Report

On

"Design of Cross-Country Multi-Product Pipeline"

Submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

(Applied Petroleum Engineering)

From

University of Petroleum and Energy Studies

Dehradun

By

Anvesh Srivastava (R010207016)

Chanchal Kumar Tiwari (R010207020)

Joy Barua (R010207026)

Kamini Uniyal(R240207024)

Under the Guidance of

Mr. Adarsh Kumar Arya

College Of Engineering Studies

University of Petroleum & Energy Studies

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April 11, 2011

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Under the Guidance of

Mr. Adarsh Kumar Arya

Assistant Professor of Chemical Engineering

Approved

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Dean

College of Engineering

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CERTIFICATE

This is to certify that the work contained in this thesis titled "Design of cross country multiproduct pipeline from Rewari to Kanpur" has been carried out by *Anvesh Srivastava, Chanchal Kumar Tiwari, Joy Barua* & *Kamini Uniyal* under my supervision and has not been submitted elsewhere for a degree.

Mr. Adarsh Kumar Arya

Assistant Professor

(3^{rd} May 2011)

Acknowledgement

We are greatly indebted to our guide **Mr. Adarsh Kumar Arya, Assistant Professor, UPES**, for providing us an opportunity to work under his guidance. His unflinching support, suggestions and directions have helped in smooth progress of the project work. He has been a constant source of inspiration in all possible ways for successful completion of my project work.

We would like to thank our senior **Mr. Ritesh Srivastava, Officer Operations** at **HPCL-MDPL Jaipur**, who is more like a brother to us. His knowledge and work experience in the field of pipeline design and engineering was the greatest help we could have wished for.

We would also like to thank **Mr. Ravi Kumar, Senior Manager** at **MDPL Jaipur** and **Mr. Akhil Pachaury, Officer Operations** at **MDPL Jaipur.**

Finally, we would like to thank our families for their support. It would have been impossible for us to accomplish this study without their support.

Anvesh Srivastava

Chanchal Kumar Tiwari

Joy Barua

Kamini Uniyal

ABSTRACT

Keeping in mind, for fulfilling the demand of petroleum product from one place to other pipeline played a major role in transporting of crude oil from one destination to other. This facility comes out to be more environment friendly, economical and safest mode of transportation. Pipelie affects daily life in most part of the world. Modern people's lives are base on the environment in which energy plays a predominant role. Oil and gas are the major supply of the energy and pipeline are the means of transporting the energy. These pipelines are mostly buried and operate without disturbing the normal pursuit. They carry large volume of Natural Gas, crude oil and other products in continuous stream.

The objective of this project is to design a **Cross-country Multi-Product Pipeline** which starts from Source A to Destination B in order to meet the present demand. The distance between these two destinations is 450 Kms (assumed) having a rough terrain with minimum elevation 390 fts. Hence designing is been done by taking the two pipes of different diameter with each having two different wall thickness. Thereby making proper analysis of the result, on the basis of economic feasibility the best suited diameter is been selected.

The designing for this project is been done on the basis of standards approved by the petroleum industry in order to attain the satisfactory design. The standards followed are ASME B 31.8, API 5L, Pipeline rule of thumb, Liquid Pipeline Hydraulics, Mohitpour: Pipeline design & Construction along with relevant data picked through websites.

The conclusion of this thesis is been drawn by analysing all the facts come across while designing and later-on while performing economic calculation. For the design two diameter and two wall thickness is been considered and after performing all the calculations I conclude that the pipeline having **"outer diameter"** with **"wall thickness"** will be suitable.

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1.1 BACKGROUND

Presently, LPG, Gasoline, Diesel, Kerosene coal are the main hydrocarbons being used as source of energy for domestic/commercial/industrial purposes. These sources have their own merits and demerits, which are known to all. The major issue associated with these conventional sources of energy is their impact on environment in the form of direct effects on living and non-living things and indirect effect- Global-Warming.

Under the circumstances stated above, transportation of Oil & Gas from one point to others (onshore) requires efficient, safe and cost-effective mode. The only mode for crude product transportation that fulfill all these conditions is a Cross Country Pipeline system which uses cleaner fuel (Natural Gas) to run the compressors and generate the required power at various stations along the pipeline. Pipelining is the technically and economically feasible mode and thus widely used throughout the world. In India many oil product pipelines are operational, many are under construction and many more are under different stages of implementation.

1.2 PIPELINE INDUSTRY IN INDIA

The oil pipeline industry in India is governed by a set of 'Guidelines for Laying Petroleum Product Pipelines' under the Ministry of Petroleum and Natural Gas [Gazette Notification No. P- 20012/5/99-PP dated 20.11.2002, annexed pp 7-8]. These guidelines are not for the pipeline industry to take guidance from in the laying of pipelines, instead these are rules that the Government has declared for itself to observe in allowing pipelines to be laid. The Government acquires the right of user (RoU) in lands along the entire route of a proposed pipeline exercising the power of eminent domain under The Petroleum Pipelines (Acquisition of Right of User in Land) Act, 1962 made by Parliament. If the Government does not acquire and then grant this RoU to a proposed pipeline, the pipeline will never be laid.

1.3 OVERVIEW OF THE PROJECT

This thesis consists of designing of a **Cross-country Multi-Product Pipeline** which starts from Source A (Rewari) to Destination B (Kanpur) in order to meet the present demand. The distance between these two destinations is 413 Kms having a rough terrain with difference in elevation 390 fts. Hence designing is been done by taking the four pipes of different diameter with each having two different wall thickness. Thereby making proper analysis of the result, on the basis of economic feasibility the best suited diameter is been selected.

2. CROSS COUNTRY PIPELINE

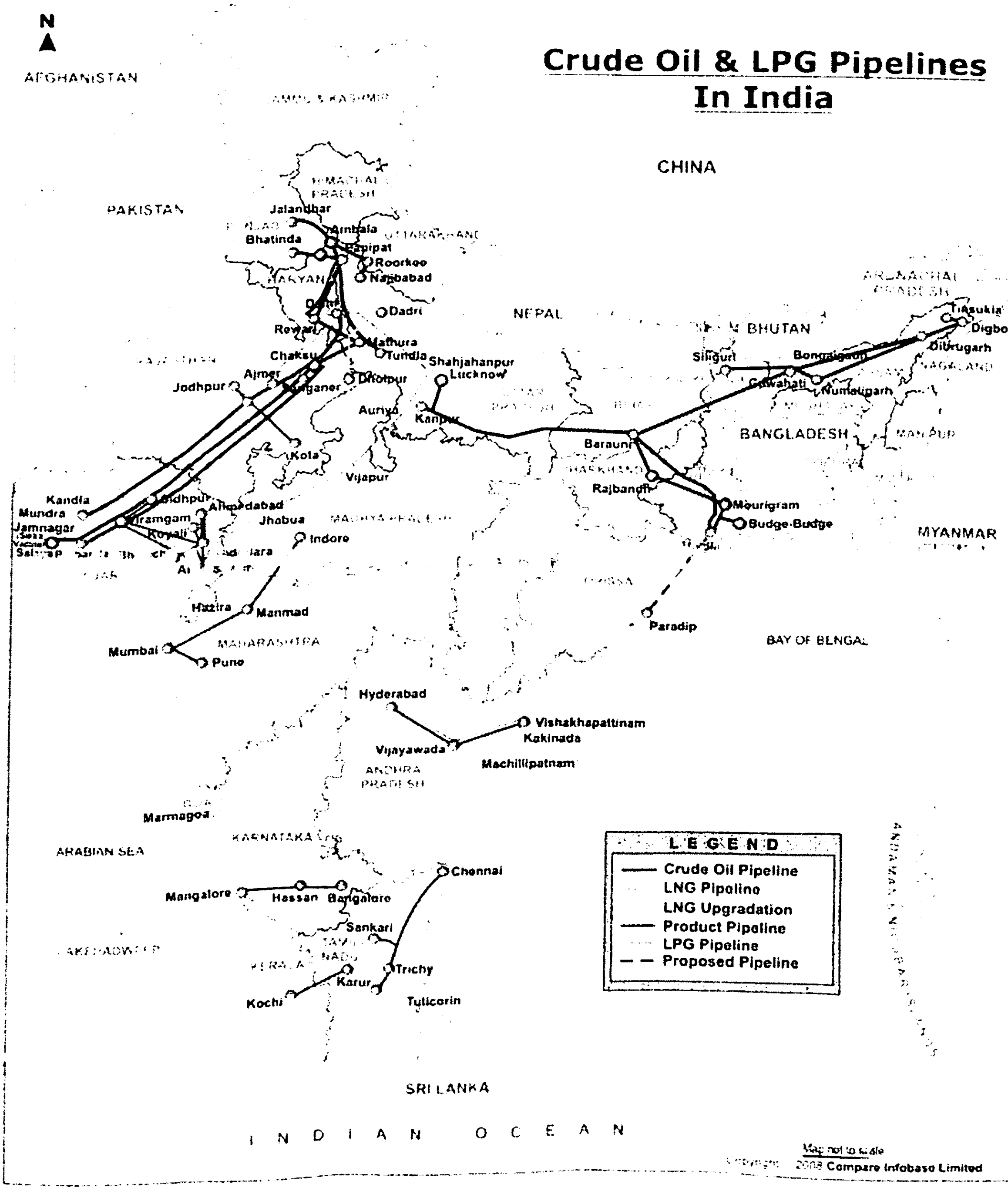
Definition: "A cross country pipeline is a pipeline which starts from a country and its destination is another country but it passes through one or more other countries. It can carry oil gas supply petroleum supply etc."

2.1 INDIAN PIPELINE SCENARIO:

Indian, pipelines are the safest and most efficient means of transporting crude oil and producing fields to refineries and processing plants and of distributing petroleum products gas to the consumer. Pipelines between refineries and major urban centres are replacing mode of transportation.

India's first cross country gas pipeline Hazira-Bijaipur-Jagdishpur (HBJ) network of 1700 km was executed and commissioned by GAIL (India) Ltd in 1987 with a gas transportation capacity of 18.2 MMSCMD mainly to link the gas sourced from Bombay South Bassein offshore field. Since then, the pipeline capacity has been increased and project up-gradation work was completed by 1997-98. The 3397 km long pipeline with a capacity of 33.4 MMSCMD and diameter of pipeline is up to 36 inches traverses the six Indian states of Gujarat, Rajasthan, Madhya Pradesh, Uttar Pradesh, Delhi and Haryana. The Dahej-Vijaipur pipeline (DVPL), the India's first pipeline to carry LNG was executed and commissioned by GAIL. The 42 inch 770 km long onshore pipeline carries a natural gas pipeline with a capacity of 24 MMSCMD.

The East-west pipeline (EWPL) is the next single largest project undertaken in India. Implemented by Reliance Gas Transportation Infrastructure Ltd (RGTIL), a company promoted by the promoters of Reliance Industries Ltd (RIL), at a cost of about $4 billion, the east-west network has been laid to ferry gas from RIL's prolific Krishna Godavari Basin KG Block. The 1,385 km long 48 inch gas pipeline traverses the four States of Andhra Pradesh, Karnataka, Maharashtra, and Gujarat. The EWPL network can transport 80 MMSCMD of gas. Cairn India's Mangala Development Pipeline (MDP) is the world's longest continuously heated and insulated 24" crude oil onshore pipeline of 670 km long. The 24" MDP crude oil pipeline which is using Skin Effect Heat Management System (SEHMS) to ensure that the crude oil remains above the Wax Appearance Temperature (WAT) of 65oC, throughout the pipeline. The main line has 8" gas line running parallel which feeds gas to all the approximate 36 above ground power generator Installations located at every approximate 18 km distance enroute the pipeline which produces the necessary power to keep the pipeline at the required temperature. The Mangala Processing Terminal has a peak plateau production of 175,000 barrels of oil per day, expected by 2011.



