DESIGN AND COST ESTIMATION OF MUNDRA-BHATINDA CRUDE OIL PIPELINE

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

MASTER OF TECHNOLOGY

IN

PIPELINE ENGINEERING

By

HARISH RAM. K

R150209014

Under the guidance of

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College of Engineering

University of Petroleum & Energy Studies

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CERTIFICATE

This is to certify that the work contained in this thesis titled "**Design and Cost Estimation of Mundra-Bhatinda Crude Oil Pipeline**" has been carried out by **Harish Ram. K** under my/our supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

In this project, we are determining a suitable design for a crude oil pipeline of API5L specification, which passes from Mundra to Bhatinda and is 1014 kilometers long and which has a capacity of 9 MMTPA. Crude oil is received in Mundra crude oil terminal (COT) from a crude oil carrier via single point mooring and is then pumped to the destination at a required pressure. A design is said to be perfect when the quality of pipeline is the best as well as the cost involved in both construction and operation of the pipeline is optimum. With the known details of the pipeline, we are analyzing the entire length of the pipeline with several options and finally picking the right option for the perfect design of the pipeline. Both the mechanical design as well as the hydraulic design is determined in this project. Several factors like diameters, thickness, grades of pipeline and viscosity, density, pour point, specific gravity of the liquid transported (crude oil) and pressure are involved in determining the apt design of the crude oil pipeline. By the end of each stage of analysis, certain assumptions qualify for the next stage of testing for design and certain assumptions are rejected. After determining the suitable design for the entire length of the crude oil pipeline, the capital costs and the operating costs of the selected design are found out and the design with optimum cost is selected to be the best design.

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K·Harish Ram

HARISH RAM. K

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NOMENCLATURE

ASME – The American Society of Mechanical Engineers.

API – American Petroleum Institute.

MMTPA – Million Metric Tonnes per Annum.

Q – Discharge in m^3/s.

D – Outer Diameter of Pipeline in inches.

ID – Inner Diameter of pipeline in inches.

T_1 – Temperature of fluid entering the pipeline in degree Celsius.

T_2 – Temperature of fluid leaving the pipe in degree Celsius.

T_S – Soil Temperature in degree Celsius.

T_m – Mean temperature of the fluid in pipe in degree Celsius.

A – Area of cross section of pipeline in m^2.

V – Velocity of fluid in m/s.

Psi – Pounds per Square Inch.

MAOP – Maximum Allowable Operating Pressure in psi.

S – Specified minimum yield strength in psi.

t – Nominal wall thickness in inch.

WT – Nominal Wall Thickness in inch.

F – Location class factor for pipelines.

E – Longitudinal joint factor for pipelines.

T – Temperature de-rating factor.

R – Reynolds number, dimensionless.

Rm – Modified Reynolds number, dimensionless.

cSt – Centistokes.

v – Kinematic viscosity in cSt.

P_f – Frictional pressure drop in psi/mile.

f – Friction factor, dimensionless.

Sg – Liquid specific gravity.

KW – Kilowatt.

kPa – Kilo Pascal.

P – Power required in kw.

p – Pressure in kPa.

CHAPTER 1

INTRODUCTION

1.0 Introduction

Pipelines are a series of interconnected segments that is used to transport fluids starting from water, natural gas to various petroleum and its products that form the lifeline of day to day activities. Petroleum pipelines form a bridge for transportation of petroleum products from reservoir to refineries or from gathering stations to refineries or from wells to gathering stations or from tankers to refineries and also from refineries to the consumers. Pipelines are expensive assets of a country and must be suitably utilized and maintained for a better lifetime of the pipeline and better revenue of the country.

Transportation of petroleum and its products can be done by other modes like rails, roads in case of on-shore transportation and by tankers, barges in case of off-shore transportation, but pipelines have an edge over all the above mentioned ways by reducing the cost of transportation. The main intention of constructing and maintaining a pipeline is the transportation of fluids in an economical way.

