi * 0.49374^2 / (4)$

= $0.1915\ m^2$

C) Velocity of flow:-

V = Q/A

= $8.73*10^2 / (0.1915)$

= 4558.75 m/hr

= 1.27 m/sec

D) Reynolds number:-

Re = V D / v

= $1.27 * 0.49374 / (1 * 10^{-6})$

= 627049.8 > 4000

Thus the flow is turbulent.

E) Friction factor:-

$1/\sqrt{f} = -2 \log (e / 3.7D + 2.51 / R\sqrt{f})$

e = 0.002 in (roughness)

= 0.000051 m

$1/\sqrt{f} = -2 \log ((0.000051 / 3.7 * 0.4934) + (2.51 / 627049.8 * \sqrt{0.02})$

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

f = 0.0141

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

$h_f = f L V^2/(2gd)$

$= 0.0141 * (82000+86000) * 1.27^2 / (2 * 9.8 * 0.49374)$

$= 394.8$ 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 = S * 2T * S.F/D

= 52000 * 2 * (0.281) * 0.72/ (20)

= 1052.06 psi

= 73.98 kg /cm^2

= $73.98 * 10^4 / (835.9)$

= 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 = $5.6 * 10^9 / (8000)$ kg/hr

=$5.6 * 10^9 / (8000 * 0.8359 * 10^3) = 873$ 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 = $\pi * D^2/4$

= $\pi * 0.49374^2/4$

= 0.1915 m^2

C) Velocity of flow:-

V = Q/A

= $8.73*10^2/0.1915$

= 4558.75 m/hr

= 1.27 m/sec

D) Reynolds number:-

Re= V D / v

= $1.27 * 0.49374 / (1 * 10^{-6})$

= 627049.8 > 4000

Thus the flow is turbulent.

E) Friction factor:-

$1/\sqrt{f} = -2 \log(e / 3.7D + 2.51 / R\sqrt{f})$

e = 0.002 in (roughness)

= 0.000051 m

$1/\sqrt{f} = -2 \log ((0.000051 / 3.7 * 0.4934) + (2.51 / 627049.8 * \sqrt{0.02})$

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

f = 0.0141

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

$h_f = f L V^2 / 2gd$

$= 0.0141 * 82000 * 1.27^2 / (2 * 9.8 * 0.49374) = 192.7$ m

G) Station discharge head:-

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

= 192.7 + (125-4.39) + 50

= 192.7 + 120.61 + 50

= 363.31 m

H) Maximum allowable operating pressure:-

MAOP = S * 2T * S.F/D

= 52000 * 2 * (0.281) * 0.72 / 20

= 1052.06 psi

= 73.98 kg /cm^2

= 73.98*10^4 / 835.9

= 885.03 m

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

I) Horsepower Required:-

BHP = Q * H * S * 1000 / 75 * n_1 *n_2

= 873* 363.31 * 0.8359 * 1000 / 75 * 0.8 * 0.9 * 3600

= 1363.8 HP

Installed hp = 1.1 * BHP

= 1500.18 HP

= 1119.13 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 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.

$Q = 5.6 * 10^9 / 8000$ kg/hr

$=5.6 * 10^9 / (8000 * 0.8359 * 10^3)$

$= 873\ m^3/hr$

B) Cross sectional area of the pipe:-

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

= 0.49374 m

$Area = \pi * D^2 / 4$

$= \pi * 0.49374^2 / 4$

$= 0.1915\ m^2$

C) Velocity of flow:-

V = Q/A

$= 8.73*10^2 / 0.1915$

= 4558.75 m/hr

= 1.27 m/sec

D) Reynolds number:-

Re = V D / v

$= 1.27 * 0.49374 / (1 * 10^{-6})\ m^3/hr$

$= 627049.8 > 4000$

Thus the flow is turbulent.

E) Friction factor:-

$1/\sqrt{f} = -2 \log (e / 3.7D + 2.51 / R\sqrt{f})$

e = 0.002 in (roughness)

= 0.000051 m

$1/\sqrt{f} = -2 \log ((0.000051 / 3.7 * 0.4934) + (2.51 / 627049.8 * \sqrt{0.02})$

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

f = 0.0141

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

$h_f = f L V^2 / (2gd)$

$= 0.0141 * 86000 * 1.27^2 / 2 * 9.8 * 0.49374$

= 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 = S * 2T * S.F / D

= 52000 * 2 * (0.281) * 0.72 / 20

= 1052.06 psi

$= 73.98\ kg/cm^2$

$= 73.98 * 10^4 / 835.9$

= 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.