3. THEORETICAL DEVELOPMENT

3.1 FACTORS AFFECTING PIPELINE DESIGN:

In order to design a pipeline various factors are taken into consideration:-

- Volume of the liquid required to be transported. The liquid can be crude oil, petrochemical feedstock etc. The throughput is measured in Volume per unit time.
- Initial and final destination
- Properties of the fluid to be transported such as viscosity and specific gravity.
- Route profile, topography of the right of way.
- Maximum Allowable Operating Pressure (MAOP).
- Pipe diameter, wall thickness and grade of pipe material(yield strength)
- Number of pumping stations
- Horsepower required by the pumping stations

3.2 Route Profile:

The route for the laying of the pipeline should be essentially straight. The selection of route also known as Right of Way (ROW) is an important phase in pipeline design and construction. Elevation is taken into consideration to find out the hydraulic pressure.

3.3Fluid Flow Velocity:

The flow velocity of the fluid in the pipe is limited to 2m/sec. This is a safety consideration since above this value there is a danger of formation of charge. During the flow of fluid in the pipe the friction between the insides of pipe walls causes development of charge. This charge can be dangerous if the fluid flowing is inflammable as the charge will cause ignition resulting in explosion causing loss of life and property.

3.4Specific Gravity:

The density of a liquid is defined as its mass per unit volume. Its units are Kg/m^3 or lb/ft^3. Specific gravity is defined as the ratio of density of liquid to density of water at standard temperature (60^0F). The specific gravity of water is 1. The specific gravities of petroleum products such as gasoline, turbine fuel and diesel fuel are 0.73, 0.81 and 0.84 respectively.

3.5Viscosity:

Viscosity is the measure of the resistance to flow. This resistance occurs when the successive layers of liquid move against each other and generate friction. This occurs due to the fact that there is a velocity difference between the fluid flowing in the centre and at the walls. The velocity at the centre is maximum and reduces as one move towards the walls. Due to this a velocity gradient is setup. The viscosity is given by the Newton's law of viscosity. The law states that the sheer stress between the adjacent layers of the flowing liquid is proportional to the velocity gradient. The constant of proportionality is known as the absolute viscosity.

Shear stress = (viscosity) X (velocity gradient)

The viscosity is measured in lb-s/ft^2 or in Pascal-s. Other units include poise and centipoises. The kinematic viscosity is defined as the ratio of the absolute viscosity and density at constant temperature.

$V=\mu/\rho$
Where:-
V=kinematic viscosity
μ=absolute viscosity
ρ=density

3.6Calculation of Diameter:

In order to calculate the diameter we use the value of the throughput (flow rate) and using the equation- $D = K*\sqrt{\frac{4*Q}{3.14*V}}$ we find out the value of the diameter. Here Q is the flow rate and V is the velocity. The velocity cannot be more than 2m/s since it will cause charge development and lead to failure of the design. Then using the standard available diameter of the pipe from the ASTM Table B31.4 (American Society for Testing and Materials). From this table we select the grade of pipe and its corresponding thickness and yield stress. These values are further used to calculate the Maximum Allowable Operating Pressure. The grade of the pipe is carefully chosen in order to optimize the MAOP and the cost of pipe. A higher grade pipe will withstand a higher value of MAOP but will cost more and vice versa.

3.7Reynolds Number:

Reynolds number is a dimensionless quantity that represents the ratio of inertial force to viscous force. In other words Reynolds number is the ratio between the force that is moving the fluid to the force which opposes the flow. In pipeline design Reynolds number plays an important role since it is the major factor in choosing the pipe diameter. In pipeline the inertial force is the driving force generated by the pumps and the viscous force is due to the drag created by the flowing fluid. The values of Reynolds decide whether the flow is laminar or turbulent. If the value of Reynolds number is less than 2100 then the fluid is moving evenly and the flow is said to be laminar. In case the Reynolds number is greater than 3000 then the flow is said to be turbulent. At a value typically at 2320 the flow is neither laminar nor turbulent this value is known as critical Reynolds number. In pipeline design we prefer using a turbulent flow with Reynolds number greater than 3000 in case more than one fluid is being transported through the pipeline. The higher Reynolds number helps in arresting back mixing of the products reducing the formation of interface. The interface is basically the contact area between the two liquids which starts expanding due to back mixing of the products. This interface is difficult to separate and may result in the contamination of the purer product (such as ATF) or loss of the same.

3.8 Friction Factor:

The Darcy friction factor is a dimensionless number which gives the ratio between the mean velocity of the fluid and the pressure gradient. For pipeline design Colebrook-White Equation is used. The value of the friction factor is iterated to find the most accurate value. This value is then used to calculate the head loss due to friction. This is an important factor in deciding the pumping head required and calculating the number of pumping stations.

3.9 Pressure Calculations:

The calculation of the total head required for pumping the fluid from one destination to the other depends on the following factors:-

- Pipe diameter, thickness of wall and roughness
- Length of pipe
- Change in elevation from one point to the other
- Properties of liquid (viscosity and specific gravity)
- Throughput(Flow rate)

On increasing the pipe diameter (keeping other factors constant) the frictional head pressure will decrease and hence the total pressure will decrease. If we increase the roughness or the thickness of the pipe it will result in the increase in frictional head pressure which will rise in the value of the total head pressure. The elevation profile affects the total pressure since at a point with higher elevation the total pressure will be more than the pressure at a lower elevation or flat terrain. If the viscosity and specific gravity of the liquid is more, then the frictional head required will be more hence the total pressure will be more.

Thus the total pressure can be defined as the sum of friction head pressure, elevation head pressure and delivery head pressure at the terminus.

3.10 Maximum Allowable Operating Pressure:

In order to transport fluid through a pipeline we need to apply sufficient pressure to overcome the frictional head and the elevation head. As the length of the pipeline increases the magnitude of pressure required to pump the fluid correspondingly increases. However, the pipeline can withstand a part of this pressure. Calculation of MAOP gives an idea about the maximum pressure at which a fluid can be pumped without causing the pipe to explode. For calculation of this MAOP we use the Barlow's equation:-

MAOP= 2*S*t*E*F/ (D-2t)

Where MAOP- Maximum Allowable Operating Pressure, psi

S- Minimum Yield Strength of pipe material, psi

t- Wall thickness, Inch

E- Weld joint Factor, dimensionless, (1.0)

F- Design Factor, (0.72)

D- Diameter of the pipe, Inch

3.11 Calculation of Number of Pumping Stations:

After calculating the total pumping head required and MAOP required we need to find out the number of pumping stations. Since the pumping head in the whole pipeline cannot be more than the MAOP we adjust the discharge pressure of dispatch and the intermediate pumping station at a value slightly less than the MAOP. The pumping stations are so located that the total pressure is equal to the total pumping head required.

3.12 Hydraulic Horse Power Requirement:

After calculating the discharge and suction head pressure we need to find the horse power of the pump in order to decide which pump to use. We also find the break horse power to calculate the actual power needed.

3.13 Economic Analysis

Any project is not considered to be complete or successful if it is not economical. The economics of the project is the major factor which enables the managers to decide the best alternative to choose from the given design calculations. In pipeline economics various factors are taken into consideration such as cost of pipe, cost of developing the Right Of Way, cost of operation, cost of maintenance and other costs which are incurred either in construction, operation and maintenance. The choice of the design depends on the capital available, the given conditions and the predicted revenue that will be generated from the pipeline.

4. FORMULA USED:

4.1 Diameter (D):

$$D=K * \sqrt{\left(\frac{4*Q}{3.14*v}\right)}$$

Where Q- Flow rate, bbl/day

v- Fluid flow velocity, m/sec

D- Diameter of the pipe, Inch

K- Conversion factor, dimensionless

K can be calculated as follows

$K=\sqrt{\frac{0.158987}{86,400}}*39.37 = 0.0534$ (conversions used are given)

4.2 Reynolds Number (Re):

$$Re= 92.24*Q/(v*D)$$

Where Re- Reynolds Number, dimensionless number

Q- Flow rate, bbl/day

v- Kinematic viscosity of the fluid, cSt

D- Diameter of the pipe, Inch

4.3 Friction Factor (f):

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

$$1/\sqrt{f} = -2\text{Log}_{10}\,[(e/3.7D) + 2.51/(Re\sqrt{f})]$$

Where f- Friction factor, dimensionless number

e- Pipe roughness, inch (e = 0.002 inch assumed)

D- Diameter of the pipe, inch

Re- Reynolds number, dimensionless number

4.4 Pressure drop due to friction (P_f):

$P_f = 0.0605 * f * Q^2 * (Sg/D^5)$

Where P_f - Pressure drop due to friction, psi/mile of pipe length

Q- Liquid flow rate, bbl/day

f- Darcy friction factor, dimensionless

Sg- Liquid specific gravity

D- Pipe internal diameter, Inch

4.5 Total Pressure required at the beginning of pipeline (P):

P= Pressure drop due to friction + Elevation head + Delivery pressure

$P = P_f + H*(Sg/2.31) + P_d$

Where P- Total pressure, psi

P_f - Pressure drop due to friction, psi

H- Elevation head, ft

Sg- Specific gravity, dimensionless

P_d -Delivery pressure, psi

4.6 Pressure drop per unit length of pipeline ($\Delta p/L$):

$(\Delta p/L) = P/L$

Where $(\Delta p/L)$ - Pressure drop per unit length of pipeline, psi/mile

P- Total pressure, psi

L- Total length of pipeline, mile

4.7 Maximum Allowable Operating Pressure (MAOP):

MAOP= 2*S*t*E*F/(D-2t)

Where MAOP- Maximum Allowable Operating Pressure, psi

S- Minimum Yield Strength of pipe material, psi

t- Wall thickness, Inch

E- Weld joint Factor, dimensionless, (1.0)

F- Design Factor, (0.72)

D- Diameter of the pipe, Inch

4.8 Hydraulic Horsepower Required (HP):

HP = Q* (P_d - P_s)/33000

Where Q – flowrate , lb/min

P_d - Pump station discharge pressure, psi

P_s –Pump station suction pressure, psi

BHP= HHP/pump efficiency

IHP=BHP*1.1

Power Required =IHP/no of pumping stations

5) CALCLULATIONS-

Design Parameters:

5.1) Route Profile: We have surveyed the total distance between Rewari and Kanpur with the help of Google Earth and also considered the elevations of intermediate points on route profile.