Pipelines and preferred over other modes for one more reason "round the clock operation", which means pipelines operate almost every second of a day and thereby profits can be generated continuously. An average lifetime of pipeline is thirty years but that does not mean that the pipeline must be shut down after the specified period, it can be used till its maintenance and operation cost is less compared to the revenue generated by the same pipeline.

Pipeline transportation has many advantages like its flexible, reliable, safe, low transit loss, minimum pollution and many more. Adequate demand exists for the laying of more petroleum oil pipelines in India to meet the increasing demand within the country.

1.1 Importance of the project

With the upcoming of Guru Gobind Singh refinery in land-locked Punjab which is designed to produce Euro IV-compliant fuel, the requirement of Mundra-Bhatinda crude oil pipeline of 9MMTPA capacity to transport the imported crude oil to the refinery has found its place. It is India's biggest case of foreign direct investment in the petroleum refinery sector. Moreover Nigerian crude oil required during the year 2009-10 was 13.2 million tonnes and is estimated to increase to 18 million tonnes during the year 2012-13 and therefore the laying of this pipeline is of great importance for meeting the ever growing demand of crude oil and its products in India. Hence the design of crude oil pipeline to meet the above mentioned requirement has been done and the cost involved in the construction and operation has been calculated simultaneously.

1.2 Scope

The scope of this project is the design of a crude oil pipeline from Mundra to Bhatinda which is 1014 kilometers long and this project includes a detailed analysis, study and comparison of the various parameters of the design of the pipeline. Several grades of pipeline are assumed and several diameters and thickness have also been assumed and the best fit among all the assumptions has been selected. The elevation profile has been analyzed in a detailed manner and suitable calculations have been done, to add on to the design of the pipeline. The number of pumping stations has been determined, number of cathodic protection stations has been found and detailed cost estimation has been done for the final design selected which includes the capital expenses and the operating expenses of the selected pipeline.

CHAPTER 2

LITERATURE REVIEW

2.0 Literature Review

The literature review about pipelines has been discussed in the following sections.

2.1 Pipeline History

600 BC marked the introduction of an era that could be never be forgotten or can never be neglected, invention of pipeline by human beings in china which was primarily used to transport natural gas from brine /gas wells to heat brine so that they could recover salt from the brine. Steel was not used to construct the pipelines, rather bamboo trees were used. The bamboo sections were split lengthwise and used for the construction of pipeline. Two bamboo trees were joined together using glue and bound with twine. Gathering systems and distribution systems were first introduced in North America. In the nineteenth century, there were few transmission lines in Canada. History marked a great beginning by introducing pipelines to all the civilizations and helped them in moving forward towards their new culture and lifestyle and making new improvements in pipeline technology to serve the mankind.

Pipelines constructed in bamboo slowly began changing from plastic to steel pipelines. Each generation of pipeline technology had an edge over the previous generation of pipelines. They had their own advantages and disadvantages, but humans have tried their best to eliminate all the possible disadvantages by introducing an alternative for the existing technology. For example pipeline introduced in early 600 BC that were built using bamboo had no corrosion problems, but they had other disadvantages like lower capacity, leakage and many more. But the pipelines used these days have a high capacity and can be designed to any required capacity depending on the necessity of the customers, but in spite of their high capacity, they had problems like corrosion. But humans dint give up and they introduced the technology like cathodic protection and coatings to overcome these problems. These technologies don't prevent corrosion, but they reduce their activity on the pipeline, thereby protecting the pipeline.

2.2 Pipeline specification

Pipelines used for crude oil and its products are usually specified in terms of specification number, pipe class, grade and their dimensions.

For instance a line pipe used for crude oil transmission represented as API 5L X60 indicates that the pipeline used is of API standard and a line pipe, and X denotes the grade of the pipeline. In this pipeline X60 means, the pipeline has specified minimum yield strength of 60000 pounds per square inch. So a pipeline can have X42, X46, X52, X56, X60, X65, X70 and even X80 grade. Usually X denotes general grade, XS denotes extra strong and XXS denotes double extra strong pipe. WT represents specified wall thickness of the pipeline which is usually of the range of 0.25 inch to 1.25 inch and the pipeline can have many ranges of diameter depending on the capacity of the pipeline.