$Q = 5.6 * 10^9 / (8000)$ kg/hr

$=5.6 * 10^9 / (8000 * 0.8359 *10^3)$

$= 873\ m^3/hr$

B) Cross sectional area of the pipe:-

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

= 0.5906 m

$Area = \pi * D^2 / 4$

$= \pi * 0.5906^2 / 4$

$= 0.274\ m^2$

C) Velocity of flow:-

$V = Q/A = 8.73*10^2 / 0.274$

= 3186.13 m/hr = 0.885 m/sec

D) Reynolds number:-

Re = V D / v

$= 0.885 * 0.5906 / (1 * 10^{-6})$

= 522681 > 4000

Thus the flow is turbulent.

E) Friction factor:-

$1/\sqrt{f} = -2 \log(e / 3.7D + 2.51 / R\sqrt{f})$

e = 0.002 in (roughness)

$= 0.000051$ m

$1/\sqrt{f} = -2 \log ((0.000051 / 3.7 * 0.5906) + (2.51 / 627049.8 * \sqrt{0.02})$

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

$f = 0.0138$

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

$h_f = f L V^2 / 2gd$

$= 0.0138 * 86000 * 0.885^2 / (2 * 9.8 * 0.5906)$

$= 80.3$ m

Based on Section 3.5.1.2,

Friction loss in Enlarger from 20 in to 24 in

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

$= 0.092$

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

$= 0.0075$m

G) Station discharge head:-

$SDH = h_f + (H'' - H') + H +$ friction loss in enlarger

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

$= 80.3 + 1003 + 50 + 0.0075$

$= 1130.31$ m

H) Maximum allowable operating pressure:-

$MAOP = S * 2T * S.F / D$

$= 70000 * 2 * (0.374) * 0.72 / 24$

$= 1571$ psi

$= 110.5$ kg /cm^2

$= 110.5*10^4 / 835.9$

$= 1322$ 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 = Q * H * S * 1000 / (75 * n_1 *n_2)

= 873* 1130.31 * 0.8359 * 1000 / (75 * 0.8 * 0.9 * 3600)

= 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 = π * D^2 / 4

= π * 0.4952^2 / 4

= 0.1926 m^2

C) Velocity of flow:-

V = Q/A

= 7*10^2 / 0.1926

= 3634.5 m/hr = 1.01 m/sec

D) Reynolds number:-

Re = V D / v

= 1.01 * 0.4952 / (1 * 10^{-6})

= 500152 > 4000, thus flow is turbulent.

E) Friction factor:-

$1/\sqrt{f} = -2 \log (e / 3.7D + 2.51 / R\sqrt{f})$

e = 0.002 in (roughness)

= 0.000051 m

$1/\sqrt{f} = -2 \log ((0.000051 / 3.7 * 0.4952) + (2.51 / 500152 * \sqrt{0.02})$

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

f = 0.0142

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

$h_f = f L V^2 / 2gd$

$= 0.0142 * 196000 * 1.01^2 / (2 * 9.8 * 0.4952)$

= 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 = S * 2T * S.F / D

= 60000 * 2 * (0.252) * 0.72 / 20

= 1088.64 psi

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

$= 76.56 * 10^4 / 835.9$

= 915.9 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 = Q * H * S * 1000 / (75 * n_1 *n_2)

= 700* 509.52 * 0.8359 * 1000 / (75 * 0.8 * 0.9 * 3600)

= 1533.62 HP

Installed hp = 1.1 * BHP

= 1686.98 HP

= 1258.49 KW

Since only 1 pump station will be present, power required at that pump station will be 1258.49KW.

5.6 PUMP SIZING:-

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

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

and the velocity in the 24 in. pipe will be

$4.2\times (19.4/23.3)^2$ 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=1571×20/(2×70,000×0.72) =0.312 in.

Similarly for the other two pipe sizes we calculate:

For 22 inch pipe, the wall thickness is

T=1571×22/ (2×70,000×0.72) =0.343 in.

For 24 in. pipe, the wall thickness is

T=1571×24/ (2×70,000×0.72)=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 m3/h, using the Darcy Weishbach equation from Equation (4.4) and also Eqns. 4.2 and 4.3 for the 20 in. pipeline

$h_f = f\,L\,V^2 / 2gd$

$= 0.0141 * 86000 * 1.27^2 / (2 * 9.8 * 0.493776)$

$= 202.1$ m

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

$h_f = 136.74$m 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 $873 m^3/h$ using Equation (4.7).

$BHP = Q * H * S * 1000 / (75 * n_1 * n_2)$

$= 873 * 1255 * 0.8359 * 1000 / (75 * 0.8 * 0.9 * 3600)$

$= 4711.03$ HP

for 20 in.

$BHP = Q * H * S * 1000 / (75 * n_1 * n_2)$

$= 873 * 1189.74 * 0.8359 * 1000 / (75 * 0.8 * 0.9 * 3600)$

$= 4466.06$ HP

$BHP = Q * H * S * 1000 / (75 * n_1 * n_2)$

$= 873 * 1135.23 * 0.8359 * 1000 / (75 * 0.8 * 0.9 * 3600)$

$= 3621.44$ HP

for 24 in.

for 22 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.

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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