Related information:

Total distance of pipeline	413 Km (256.59 mile)
Products to be transported	1. High Speed Diesel (HSD)
	2. Motor Spirit (MS)
	3. Superior Kerosene Oil (SKO)

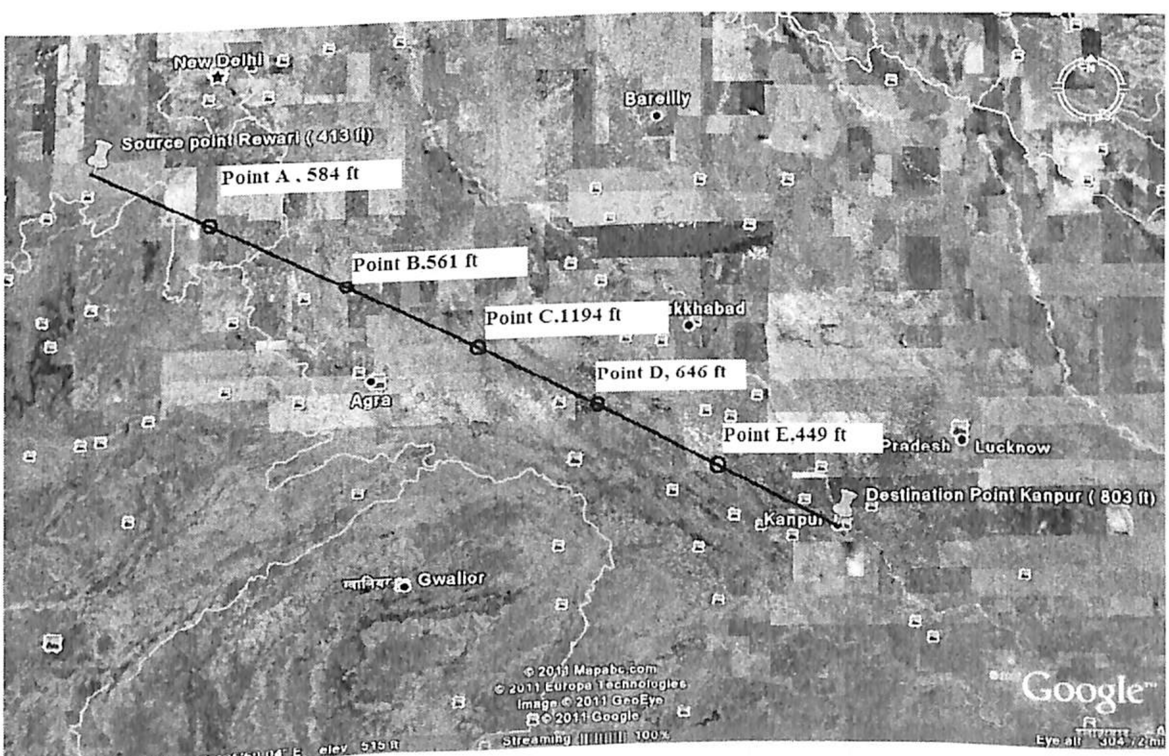


Figure 1:Pictorial View of proposed pipeline from Rewari to Kanpur

1) **Capacity**: as we know that the capacity is primary step for designing of pipeline. So we have considered the three flow-rates for our design basis:-

20,000 m^3/day and 30,000m^3/day

2) **Fluid Flow Velocity**: as we know that the velocity of fluid is not desirable more than 2metre/second in the pipeline. So we have assumed two velocities of fluids for further calculations:-

   1.5 m/s & 2 m/s

3) **Specific Gravity**: we have considered the three products to be transported in this design i.e. HSD, MS & SKO. In these three, HSD has highest specific gravity. So we have specific gravity to be 0.85 for calculation purpose.

   Density to be assumed $\boldsymbol{\rho}$ = 0.85*1000kg/m^3=850 kg/m^3

4) **Viscosity ($\boldsymbol{\mu}$)**: For HSD, the value of viscosity is higher than for MS & SKO. The value of μ is assumed to be 5 cp

   5 cp = 18 *277.77/850 cSt= 5.882 cSt

5) **e- Pipe roughness,** inch (e = 0.002 inch assumed).

6) Isothermal operation.

7) Neglecting valves and bend calculatons.

➢ 1st ASSUMPTION (for 20,000 m^3/day flow-rate):

Fluid flow velocity 1.5m/s

1. Diameter calculation(D):

$$D = K*\sqrt{\frac{4*Q}{3.14*V}}$$

$$D = 0.0534*\sqrt{\frac{4*\frac{20000}{0.158987}}{3.14*1.5}}$$

D= 17.45Inch

As we know 17.45 Inch diameter is not available in the industry so we have taken it to be **18Inch** for further calculation.

2. Reynolds Number (Re) :

Re= 92.24*Q/(v*D)

Re= 92.24*(20000/0.158987)/(5.882*18)

Re= 109,594.8509

3. Friction Factor (f):

$1/\sqrt{f} = -2\text{Log}_{10} [(e/3.7D) + 2.51/(Re\sqrt{f})]$

By trial and error approach-

Putting f= 0.02 in equation

R.H.S=7.432 and L.H.S.= 7.07

Putting f= 0.018 in equation

R.H.S.=7.395 and L.H.S.=7.4536

Putting f= 0.0185 in equation

R.H.S.= 7.404 and L.H.S.=7.352

Putting f= 0.0182 in equation

R.H.S.=7.398 and L.H.S.= 7.408

So **f = 0.0182**

4. **Pressure Head (P_f):**

$P_f = 0.0605 * f * Q^2 \, (Sg/D^5)$

$P_f = 0.0605*0.0182*(20000/0.158987)^2*(0.85/18^5)$

$\mathbf{P_f = 7.838}$ **psi/mile**

5. **Total Pressure required at the beginning of pipeline (P):**

$P = P_f + H*(Sg/2.31) + P_d$

$P = 7.838*256.59 + (803-413)*0.85/2.31 + 50$

P= 2204.658 psi

6. **Pressure drop per unit length of pipeline (Δp/L):**

$\Delta p/L = P/L$

$\Delta p/L = 2204.658/256.59$

Δp/L= 8.592 psi/mile

7. **Maximum Allowable Operating Pressure (MAOP):**

MAOP= 2*S*t*E*F/(D-2t)

MAOP=2*42000*0.312*1.0*0.72/(18-2*0.312)

MAOP=1085.96 psi

8. **Total Frictional Pressure drop-**

Rewari	→	**Point C**	→	**Kanpur**
(413 ft)	**(128.295mile)**	**(1194 ft)**	**(128.295mile)**	**(803 ft)**

Δp from Rewari to Point C = Δp/L*128.295 psi

=8.592*128.295 psi

=1094.23 psi

Again, Δp from Point C to Kanpur =Δp/L*128.295 psi

=8.529*128.295 psi =**1094.23 psi**

9. Calculation of Pressure required at the Rewari for Pumping-

Since Point C has elevation of 1194. ft which is peak point in overall route profile. Considering the portion from Rewari to Point C which has elevation difference equal to-

Elevation difference between Rewari and Point C = (1194-413) ft

=781 ft

Pressure required at the Rewari to get over peak at Point C= frictional pressure drop + pressure drop due to elevation difference =1094.23 + 781*0.85/2.31 psi

=1381.61 psi

In the pipeline flow, it is desirable that the liquid product at the top of the peak point should be at some minimum pressure, which is higher than the vapour pressure of the product. (for refined products and crude oil , this value should be taken between 10 to 20 psi.)

Pressure required at the Rewari to get over peak at Point C= (1381.61 +10) psi = 1391.61 psi

Elevation difference between Point C and Kanpur = (1194-803) ft =391 ft

Arrival pressure at the Kanpur = minimum pressure desirable + pressure drop due to elevation difference – frictional pressure drop = (10 + 391*0.85/2.31 -1094.23) psi

= -940.36 psi

So, this pressure 940.36 psi should be added to total pressure at the Rewari for pumping.

Minimum delievery pressure required at Kanpur = 50 psi

Total pressure required at Rewari= (Pressure required at the Rewari to get over peak at Point C + Minimum delievery pressure +940.36) psi = (1391.61 + 50 + 940.36) psi = **2381.97 psi**

Total pressure at the Kanpur = (arrival pressure at Kanpur + minimum delivery pressure +940.36) = -940.36 + 50 + 940.36 = **50 psi**

10.Hydraulic Pressure Gradient & number of Pumping Stations-

Horsepower calculation since the pressure required at Rewari is 2381.97 psi and maximum allowable operating pressure (MAOP) is 1085.96 psi. So we would require two intermediate pumping stations between Kanpur and Rewari to limit the maximum pressure in the pipeline to 1085.96 psi. Due to MAOP limits, pressure required will be provided in steps. So there will be 3 pumping station in the pipeline.

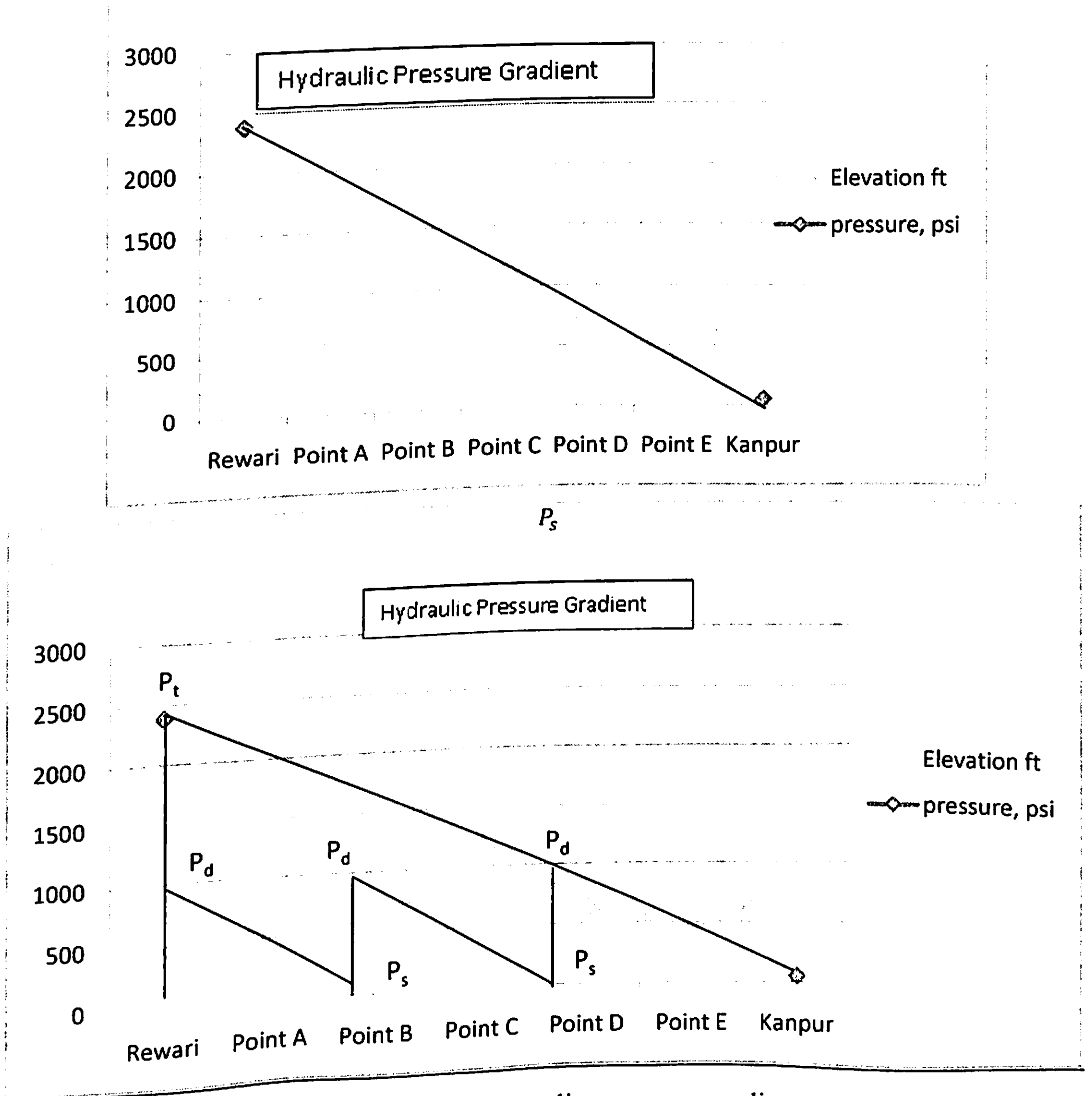


Figure 2(a,b). Hydraulic pressure gradient

11. Hydraulic Pressure Gradient

Where P_d –Pump station discharge pressure

P_s –Pump station suction pressure

P_t -total pressure required

So $P_t = P_d + P_d - P_s + P_d - P_s$

Solving for P_d ,

$P_d = (P_t + 2P_s)/3$

Considering a minimum suction pressure of 50 psi for each pumping station, each pump station would have a discharge pressure of