2.3 Pipeline design

A pipeline design is said to consist of two components which are,

1. Hydraulic design

2. Mechanical design

Hydraulic design consists of evaluating the physical characteristics of the liquid to be transported, quantity of liquid to be transported, pipeline route and topography, range of temperature, pressure, environmental conditions along the route and the number and location of the pump stations with respect to hydraulic characteristics.

Mechanical design consists of selection of pipe material, specification of physical line pipe properties like diameter, thickness required by stresses imposed on system by hydraulic, thermal and external loading and finally the type, size, power of pump and other auxiliary equipments required.

2.4 Steps involved in crude oil pipeline design

a) Determination of crude oil properties at the required temperature.

b) Assuming a specific capacity for the pipeline.

c) Calculating the approximate diameter for the pipeline.

d) Various thicknesses required for the pipeline is assumed.

e) Different grades are assumed and the best grade is selected after the calculation.

f) Preliminary pipeline route and the corresponding elevation profile of the ground route are noted down.

g) Maximum allowable operating pressure is computed for all the assumed grades and dimensions.

h) Required delivery pressure is assumed.

i) Discharge pressure is then calculated for all the grades depending on the elevation pressure, frictional pressure and the required delivery pressure.

j) Pump stations and their locations are then computed and the pipeline with least number of pump stations is selected.

k) Pump power required is then calculated and the pipeline that utilizes least pump power is selected.

l) Number of cathodic protection stations and their locations are then found.

2.5 Pipeline route for the Mundra – Bhatinda crude oil pipeline

The preliminary pipeline route is identified and is shown in the diagram below.