$P_d = (2381.97 + 2*50)/3$

$\mathbf{P_d = 827.32}$ **psi**

12. Horsepower Required (HP)-

HP = Q* (P_d - P_s)/33000

Flowrate ,Q can be calculated in lb/min as follows-

Q = 20000/(0.158987*24)*(5.6164/60)*0.85*62.34

Q =25998.582 lb/min

HP required is

HP = 25998.582*(827.32- 50)/33000

HP =612.40Hp

BHP= HHP/ Efficiency

BHP= 612.40/0.75

=816.53 HP

IHP= 1.1*BHP

IHP= 1.1*816.53

=898.18Hp

Power Required= IHP/n

Power required= 898.18/3

=300Hp

13. Cost Analysis-

Area of main pipe= $3.14*(od^2 - id^2)/4$

$=3.14*(18^2-17.25^2)/4$

$=17.219$ inch^2 $=17.219*0.0006452$ m^2

=0.0111 m^2

Cost of the main line pipe= area of main line *L*8500*material cost

= 0.0111*413000*8500*40 =**155.87 crores**

Pump Cost =IHP * cost of 1Kw

Pump cost = 898.18* 300

=0.027 crores

Total Cost = cost of main line pipe + Pump cost

= 155.87 + 0.027

=155.4 crores

Preparation cost = 40% of Total cost = 62.4 crores

Service cost = 15% of Total cost = 23.4 crores

Capital cost = Total cost + Service cost + Preparation cost = 241.7 crores

Utilities = IHP * Electrical rate * working hour = 898.18 * 100 * 8000 = 71.85 crores

Cost of Consumables = 40% of Utilities = 28.7 crores

Labor cost = 10% of Utilities = 7.2 crores

Maintenance cost = 15% of Utilities = 10.8 crores

Administration Cost = 10% of Utilities = 7.2 crores

Total Operating Cost = Utilities + consumables + Labor + Maintenance + Administration cost = 71.8 + 28.7 + 7.2 + 10.8 + 7.2

= 125.7 Crores

- **2nd ASSUMPTION (for 20,000 m^3/day flow-rate):**

Fluid flow velocity 2 m/s

1. **Diameter calculation(D):**

$D = K*\sqrt{\frac{4*Q}{3.14*V}}$

$D = 0.0534*\sqrt{\frac{4*\frac{20000}{0.158987}}{3.14*2}}$

D= 15.12Inch

As we know 15.12 Inch diameter is not available in the industry so we have taken it to be **16 Inch** for further calculation.

2. **Reynolds Number (Re) :**

Re= 92.24*Q/(v*D)

Re= 92.24*(20000/0.158987)/(5.882*16)

Re= 123,294.20

3. **Friction Factor (f):**

$1/\sqrt{f} = -2Log_{10} [(e/3.7D) + 2.51/ (Re\sqrt{f})]$

By trial and error approach-

Putting f= 0.02 in equation

R.H.S=7.50 and L.H.S.= 7.07

Putting f= 0.018 in equation

R.H.S =7.463 and L.H.S.=7.4536

So **f = 0.018**

4. **Pressure Head (P_f):**

P_f= 0.0605*f*Q^2*(Sg/D^5)

P_f= 0.0605*0.018*$(20000/0.158987)^2$*($0.85/16^5$)

P_f= 13.96 psi/mile

5. **Total Pressure required at the beginning of pipeline (P):**

P= P_f + H*(Sg/2.31) + P_d

P= 13.96*256.59 + (803-413)*0.85/2.31 + 50 = **P= 3775.50 psi**

6. **Pressure drop per unit length of pipeline (Δp/L):**

Δp/L= P/L

Δp/L= 3775.50/256.59

Δp/L= 14.71 psi/mile

7. **Maximum Allowable Operating Pressure (MAOP):**

MAOP= 2*S*t*E*F/(D-2t)

MAOP=2*42000*0.312*1.0*0.72/(16-2*0.312)

MAOP=1227.22 psi

8. **Total Frictional Pressure drop-**

Rewari ⟶ **Point C** ⟶ **Kanpur**

(413 ft) **(128.295mile)** **(1194 ft)** **(128.295mile)** **(803 ft)**

Δp from Rewari to Point C= Δp/L*128.295 psi

=14.71*128.295 psi

=1887.22 psi

Again,

Δp from Point C to Kanpur =Δp/L*128.295 psi

=14.71*128.295 psi

=1887.22 psi

9. **Calculation of Pressure required at the Rewari for Pumping-**

Since Point C has elevation of 1194 ft which is peak point in overall route profile. Considering the portion from Rewari to Point C which has elevation difference equal to-

Elevation difference between Rewari and Point C= (1194-413) ft =781 ft

Pressure required at the Rewari to get over peak at Point C= frictional pressure drop + pressure drop due to elevation difference =1887.22 + 781*0.85/2.31 psi =2174.60 psi

In the pipeline flow, it is desirable that the liquid product at the top of the peak point should be at some minimum pressure, which is higher than the vapour pressure of the product. (For refined products and crude oil , this value should be taken between 10 to 20 psi.)

Pressure required at the Rewari to get over peak at Point C= (2174.60 +10) psi = 2184.60 psi

Elevation difference between Point C and Kanpur = (1194-803) ft = 391 ft

Arrival pressure at the Kanpur = minimum pressure desirable + pressure drop due to elevation difference – frictional pressure drop = (10 + 391*0.85/2.31 -1887.22) psi

= -1733.35 psi

So, this pressure 1733.35 psi should be added to total pressure at the Rewari for pumping.

Minimum delievery pressure required at Kanpur = 50 psi

Total pressure required at Rewari= (Pressure required at the Rewari to get over peak at Point C + Minimum delievery pressure +1733.35) psi = (2174.60 + 50 + 1733.35) psi

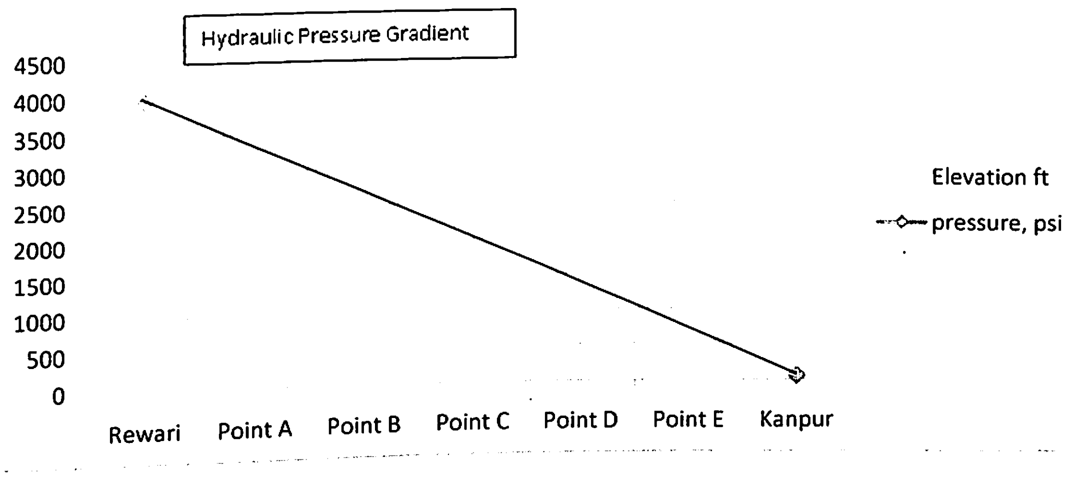
= **3957.85 psi**

Total pressure at the Kanpur = (arrival pressure at Kanpur + minimum delivery pressure) +1733.35 = -1733.35 + 50 + 1733.35 = **50 psi**

10.Hydraulic Pressure Gradient & number of Pumping Stations-

Horsepower calculation since the pressure required at rewari is 3957.85 psi and maximum allowable operating pressure (MAOP) is 1227.22 psi. So we would require three intermediate pumping station between Kanpur and Rewari to limit the maximum pressure in the pipeline to 1227.22 psi. Due to MAOP limits, pressure required will be provided in steps. So there will be 4 pumping station in the pipeline.

Draw hydraulic pressure gradient in



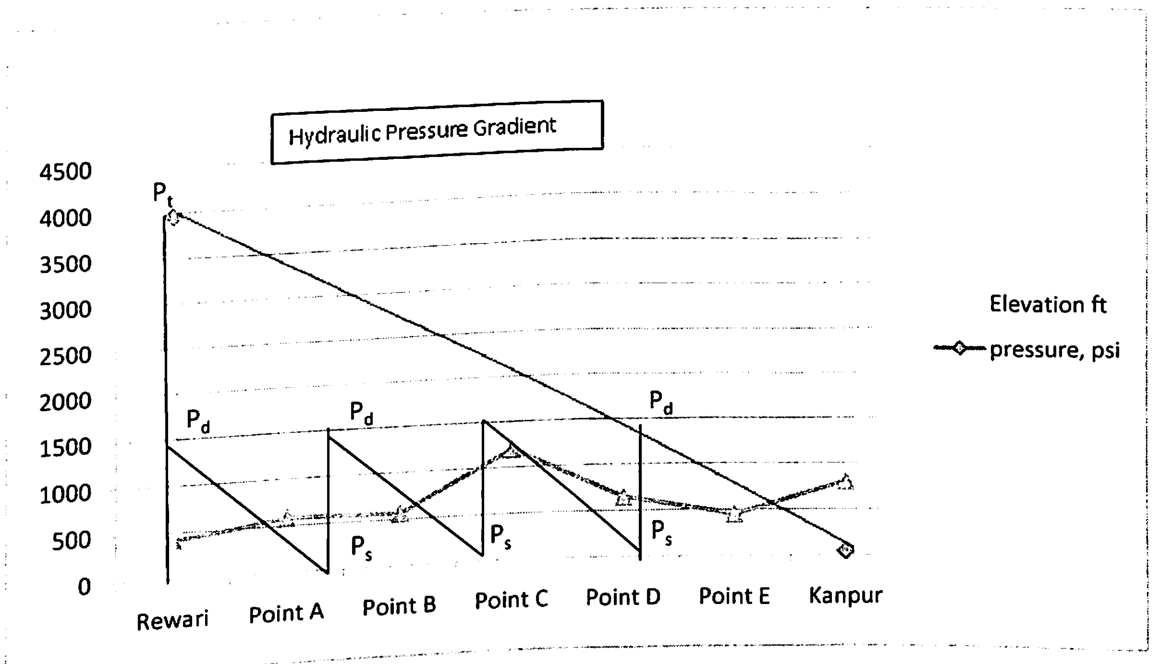


Figure 3(a,b). Hydraulic pressure gradient

11.Hydraulic Pressure Gradient

Where P_d –Pump station discharge pressure

P_s –Pump station suction pressure

P_t -total pressure required

So $P_t = P_d + P_d - P_s + P_d - P_s$

Solving for P_d ,

$P_d = (P_t + 2P_s)/3$

Considering a minimum suction pressure of 50 psi for each pumping station, each pump station would have a discharge pressure of

$\boldsymbol{P_d}$ = (3957.85 + 3*50)/4

$\boldsymbol{P_d}$ **= 1026.96 psi**

12.Hydraulic Horsepower Required (HP)-

HP = Q* ($\boldsymbol{P_d}$ - $\boldsymbol{P_S}$)/33000

Flow-rate, Q can be calculated in lb/min as follows-

Q = 20000/ (0.158987*24)*(5.6164/60)*0.85*62.34

Q =25998.582 lb/min

HP required is

HP = 25998.582*(1026.96- 50)/33000

HP =769.68

BHP= HHP/ Efficiency

BHP= 769.68/0.75

=1026.24 HP

IHP= 1.1*BHP

IHP= 1.1*1026.24

= 1128.86Hp

Power Required= IHP/n

Power required= 1128.86/4

=282Hp

13. Cost Analysis-

Area of main pipe= $3.14*(od^2 - id^2)/4$

$=3.14*(16^2-15.3^2)/4$

$=17.96\ inch^2 = 17.96*0.0006452\ m^2$

$\mathbf{=0.0116\ m^2}$

Cost of the main line pipe= area of main line *L*8500*material cost

= 0.0116*413000*8500*40 =**162.72 crores**

Pump Cost =IHP * cost of 1Kw

Pump cost = 1128.86* 300

=0.034 crores

Total Cost = cost of main line pipe + Pump cost

= 162.72 + 0.034

=162.75 crores

Preparation cost = 40% of Total cost = 65 crores

Service cost = 15% of Total cost = 24.4 crores

Capital cost = Total cost + Service cost + Preparation cost = 252.15 crores

Utilities = IHP * Electrical rate * working hour = 1128.86 * 100 * 8000 = 90.3 crores

Cost of Consumables = 40% of Utilities = 36 crores

Labor cost = 10% of Utilities = 9 crores

Maintenance cost = 15% of Utilities = 13.4 crores

Administration Cost = 10% of Utilities = 9 crores

Total Operating Cost = Utilities + consumables + Labor + Maintenance + Administration cost = 90.3 + 36 + 9 + 13.4 + 9

= 157.7 Crores

- 3^{rd} **ASSUMPTION (for 30,000 m^3/day flow-rate):**

Fluid flow velocity 1.5 metre/second

1) Diameter calculation(D):

$$D = K*\sqrt{\frac{4*Q}{3.14*v}}$$

$$D = 0.0534*\sqrt{\frac{4*\frac{30000}{0.158987}}{3.14*1.5}}$$

D= 21.38Inch

As we know 21.38 Inch diameter is not available in the industry so we have taken it to be **22Inch** for further calculation.

2) Reynolds Number (Re) :

Re= 92.24*Q/ (v*D)

Re= 92.24*(30000/0.158987)/ (5.882*22)

Re= 134,502.77

3) Friction Factor (f):

$1/\sqrt{f} = -2Log_{10}$ [(e/3.7D) + 2.51/(Re$\sqrt{f}$)]

By trial and error approach-

Putting f= 0.02 in equation

R.H.S=7.611 and L.H.S = 7.07

Putting f= 0.018 in equation

R.H.S =7.572 and L.H.S =7.4536

Putting f= 0.0178

R.H.S = 7.563 and L.H.S =7.495

Putting f= 0.0176 in equation

R.H.S =7.564 and L.H.S = 7.537

So **f = 0.0176**

4) **Pressure Head (P_f):**

$P_f = 0.0605 * f * Q^2 * (Sg/D^5)$

$P_f = 0.0605*0.0176*(30000/0.158987)^2*(0.85/22^5)$

P_f **= 6.253 psi/mile**

5) **Total Pressure required at the beginning of pipeline (P):**

$P = P_f + H*(Sg/2.31) + P_d$

P= 6.253*256.59 + (803-413)*0.85/2.31 + 50

P= 1797.96 psi

6) **Pressure drop per unit length of pipeline (Δp/L):**

Δp/L= P/L

Δp/L= 1797.96/256.59

Δp/L= 7.007 psi/mile

7) **Maximum Allowable Operating Pressure (MAOP):**

MAOP= 2*S*t*E*F/ (D-2t)

MAOP=2*42000*0.375*1.0*0.72/(22-2*0.375)

MAOP=1067.29 psi

8) Total Frictional Pressure drop-

Rewari ⟶ **Point C** ⟶ **Kanpur**

(413 ft) **(128.295mile)** **(1194 ft)** **(128.295mile)** **(803 ft)**

Δp from Rewari to Point C= $\Delta p/L$*128.295 psi

=7.007*128.295 psi

=898.96 psi

Again,

Δp from Point C to Kanpur =$\Delta p/L$*128.295 psi

=7.007*128.295 psi

=898.96 psi

9) Calculation of Pressure required at the Rewari for Pumping-

Since Point C has elevation of 1194 ft which is peak point in overall route profile. Considering the portion from Rewari to Point C which has elevation difference equal to-

Elevation difference between Rewari and Point C= (1194-413) ft =781 ft

Pressure required at the Rewari to get over peak at Point C= frictional pressure drop + pressure drop due to elevation difference = 898.96 + 781*0.85/2.31 psi =1186.34 psi

In the pipeline flow, it is desirable that the liquid product at the top of the peak point should be at some minimum pressure, which is higher than the vapour pressure of the product. (for refined products and crude oil , this value should be taken between 10 to 20 psi.)

Pressure required at the Rewari to get over peak at Point C= (1186.34 +10) psi = 1196.34 psi

Elevation difference between Point C and Kanpur = (1194-803) ft =391 ft

Arrival pressure at the Kanpur = minimum pressure desirable + pressure drop due to elevation difference – frictional pressure drop = (10 + 391*0.85/2.31 -898.96) psi

= -745.09 psi

So, this pressure 745.09 psi should be added to total pressure at the Rewari for pumping.

Minimum delievery pressure required at Kanpur = 50 psi

Total pressure required at Rewari= (Pressure required at the Rewari to get over peak at Point C + Minimum delievery pressure +745.09) psi = (1196.34 + 50 + 745.09) psi

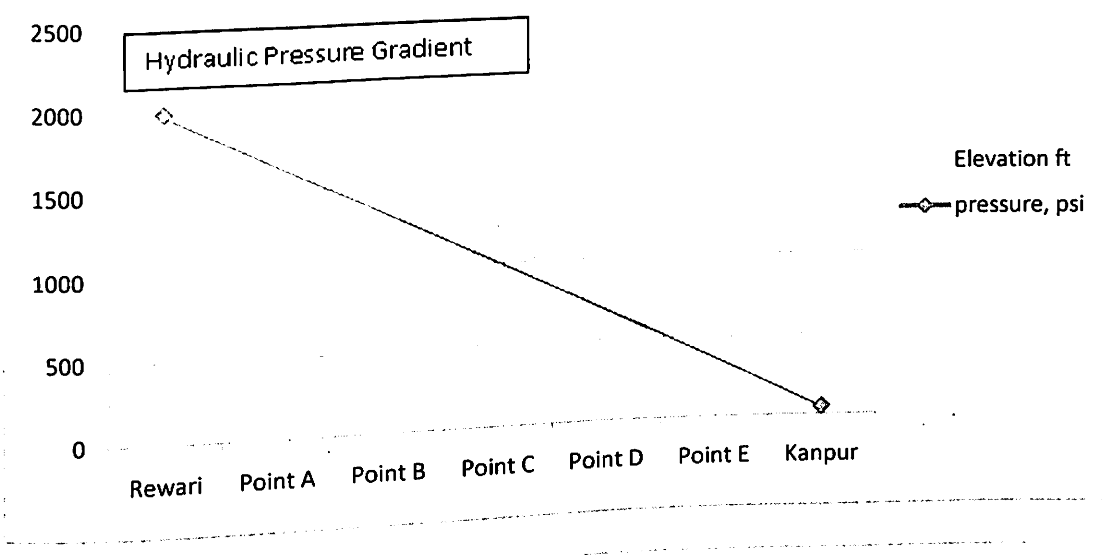
=1991.43 psi

Total pressure at the Kanpur = (arrival pressure at Kanpur + minimum delievery pressure + 745.09 = -745.09 + 50 + 745.09 = **50 psi**

10) <u>Hydraulic Pressure Gradient & number of Pumping Stations-</u>

Horsepower calculation since the pressure required at rewari is 1991.43 psi and maximum allowable operating pressure (MAOP) is 1067.24 psi. So we would require 1 intermediate pumping station between Kanpur and Rewari to limit the maximum pressure in the pipeline to 1067.24 psi. Due to MAOP limits, pressure required will be provided in steps. So there will be 2 pumping station in the pipeline.