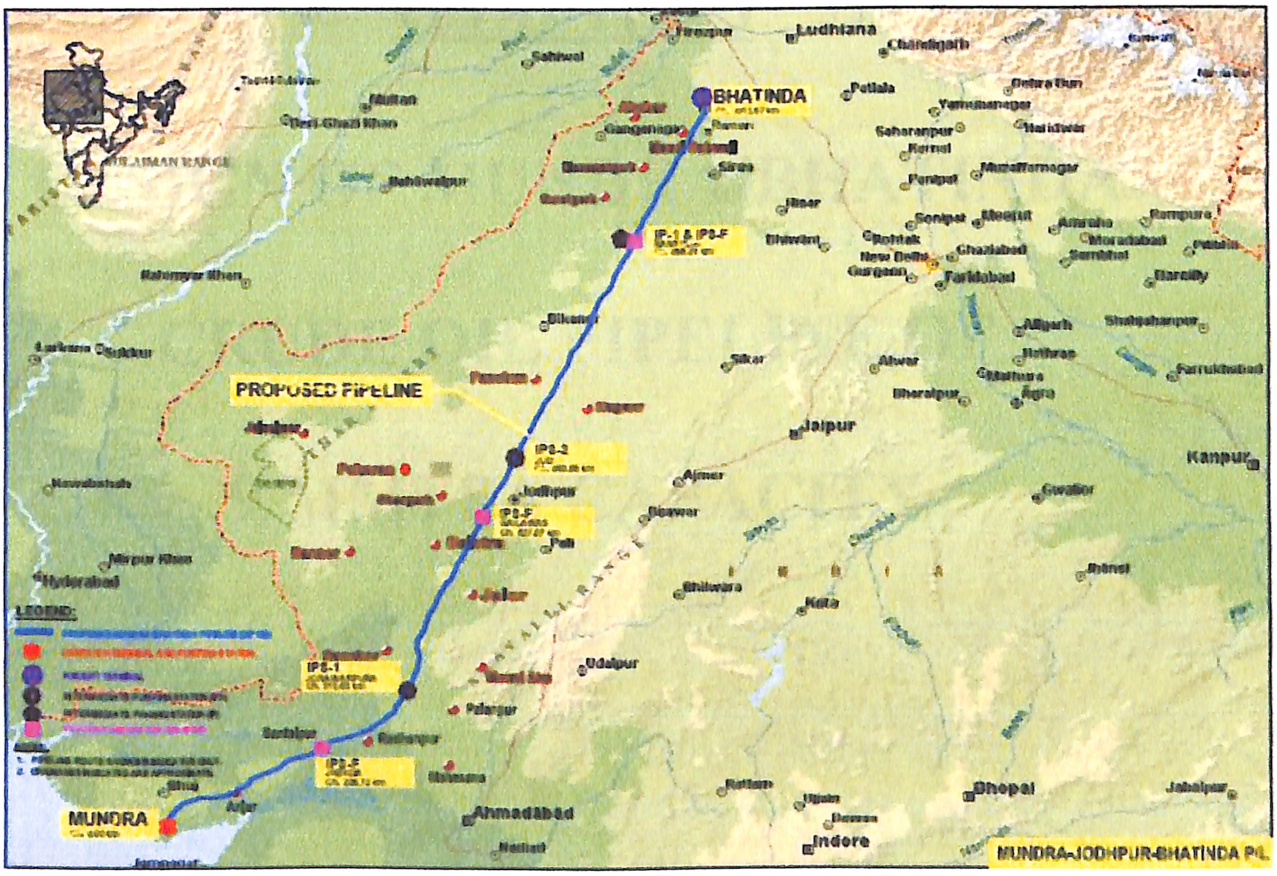

Figure 1: Mundra - Bhatinda pipeline route

CHAPTER 3

DESIGN OF MUNDRA-BHATINDA CRUDE OIL PIPELINE OF 9 MMTPA CAPACITY

3.0 Design of Mundra - Bhatinda crude oil pipeline

The design of Mundra to Bhatinda crude oil pipeline is covered in this chapter .Each section in this chapter has a vital role in the design part of the pipeline.

3.1 Crude oil specifications

Crude oil Type:	Nigerian bonny light crude oil (BLCO)
Specific gravity:	0.85
Pour point:	<40F/4.44° C
Viscosity @ 40 ° C:	4.99 cSt
Viscosity @ 50 ° C:	4.05 cSt
Color:	Dark brown

3.2 Characteristics of crude oil

Since the properties of crude oil vary with temperature, we have to find out an average temperature of the pipeline, so as to find out the mean temperature of the crude oil. This can be done by using Logarithmic Mean Temperature Difference method (LMTD) for the entire pipeline.

$$Tm\text{-}Ts = ((T_1\text{-}Ts)\text{-}(T_2\text{-}Ts)) / (\log_e [(T_1\text{-}Ts)/ (T_2\text{-}Ts)])$$

Here, $T_1 = 32^\circ$ C, $T_2 = 25^\circ$ C, $T_S = 22^\circ$ C.

Substituting the values, we get a mean temperature of 28° C which is to be used for the entire calculation purpose of the pipeline design. Hence $T_m = 28^\circ$ C.

Now in order to know the viscosity of the crude oil at 28 ° C, we use a formula from ASTM D341 code. The formula is given as,

$$\text{Log.log}\,(v+0.7) = A + B \log (T + 273) \rightarrow (a)$$

Now we know the values of viscosity of the liquid at 40 ° C & 50 ° C, using which we will be finding the constants in the given formula by substituting both the values separately in the equation and solving. Upon solving the values of A and B, we get,

A = 8.57855, B = 3.48643

Now substitute both these values in (a) equation, and we get the value of viscosity at 28 ° C as 6.63 cSt. Therefore the values of viscosity and density of crude oil at 28 ° C are,

- Density = 850 kg/m^3.
- Viscosity = 6.63 centistokes.

These are the values that have to be used for the entire design calculation of the crude oil pipeline.

3.3 Diameter calculation for 9 MMTPA pipeline

The thumb rule that is used in the case of a petroleum pipeline is the assumption of velocity of fluid to be in the range of 1.3 to 1.8 m/s. Here we assume a velocity of 1.5 m/s for the crude oil that we use.

We know that discharge is the product of area of cross section and the velocity of fluid, that is

$$Q = A * V$$

The number of working hours for the pipeline is 8000 hours. Hence the discharge in m^3/s,

$Q = (9 * 1000000 * 1000) / (850 * 8000 * 3600)$

$Q = 0.3676\ m^3/s$.

Now, Area $A = Q/V = (0.3676\ m^3/s) / (1.5\ m/s)$

$A = 0.2451\ m^2 = (\pi/4) * D^2$

$D = 0.5587$ meter = 21.99 inch.

Now we have got an approximate value for the diameter, but we shall assume three diameters above 21.99 inch and we shall analyze all the three diameters to find the suitable one. The diameters that we are going to assume are shown in the next section of this chapter.

3.4 Parameters to be analyzed

Various diameters, thickness and grades are analyzed and the suitable one is picked among all the other options.

- Diameters to be analyzed = 22 inch, 24 inch, 26 inch.
- Thickness to be analyzed = 0.25 inch, 0.281 inch, 0.312 inch. These thicknesses are used for design calculation purpose.
- Grades = API 5L X56, API 5L X60, API 5L X65.

3.5 Route identification and elevation profile

The pipeline route must be selected carefully and suitable surveys like cadastral survey must be carried out to ascertain the availability of corridor of specified width. The pipeline route must have the least number of rivers, canals, highway crossings so as to reduce the expenses on crossings. The pipeline route must be selected so that the pipeline has the optimum distance possible. After the pipeline route has been identified, the elevation profile must be noted down. This is done be surveying the entire pipeline route.

Terrain analysis has to be carried out in a detailed manner. In eco-sensitive areas, aerial imagery is used. Geographical information system plays a vital role in pipeline route identification. The major considerations while pipeline routing are townships, major river crossings, canals, national highways, existing pipeline crossings, historical reserves and forest reserve sites.

In our pipeline we have around 15 river crossings and several canal crossings and highway crossings, but only open cut crossing and cased crossings are used. Horizontal directional drilling is not used in the entire length of pipeline since the cost is more when compared to other crossings.

The elevation of the ground along the direction of pipeline along with the chainage and location is given below in the table.

Table 1: Location vs. Chainage vs. Elevation

Location	Chainage(km)	Elevation(meter)
Mundra	0	15
Bhachau	93	42
Santalpur	198	15
Dev	250	34
Juna raviyana	282	78
Bargaon	363	250
Bhadra	405	198
Jhalwar	545	320
Kantiya	643	364
Sateran	699	222
Kakra	732	318
Shri Dungargarh	796	270
Alsisar	824	288
Sawar	870	208
Topariyan	934	190
Maujakhera	960	230
Nakaura	963	215
Bhatinda	1014	206

This elevation profile helps us in analyzing the hydraulic profile of the entire pipeline route. The graph for the elevation versus chainage is shown below corresponding to the table1.This elevation profile aids us in analyzing the pressure loss due to elevation for the entire pipeline route.