Draw hydraulic pressure gradient in



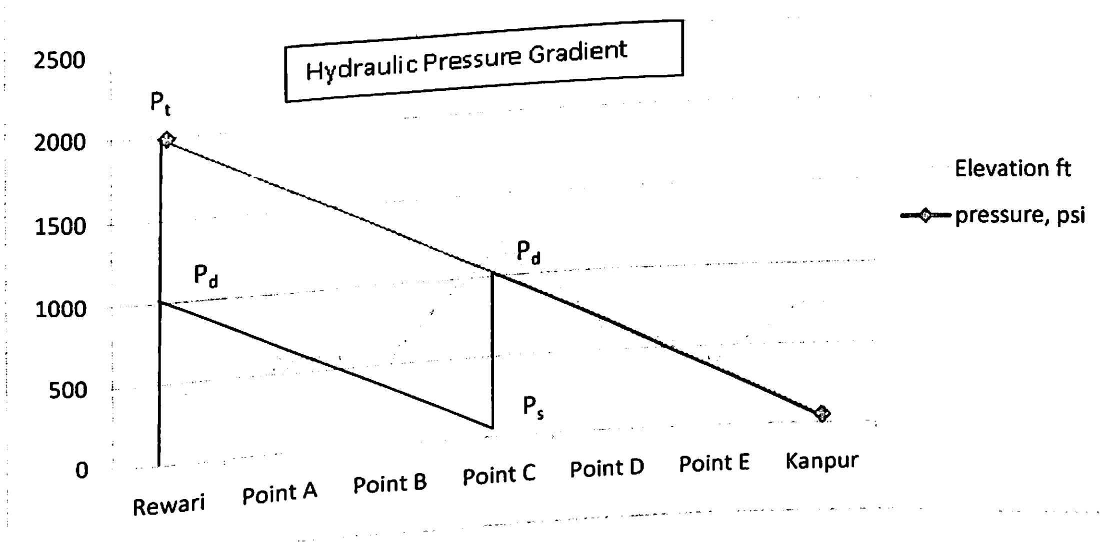


Figure 4(a,b). Hydraulic pressure gradient

11) Hydraulic Pressure Gradient

Where P_d –Pump station discharge pressure

P_s –Pump station suction pressure

P_t -total pressure required

So $P_t = P_d + P_d - P_s + P_d - P_s$

Solving for P_d ,

$P_d = (P_t + P_s)/2$

Considering a minimum suction pressure of 50 psi for each pumping station, each pump station would have a discharge pressure of

Considering a minimum suction pressure of 50 psi for each pumping station, each pump station would have a discharge pressure of

$\boldsymbol{P_d}$ = (1991.43 + 50)/2

$\boldsymbol{P_d}$ = **1020.72 psi**

12) Hydraulic Horsepower Required (HP)-

HP = Q* (P_d - P_s)/33000

Flowrate ,Q can be calculated in lb/min as follows-

Q = 30000/(0.158987*24)*(5.6164/60)*0.85*62.34

Q =38,988.873 lb/min

HP required is : HP = 38988.873*(1020.72- 50)/33000

HP =1146.887

BHP= HHP/ Efficiency

BHP= 1146.8/0.75

=1529.2 HP

IHP= 1.1*BHP

IHP= 1.1*1529.2

= 1682HP

Power Required= IHP/n

Power required= 1682/2

=841HP

13) Cost Analysis-

Area of main pipe= 3.14* (od² - id²)/4

$=3.14*(22^2-21.25^2)/4$

$=25.5\ inch^2 = 25.5*0.0006452\ m^2$

=0.016 m²

Cost of the main line pipe= area of main line *L*8500*material cost

= 0.016*413000*8500*40 **=224.7 crores**

Pump Cost =IHP * cost of 1Kw

Pump cost = 1682* 300

=0.05 crores

Total Cost = cost of main line pipe + Pump cost

= 224.7 + 0.05

=224.75 crores

Preparation cost = 40% of Total cost = 89.9 crores

Service cost = 15% of Total cost = 33.7 crores

Capital cost = Total cost + Service cost + Preparation cost = 348.35 crores

Utilities = IHP * Electrical rate * working hour = 1682 * 100 * 8000 = 134.56 crores

Cost of Consumables = 40% of Utilities = 53.82 crores

Labor cost = 10% of Utilities = 13.4 crores

Maintenance cost = 15% of Utilities = 20.2 crores

Administration Cost = 10% of Utilities = 13.4 crores

Total Operating Cost = Utilities + consumables + Labor + Maintenance + Administration cost = 134.56 + 13.4 + 20.2 + 13.4 + 53.82

= 240.4 Crores

➢ 4^{th} ASSUMPTION (for 30,000 m^3/day flow-rate):

Fluid flow velocity 2 m/s

1) Diameter calculation (D):

$D = K*\sqrt{\frac{4*Q}{3.14*V}}$

$D = 0.0534*\sqrt{\frac{4*\frac{30000}{0.158987}}{3.14*2}}$

D= 18.51Inch

As we know 18.51 Inch diameter is not available in the industry so we have taken it to be **20Inch** for further calculation.

2) Reynolds Number (Re) :

Re= 92.24*Q/(v*D)

Re= 92.24*(30000/0.158987)/(5.882*20)

Re= 147,953.04

3) Friction Factor (f):

$1/\sqrt{f} = -2Log_{10}$ [(e/3.7D) + 2.51/(Re$\sqrt{f}$)]

By trial and error approach-

Putting f= 0.02 in equation

R.H.S=7.665 and L.H.S= 7.07

Putting f= 0.018 in equation

R.H.S=7.627 and L.H.S=7.453

Putting f= 0.0175 in equation

R.H.S=7.617 and L.H.S=7.559

Putting f= 0.0173 in equation

R.H.S.=7.613 and L.H.S.=7.602

So f = **0.0173**

4) Pressure Head (P_d):

$P_d = 0.0605*f*Q^2(Sg/D^5)$

$P_d = 0.0605*0.0173*(30000/0.158987)^2*(0.85/20^5)$

P_d = **9.899 psi/mile**

5) Total Pressure required at the beginning of pipeline (P):

$P= P_d + H*(Sg/2.31) + P_f$

$P= 9.899*256.59 + (803-413)*0.85/2.31 + 50$

P= 2733.49 psi

6) Pressure drop per unit length of pipeline ($\Delta p/L$):

$\Delta p/L= P/L$

$\Delta p/L= 2733.49/256.59$

$\Delta p/L$= 10.65 psi/mile

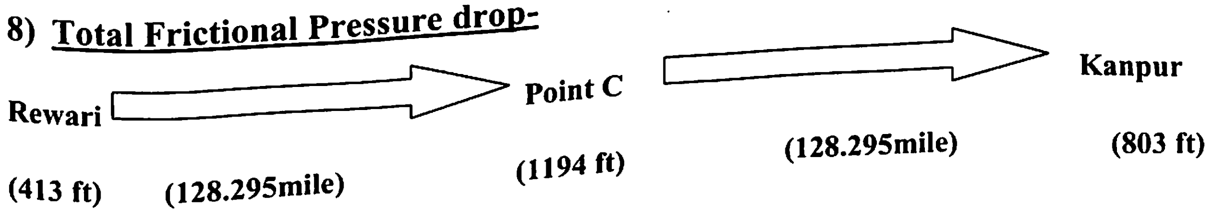
7) Maximum Allowable Operating Pressure (MAOP):

$MAOP= 2*S*t*E*F/(D-2t)$

$MAOP=2*42000*0.375*1.0*0.72/(20-2*0.375)$

MAOP=1178.18 psi

8) Total Frictional Pressure drop-



Δp from Rewari to Point C= $\Delta p/L*128.295$ psi

=10.65*128.295 psi

=1366.34 psi

Again, Δp from Point C to Kanpur =Δp/L*128.295 psi

=10.65*128.295 psi

=1366.34 psi

9) Calculation of Pressure required at the Rewari for Pumping-

Since Point C has elevation of 1194 ft which is peak point in overall route profile. Considering the portion from Rewari to Point C which has elevation difference equal to-
Elevation difference between Rewari and Point C= (1194-413) ft = 781 ft

Pressure required at the Rewari to get over peak at Point C= frictional pressure drop + pressure drop due to elevation difference =1366.34 + 781*0.85/2.31 psi =1653.72 psi
In the pipeline flow, it is desirable that the liquid product at the top of the peak point should be at some minimum pressure, which is higher than the vapour pressure of the product. **(for refined products and crude oil , this value should be taken between 10 to 20 psi.)**

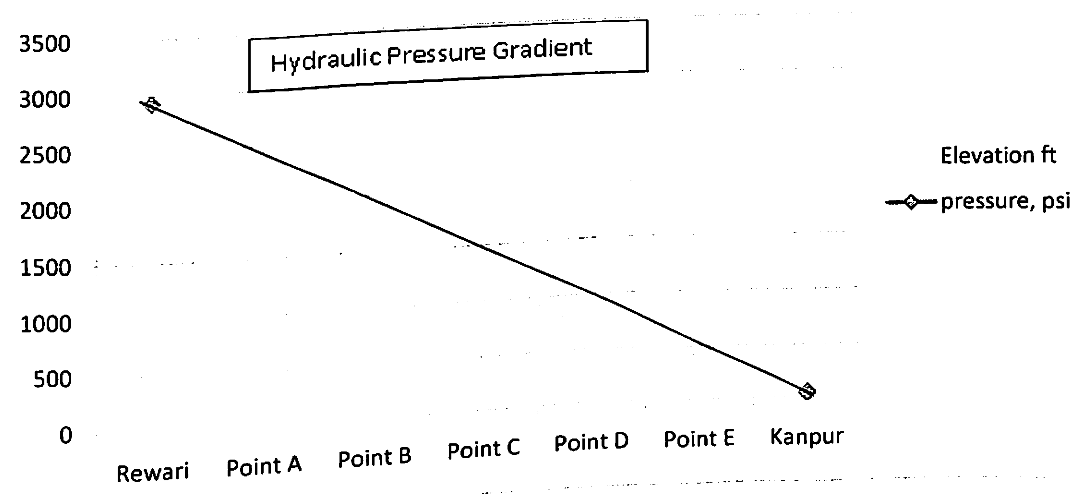
Pressure required at the Rewari to get over peak at Point C= (1653.72 +10) psi = 1663.72 psi
Elevation difference between Point C and Kanpur = (1194-803) ft =391 ft
Arrival pressure at the Kanpur = minimum pressure desirable + pressure drop due to elevation Difference – frictional pressure drop= (10 + 391*0.85/2.31 -1366.34) psi = -1212.47 psi
So, this pressure 1212.47 psi should be added to total pressure at the Rewari for pumping.
Minimum delievery pressure required at Kanpur = 50 psi

Total pressure required at Rewari= (Pressure required at the Rewari to get over peak at Point C + Minimum delievery pressure +1212.47) psi= (1663.72 + 50 + 1212.47) psi
= 2926.19 psi

Total pressure at the Kanpur =(arrival pressure at Kanpur + minimum delievery pressure) +1212.47 = -1212.47 + 50 + 1212.47 = **50 psi**

10) Hydraulic Pressure Gradient & number of Pumping Stations-

Horsepower calculation since the pressure required at rewari is 2926.19 psi and maximum allowable operating pressure (MAOP) is 1178.18 psi. So we would require two intermediate pumping station between Kanpur and Rewari to limit the maximum pressure in the pipeline to 1178.18 psi. Due to MAOP limits, pressure required will be provided in steps. **So there will be 3 pumping station in the pipeline.**



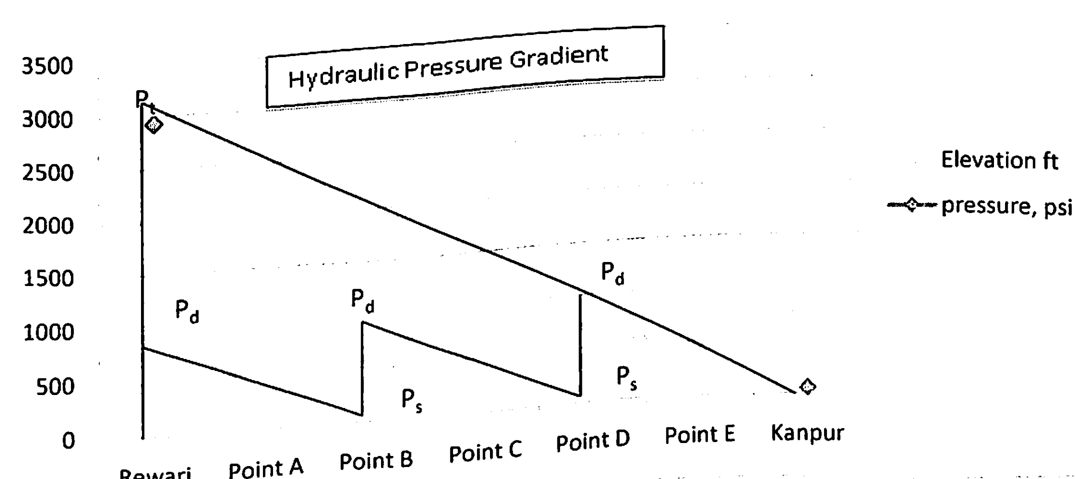


Figure 4(a,b). Hydraulic pressure gradient

11) Hydraulic Pressure Gradient

Where P_d –Pump station discharge pressure

P_s –Pump station suction pressure

P_t -total pressure required

So $P_t = P_d + P_d - P_s + P_d - P_s$

Solving for P_d ,

$P_d = (P_t + 2P_s)/3$

Considering a minimum suction pressure of 50 psi for each pumping station, each pump station would have a discharge pressure of

P_d = (2926.19 + 3*50)/4

P_d = 769.04 psi

12) Hydraulic Horsepower Required (HP)-

HP = Q* (P_d- P_s)/33000

Flow-rate, Q can be calculated in lb/min as follows-

Q = 30000/(0.158987*24)*(5.6164/60)*0.85*62.34

Q =38997.873 lb/min

HP required is: HP = 38997.873*(769.04 - 50)/33000

HP =849.728

BHP= HHP/ Efficiency

BHP= 849.7/0.75

=1132.9 HP

IHP= 1.1*BHP

IHP= 1.1*1132.9

= 1246

Power Required= IHP/n

Power required= 1246/3

=415

13) Cost Analysis-

Area of main pipe= 3.14* (od^2 - id^2)/4

=3.14*(20^2-19.25^2)/4

=23.1 $inch^2$ =23.1*0.0006452 m^2

=0.015 m^2

Cost of the main line pipe= area of main line *L*8500*material cost

= 0.015*413000*8500*40 =**210.6 crores**

Pump Cost =IHP * cost of 1Kw

Pump cost = 1246* 300

=**0.037 crores**

Total Cost = cost of main line pipe + Pump cost

= 210.6 + 0.037

=210.64 crores

Preparation cost = 40% of Total cost = 84.25 crores

Service cost = 15% of Total cost = 31.6 crores

Capital cost = Total cost + Service cost + Preparation cost = 326.5 crores

Utilities = IHP * Electrical rate * working hour = 1246 * 100 * 8000 = 99.7 crores

Cost of Consumables = 40% of Utilities = 39.9 crores

Labor cost = 10% of Utilities = 9.9 crores

Maintenance cost = 15% of Utilities = 14.8 crores

Administration Cost = 10% of Utilities = 9.9 crores

Total Operating Cost = Utilities + consumables + Labor + Maintenance + Administration cost = 99.7 + 39.9 + 9.9 + 14.8 + 9.9

= 174.2 Crores

6) CONCLUSION:

After calculating for different flow-rates at different velocities we get four different diameters with different number of pumping stations and consequently different capital and operating cost.

Flow-rate (m3/d)	Velocity (m/s)	Diameter (inches)	Number of Pumping Stations	Capital Cost(crores)	Operating Cost (crores)	Total Cost (crores)
20000	1.5	18	3	241.7	125.7	367.4
	2	16	4	252.15	157.7	409.85
30000	1.5	22	2	348.35	240.4	588.75
	2	20	3	326.5	174.5	501

After studying the total cost involved in the various diameters we can select the 20" diameter as the optimum since it can be used to accommodate the flow rate for the lesser diameter. This is also useful when we intend to increase the flowrate in the future which will require larger diameter. The 20" diameter pipeline can be used for increased flowrate by decreasing the velocity. It also requires less number of pumping stations hence low operation cost is incurred.

Table for Pipe Sizing

MLS

MOTILAL LAXMICHAND SANGHAVI

MUMBAI 400 004 (INDIA)

Office 2346 43 64
2346 23 93
2346 83 86
2347 37 52

Weight & Test Pressures According To ANSI B36.10

A333 A335

Nominal Size in	Nominal Size mm	Outside Diameter in	Outside Diameter mm	Wall Thickness in	Wall Thickness mm	Class	Sched No.	Nominal Weight lb/ft	Nominal Weight Kg/ft	Nominal Weight Kg/m	Test Pressure Min Butt Welded psi	Butt Welded Kg/cm2	Grade A psi	Grade A Kg/cm2	Grade B psi	Grade B Kg/cm2
1/8	6	0.405	10.3	.068	1.7	std	40	0.24	0.11	0.36	700	49.2	700	49.2	700	49.2
				.095	2.4	xs	80	0.31	0.14	0.47	850	59.8	850	59.8	850	59.8
1/4	8	0.540	13.7	.088	2.24	std	40	0.42	0.19	0.63	700	49.2	700	49.2	700	49.2
				.119	3.02	xs	80	0.54	0.24	0.80	850	59.8	850	59.8	850	59.8
3/8	10	0.675	17.1	.091	2.31	std	40	0.57	0.26	0.84	700	49.2	700	49.2	700	49.2
				.126	3.20	xs	80	0.74	0.34	1.10	850	59.8	850	59.8	850	59.8
1/2	15	0.840	21.3	.109	2.77	std	40	0.85	0.39	1.27	700	49.2	700	49.2	700	49.2
				.147	3.73	xs	80	1.09	0.49	1.62	850	59.8	850	59.8	850	59.8
				.188	4.78	--	160	1.31	0.60	1.95	1000	70.3	1000	70.3	1000	70.3
				.294	7.47	xxs	--	1.71	0.78	2.55	1000	70.3	1000	70.3	1000	70.3
3/4	20	1.050	26.7	.113	2.87	std	40	1.13	0.51	1.69	700	49.2	700	49.2	700	49.2
				.154	3.91	xs	80	1.47	0.67	2.20	850	59.8	850	59.8	850	59.8
				.218	5.56	--	160	1.94	0.88	2.90	1000	70.3	1000	70.3	1000	70.3
				.308	7.82	xxs	--	2.44	1.11	3.63	1000	70.3	1000	70.3	1000	70.3
1	25	1.315	33.4	.133	3.38	std	40	1.68	0.76	2.50	700	49.2	700	49.2	700	49.2
				.179	4.55	xs	80	2.17	0.98	3.23	850	59.8	850	59.8	850	59.8
				.250	6.35	--	160	2.84	1.29	4.23	1000	70.3	1000	70.3	1000	70.3
				.358	9.09	xxs	--	3.66	1.66	5.45	1000	70.3	1000	70.3	1000	70.3
1 1/4	32	1.660	42.2	.140	3.56	std	40	2.27	1.03	3.38	1000	70.3	1000	70.3	1000	70.3
				.191	4.85	xs	80	3.00	1.36	4.47	1300	91.4	1500	105.5	1500	105.5
				.250	6.35	--	160	3.76	1.71	5.60	1400	98.4	1800	126.5	1800	126.5
				.382	9.70	xxs	--	5.21	2.36	7.76	1400	98.4	1800	126.5	1800	126.5
1 1/2	40	1.900	48.3	.145	3.68	std	40	2.72	1.23	4.05	1000	70.3	1000	70.3	1000	70.3
				.200	5.08	xs	80	3.63	1.65	5.41	1300	91.4	1500	105.5	1600	112.5
				.281	7.14	--	160	4.86	2.20	7.24	1400	98.4	1800	126.5	1900	133.6
				.400	10.15	xxs	--	6.41	2.91	9.55	1400	98.4	1800	126.5	1900	133.6
2	50	2.375	60.3	.154	3.91	std	40	3.65	1.66	5.44	1000	70.3	2300	161.7	2500	175.8
				.218	5.54	xs	80	5.02	2.28	7.48	1300	91.4	2500	175.8	2500	175.8
				.344	8.74	--	160	7.46	3.38	11.11	--	--	2500	175.8	2500	175.8
				.436	11.13	xxs	--	9.03	4.10	13.45	1400	98.4	2500	175.8	2500	175.8
2 1/2	65	2.875	73.0	.203	5.16	std	40	5.79	2.63	8.62	1000	70.3	2500	175.8	2500	175.8
				.276	7.01	xs	80	7.66	3.47	11.41	1300	91.4	2500	175.8	2500	175.8
				.375	9.53	--	160	10.01	4.54	14.91	1400	98.4	2500	175.8	2500	175.8
				.552	14.02	xxs	--	18.70	6.21	20.39	1400	98.4	2500	175.8	2500	175.8
3	80	3.500	88.9	.188	4.78	--	--	6.63	3.01	9.87	1000	70.3	--	--	--	--
				.216	5.49	std	40	7.58	3.44	11.29	1000	70.3	2200	154.7	2500	175.8
				.300	7.62	xs	80	10.25	4.65	15.27	1300	91.4	2500	175.8	2500	175.8
				.438	11.13	--	160	14.31	6.489	21.33	--	--	2500	175.8	2500	175.8
				.600	15.24	xxs	--	18.58	8.13	27.67	--	--	2500	175.8	2500	175.8
3 1/2	90	4.000	101.6	.188	4.78	--	--	7.63	3.46	11.35	1200	84.4	--	--	--	--
				.226	5.74	std	40	9.11	4.13	13.57	1200	84.4	2000	140.6	2400	168.7
				.318	8.08	xs	80	12.51	5.67	18.63	1700	119.5	2800	196.8	2800	196.8
4	100	4.500	114.3	.156	3.96	--	--	7.25	3.29	10.79	1000	70.3	--	--	--	--
				.188	4.78	--	--	8.64	3.92	12.86	1200	84.4	--	--	--	--
				.219	5.56	--	--	10.00	4.54	14.88	1200	84.4	--	--	--	--
				.237	8.02	std	40	10.79	4.89	16.07	1200	84.4	1900	133.6	2200	154.7
				.337	8.56	xs	80	14.98	6.79	22.31	1700	119.5	2700	189.8	2800	196.8
				.438	11.13	--	120	18.98	8.61	28.30	--	--	2800	196.8	2800	196.8
				.531	13.49	--	160	22.52	10.21	33.53	--	--	2800	196.8	2800	196.8
				.674	17.12	xxs	--	27.54	12.49	41.02	--	--	2800	196.8	2800	196.8
5	125	5.563	141.3	.258	6.55	std	40	14.62	6.63	21.78	--	--	1700	119.5	1900	133.6
				.375	9.35	xs	80	20.78	9.43	30.95	--	--	2400	168.7	2800	196.8
				.500	12.70	--	120	27.04	12.27	40.28	--	--	2800	196.8	2800	196.8
				.625	15.88	--	160	32.96	14.95	49.09	--	--	2800	196.8	2800	196.8
				.750	19.05	xxs	--	38.55	17.49	57.42	--	--	2800	196.8	2800	196.8
6	150	6.625	168.3	.280	7.11	std	40	18.97	8.60	28.26	--	--	1500	105.5	1800	126.5
				.432	10.97	xs	80	28.57	12.96	42.56	--	--	2300	161.7	2700	189.8
				.562	14.27	--	120	35.42	15.52	54.20	--	--	2800	196.8	2800	196.8
				.719	18.26	--	160	45.34	20.57	67.55	--	--	2800	196.8	2800	196.8
				.864	21.95	xxs	--	53.16	24.11	79.18	--	--	2800	196.8	2800	196.8
8	200	8.625	219.1	.250	6.35	--	20	22.36	10.14	33.31	--	--	1000	70.3	1200	84.4
				.277	7.04	--	30	24.70	11.70	36.79	--	--	1200	84.4	1300	91.4
				.322	8.18	std	40	28.55	12.95	42.53	--	--	1300	91.4	1600	112.5
				.406	10.31	--	60	35.66	16.18	53.09	--	--	1700	119.5	2000	140.6
				.500	12.70	xs	80	43.39	19.68	64.63	--	--	2100	147.6	2400	168.7
				.594	15.09	--	100	50.93	23.10	75.89	--	--	2500	175.8	2800	196.8
				.719	18.26	--	120	60.69	27.53	90.43	--	--	2800	196.8	2800	196.8
				.812	20.62	--	140	67.79	30.75	100.93	--	--	2800	196.8	2800	196.8
				.875	22.23	xxs	--	72.42	32.85	107.87	--	--	2800	196.8	2800	196.8
				.906	23.01	--	160	74.71	33.89	111.25	--	--	2800	196.8	2800	196.8
				1.102	28.00	--	--	88.65	59.98	131.95	--	--	2500	196.8	2800	196.8
				1.260	32.00	--	--	95.16	64.38	141.64	--	--	2500	196.8	2800	196.8
				1.417	36.00	--	--	109.21	73.69	162.55	--	--	2500	196.8	2800	195.8
				1.574	40.00	--	--	118.69	80.30	176.60	--	--	2500	196.8	2800	196.8