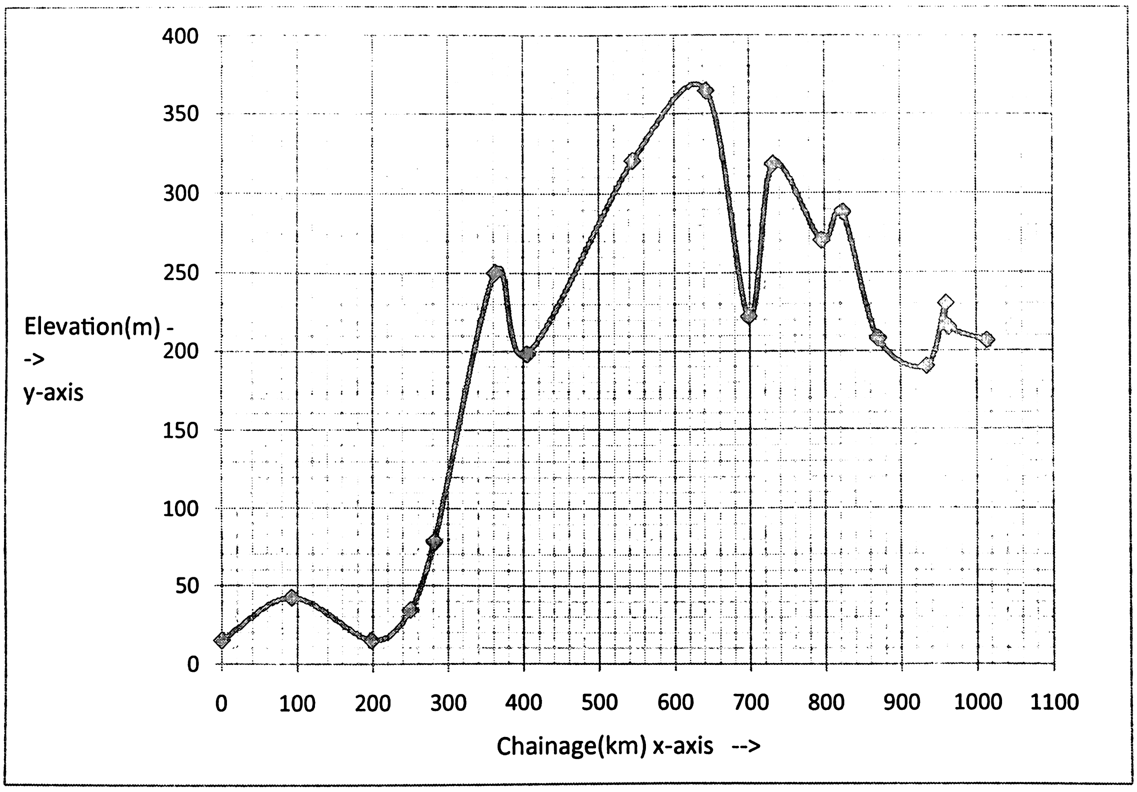

Figure 2: Chainage (km) vs. Elevation (m) graph

3.6 Hydraulic profile analysis

Hydraulic profile analysis has to be performed in a systematic manner to determine the number of intermediate pumping stations required to transfer crude oil through the entire length of pipeline.

3.6.1 MAOP calculation

The maximum allowable operating pressure (MAOP) is calculated for all the grades, diameters and thickness assumed. The MAOP is calculated using the formula, which is as per ASME B31.4,

$$P = \frac{(2 * S * t * F * E * T)}{D}$$

Where,

P = MAOP = maximum allowable operating pressure, psi. It is the maximum pressure allowed as per ASME code.

S = Specified minimum yield strength, psi. The minimum yield strength is prescribed by the specification under which the pipe is purchased from the manufacturer.

t = Nominal wall thickness, inch. It is the thickness used for the design calculation. It is given in API 5L code. Pipe may be ordered to this calculated wall thickness without adding the allowance to compensate the under thickness tolerance permitted in approved specification.

D = Nominal outside diameter, inch. This specified outside diameter must be used as given in API 5L code.

F = Location class factor as given in table 2 below.

Table 2: Safety factors for different locations

Location class	Design factor
Location class 1,division 1	0.80
Location class 1,division 2	0.72
Location class 2	0.60
Location class 3	0.50
Location class 4	0.40

- Location class 1 includes wastelands, deserts, rugged mountains, farm land and similar areas.
- Location class 2 includes fringe areas around cities or towns, and farm or industrial areas with specified population density.
- Location class 3 includes areas subdivided for residential or commercial purposes with a specified building density of specified type.
- Location class 4 includes areas where multistory buildings are prevalent, where traffic is heavy or dense, or where there are numerous other underground utilities.