Nominal Size		Outside Diameter		Wall Thickness		Class	Sched No.	Nominal Weight			Test Pressure Min					
											Butt Welded		Grade A		Grade B	
								lb/ft	Kg/ft	Kg/m	psi	Kg/cm2	psi	Kg/cm2	psi	Kg/cm2
in	mm	in	mm	in	mm											
10	250	10.750	273.1	.250	6.35	--	20	28.04	12.72	41.77	--	--	650	59.8	1000	70.3
				.279	7.11	--	--	31.20	14.15	46.64	--	--	950	66.8	1100	77.3
				.307	7.80	--	30	34.24	15.53	51.00	--	--	1000	70.3	1200	84.4
				.365	9.27	std	40	40.48	18.36	60.29	--	--	1200	84.4	1400	98.4
				.500	12.70	xs	60	54.74	24.83	81.54	--	--	1700	119.5	2000	140.6
				.594	15.09	--	80	64.40	29.21	95.97	--	--	2000	140.6	2300	161.7
				.719	18.26	--	100	77.00	34.93	114.70	--	--	2400	168.7	2800	196.8
				.844	21.44	--	120	89.27	40.49	133.00	--	--	2800	196.8	2800	196.8
				1.00	25.40	xxs	140	104.13	47.23	155.10	--	--	2800	196.8	2800	196.8
				1.125	28.58	--	160	115.65	52.46	172.25	--	--	2800	196.8	2800	196.8
				--	32.00	--	--	127.75	86.45	190.26	--	--	2800	196.8	2800	196.8
					40.00	--	--	154.38	104.47	229.93	--	--	2800	196.8	2800	196.8
10	250	10.750	273.1													
12	300	12.750	323.8	.250	6.35	--	20	33.28	15.14	49.72	--	--	700	49.2	800	56.2
				.330	8.38	--	30	43.77	19.65	65.20	--	--	950	66.8	1100	77.3
				.375	9.53	std	--	49.56	22.48	73.82	--	--	1100	77.3	1200	84.4
				.406	10.31	--	40	53.56	24.29	79.72	--	--	1100	77.3	1300	91.4
				.500	12.70	xs	--	65.42	29.67	97.44	--	--	1400	98.4	1600	112.5
				.562	14.27	--	60	73.22	33.21	108.96	--	--	1600	112.5	1900	133.6
				.668	17.48	--	80	88.57	40.17	132.01	--	--	1900	133.6	2300	161.7
				.844	21.44	--	100	107.29	48.67	159.85	--	--	2400	168.7	2800	196.8
				1.000	25.40	xxs	120	125.49	56.92	186.92	--	--	2800	196.8	2800	196.8
				1.125	28.58	--	140	139.66	63.36	208.04	--	--	2800	196.8	2800	196.8
				1.312	33.32	--	160	160.33	72.72	238.72	--	--	2800	196.8	2800	196.8
				--	40.00	--	--	188.04	125.25	279.94	--	--	2800	196.8	2800	196.8
12	300	12.750	323.8													
14	350	14.000	355.6	.250	6.35	--	10	36.71	16.65	54.68	--	--	650	45.7	750	52.7
				.312	7.92	--	20	45.68	20.72	67.94	--	--	800	56.2	950	66.8
				.375	9.53	std	30	54.57	24.75	81.28	--	--	950	66.8	1100	77.3
				.438	11.13	--	40	63.37	28.74	94.49	--	--	1100	77.3	1300	91.4
				.500	12.70	xs	--	72.09	32.70	107.38	--	--	1300	91.4	1300	91.4
				.594	15.09	--	60	85.01	38.56	126.68	--	--	1500	105.5	1500	105.5
				.750	19.05	--	80	106.13	48.14	158.08	--	--	1900	133.6	2800	196.8
				.938	23.82	--	100	130.79	59.33	194.90	--	--	2400	168.7	2800	196.8
				1.094	27.79	--	120	150.76	68.38	224.60	--	--	2800	196.8	2800	196.8
				1.250	31.75	--	140	170.22	77.21	253.53	--	--	2800	196.8	2800	196.8
				1.406	35.71	--	160	189.15	85.80	281.68	--	--	2800	196.8	2800	196.8
				--	40.00	--	--	209.11	141.50	311.31	--	--	2800	196.8	2800	196.8
14	350	14.000	355.6													
16	400	16.000	406.4	.250	6.35	--	10	42.05	19.07	62.63	--	--	550	38.7	650	45.7
				.312	7.92	--	20	52.36	32.75	77.86	--	--	700	49.2	800	56.2
				.375	9.53	std	30	62.58	28.39	93.21	--	--	850	59.8	1000	70.3
				.500	12.70	xs	40	82.77	37.54	123.29	--	--	1100	77.3	1300	91.4
				.656	16.66	--	60	107.54	48.78	160.12	--	--	1500	105.5	1700	119.5
				.844	21.44	--	80	136.53	61.95	203.48	--	--	1900	133.6	2200	154.7
				1.031	26.19	--	100	164.86	74.48	245.50	--	--	2300	161.7	2700	189.8
				1.219	30.96	--	120	192.40	87.27	286.62	--	--	2700	189.6	2800	196.8
				1.438	36.53	--	140	223.57	101.41	333.11	--	--	2800	196.8	2800	196.8
				1.594	40.49	--	160	245.22	111.23	365.39	--	--	2800	196.8	2800	196.8
16	400	16.000	406.4													
18	450	18.000	457.20	.250	6.35	--	10	47.39	21.49	70.59	--	--	550	38.7	650	45.7
				.312	7.92	--	20	59.03	26.76	87.79	--	--	650	45.7	800	56.2
				.375	9.53	std	--	70.59	32.00	105.14	--	--	750	52.7	850	59.8
				.437	11.13	--	30	82.06	37.00	122.36	--	--	850	59.8	1000	70.3
				.500	12.70	xs	--	92.45	42.37	139.19	--	--	1000	70.3	1200	84.4
				.562	14.20	--	40	104.75	47.55	155.91	--	--	1100	.77.3	1300	91.4
				.750	19.05	--	60	138.17	62.79	205.80	--	--	1500	105.5	1800	126.6
				.937	23.83	--	80	170.75	77.42	254.59	--	--	1800	126.5	2300	161.7
				1.156	29.36	--	100	207.96	94.48	309.76	--	--	2300	161.7	2800	196.8
				1.375	34.93	--	120	244.14	110.7	363.65	--	--	2700	189.8	2800	196.8
				1.562	39.67	--	140	274.73	124.4	408.45	--	--	2800	196.8	2800	196.8
				1.781	45.24	--	160	308.51	139.9	459.51	--	--	2700	189.8	2800	196.8
18	450	18.000	457.20													
20	500	20.000	508.00	.250	6.35	--	10	52.73	23.93	78.54	--	--	450	31.6	600	42.2
				.375	9.53	std	20	78.60	35.66	117.07	--	--	650	45.7	800	56.2
				.500	12.70	xs	30	104.13	47.24	155.10	--	--	900	63.3	1000	70.3
				.593	15.09	--	40	122.91	55.78	183.37	--	--	1050	73.8	1200	84.4
				.812	20.62	--	60	166.40	75.59	247.85	--	--	1400	98.4	1700	119.5
				1.031	26.2	--	80	208.87	94.79	311.29	--	--	1800	126.5	2000	140.6
				1.281	32.5	--	100	256.10	116.2	381.09	--	--	2300	161.7	2800	196.8
				1.500	38.0	--	120	296.37	134.4	440.43	--	--	2700	189.8	2800	196.8
				1.750	44.4	--	140	341.10	154.8	507.60	--	--	2800	196.8	2800	196.8
				1.968	50.0	--	160	379.01	171.9	564.71	--	--	2800	196.8	2800	198.8
20	500	20.000	508.00													
22	550	22.000	558.80	.250	6.35	--	10	57.93	26.33	86.50	--	--	400	28.1	500	35.2
				.375	9.53	std	20	86.50	39.32	129.01	--	--	600	42.2	700	49.2
				.500	12.70	xs	30	114.66	52.12	171.01	--	--	800	56.2	900	63.3
				.875	22.2	--	60	19714	89.61	294.00	--	--	1400	98.4	1500	105.5
				1.126	28.6	--	80	250.14	113.7	373.00	--	--	1800	126.5	2000	140.6
				1.374	34.9	--	100	302.50	137.5	451.00	--	--	2200	154.7	2600	182.8
				1.626	41.3	--	120	352.66	160.3	526.00	--	--	2600	182.8	2800	196.8
				1.874	47.6	--	140	402.38	182.9	600.00	--	--	2800	196.8	2800	196.8
				2.126	54.0	--	160	449.90	204.5	671.00	--	--	2800	196.8	2800	196.8
22	550	22.000	558.80													
24	600	24.000	609.60	.250	6.35	--	10	63.41	28.77	94.45	--	--	350	24.6	500	35.2
				.375	9.53	std	20	94.62	42.08	140.94	--	--	550	38.7	700	49.2
				.500	12.70	xs	--	125.49	57.00	186.92	--	--	700	49.2	800	56.2
				.552	14.27	--	30	140.80	64.00	209.54	--	--	800	56.2	1000	70.3
				.674	17.48	--	40	171.17	77.72	255.14	--	--	1000	70.3	1200	84.4
				.968	24.61	--	60	238.17	108.29	355.02	--	--	1400	98.4	1600	112.5
				1.218	31.00	--	80	296.36	134.4	441.0	--	--	1800	126.5	2000	140.6
				1.531	38.90	--	100	367.40	166.7	547.0	--	--	2200	154.7	2600	182.8
				1.812	46.00	--	120	429.39	194.88	639.0	--	--	2600	182.8	2800	196.8
				2.342	59.50	--	160	541.94	246.0	807.0	--	--	2800	196.8	2800	196.8
24	600	24.000	609.60													

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