For our pipeline we are considering a location class factor of 0.72 since most of the pipeline length passes through mountains and farm lands.

T = Temperature de-rating factor, which is given in table 3. We get a value of T=1 for this factor.

Table 3: Temperature de-rating factor

Temperature, ^{o}F	Temperature de-rating factor, T
<250	1.000
300	0.967
350	0.933
400	0.900
450	0.867

E = Longitudinal joint factor. If the type of longitudinal joint can be determined with certainty, the corresponding longitudinal factor E may be used. The longitudinal joint factor for each type of joint is shown in table 4.We are taking a value of E=1 for this factor.

Table 4: Weld joint factor

Spec. No.	Pipe class	E Factor
ASTM A 53	• Seam Less • Electric resistance welding • Furnace Butt welded: continuous weld	1.00 1.00 0.60
ASTM A 106	• Seamless	1.00
ASTM A 134	• Electric Fusion Arc Welded	0.80
ASTM A 135	• Electric resistance welded	1.00
ASTM A 139	• Electric Fusion welded	0.80
ASTM A 211	• Spiral welded steel pipe	0.80
ASTM A 333	• Seamless • Electric resistance welding	1.00 1.00
ASTM A 381	• Double submerged arc welding	1.00
ASTM A 671	• Electric fusion welded Classes 13,23,33,43,53 Classes 12,22,32,42,52	 0.80 1.00
ASTM A 672	• Electric fusion welded Classes 13,23,33,43,53 Classes 12,22,32,42,52	 0.80 1.00
API 5L	• Seamless • Electric resistance welding • Electric flash welded • Submerged arc welded • Furnace butt welded	1.00 1.00 1.00 1.00 0.60

Sample calculation for MAOP

For API 5L pipeline of material grade X56, outer diameter = 22 inch and thickness = 0.25 inch and design factor = 0.72.Material grade X56 has a specified minimum yield strength of 56000 psi. Substituting the values in MAOP equation, F=0.72, E=1, T=1, we get,

$$MAOP = (2 * 56000 * 0.25 * 0.72 * 1 * 1)/22$$

$$\text{MAOP} = 916.36 \text{ psi} = 64.52 \text{ kg / cm}^2.$$

Similarly the calculations for all the grades are done and tabulated. The tables 5, 6, 7 give the MAOP values for all the grades, diameters and thickness of the pipeline.

Table 5: MAOP for API 5L, X56 grade

Diameter, inch	Thickness, inch	Grade	SMYS, psi	Allowable stress, psi	MAOP, psi	MAOP, kg/cm^2
22	0.250	X56	56000	40320	916.36	64.52
22	0.281	X56	56000	40320	1030	72.51
22	0.312	X56	56000	40320	1143.62	80.51
24	0.250	X56	56000	40320	840	59.14
24	0.281	X56	56000	40320	944.16	66.47
24	0.312	X56	56000	40320	1048.32	73.80
26	0.250	X56	56000	40320	775.38	54.59
26	0.281	X56	56000	40320	871.53	61.36
26	0.312	X56	56000	40320	967.68	68.12

Table 6: MAOP for API 5L, X60 grade

Diameter, inch	Thickness, inch	Grade	SMYS, psi	Allowable stress, psi	MAOP, psi	MAOP, kg/cm^2
22	0.250	X60	60000	43200	981.82	69.12
22	0.281	X60	60000	43200	1103.56	77.69
22	0.312	X60	60000	43200	1225.31	86.26
24	0.250	X60	60000	43200	900	63.36
24	0.281	X60	60000	43200	1011.6	71.22
24	0.312	X60	60000	43200	1123.2	79.07
26	0.250	X60	60000	43200	830.77	58.49
26	0.281	X60	60000	43200	933.78	65.74
26	0.312	X60	60000	43200	1036.8	73

Table 7: MAOP for API 5L, X65 grade

Diameter, inch	Thickness, inch	Grade	SMYS, psi	Allowable stress, psi	MAOP, psi	MAOP, kg/cm^2
22	0.250	X65	65000	46800	1063.64	74.88
22	0.281	X65	65000	46800	1195.53	84.17
22	0.312	X65	65000	46800	1327.42	93.45
24	0.250	X65	65000	46800	975	68.64
24	0.281	X65	65000	46800	1095.9	77.15
24	0.312	X65	65000	46800	1216.8	85.66
26	0.250	X65	65000	46800	900	63.36
26	0.281	X65	65000	46800	1011.6	71.22
26	0.312	X65	65000	46800	1123.2	79.07

3.6.2 Discharge pressure calculation

The discharge pressure required at the beginning of the pipeline to transfer crude oil at a given flow rate from Mundra to Bhatinda is given by the factors like pipe diameter, wall thickness and roughness, pipe length, pipeline elevation changes from Mundra to Bhatinda, liquid specific gravity, viscosity and the flow rate.

Discharge pressure = (Friction head) + (Elevation head) + (Delivery pressure at terminus)

The delivery pressure is taken as 6 kg/cm^2 depending on the requirement at the end of the pipeline.

Frictional pressure drop calculation

Every surface offers a resistance to flow and this resistance offered by the surface to fluid flow are called friction. A pipeline is no different from normal surface; its inner wall surface offers resistance to fluid flow and thereby reducing the velocity of fluid flow. This frictional pressure drop plays a vital role in the calculation of discharge pressure since it reduces the pressure to a greater extent than any other factor in a pipeline.

The frictional drop in a crude oil pipeline is calculated using the shell-MIT equation. Using this method, a modified Reynolds number is calculated from the Reynolds number as shown.

$$R = 92.24\ (Q) / (D * v)$$

$$Rm = R / (7742)$$

Now depending on the type of flow (laminar or turbulent), the friction factor is calculated using one of the following equations.

$$f = 0.00207 / Rm \text{ (for laminar flow)}$$

$$f = 0.0018 + 0.00662\ (1/Rm)^{0.355} \text{ (for turbulent flow)}$$

We know that the flow is always turbulent inside a pipeline; hence we use the turbulent flow equation.

Finally the pressure drop due to friction is calculated using the formula,

$$P_f = \frac{0.241\ (f * Sg * Q^2)}{D^5}$$

Sample calculation for D = 22 inch, Thickness = 0.25 inch, Inner Diameter = 21.50 inch.

Q = 0.3676 m^3/s = 199765.60 bbl/day; v = 6.63 cSt.

R = 92.24 (199765.60)/ (21.5 * 6.63)

R = 129267.10

Rm = R/7742 = 16.69

$f = 0.0018 + 0.00662\ (1/16.69)^{0.355}$

f = 0.00424

$P_f = 0.241\ (0.00424 * 0.850 * 199765.60^2) / (21.5)^5$

P_f = 7.54 psi/mile.

Similarly, calculations are done for all the diameters and thickness and are shown in table 8.

Table 8: Frictional pressure drop

Diameter, inch	**Inner diameter, inch**	**Thickness, inch**	**R**	**Rm**	**Friction factor, f (dimensionless)**	**Frictional pressure drop per mile, P_f**
22	21.500	0.250	129267.10	16.69	0.00424	7.54
22	21.438	0.281	129640.95	16.75	0.00423	7.64
22	21.376	0.312	130016.97	16.79	0.00423	7.75
24	23.500	0.250	118265.65	15.28	0.00431	4.92
24	23.438	0.281	118578.49	15.32	0.00431	4.98
24	23.376	0.312	118892.99	15.36	0.00431	5.05
26	25.500	0.250	108989.91	14.08	0.00439	3.33
26	25.438	0.281	109255.55	14.11	0.00439	3.37
26	25.376	0.312	109522.49	14.15	0.00438	3.40

From table 8, few things can be clearly understood which are

- If the pipe diameter is increased, the frictional pressure drop will decrease.
- If the pipe thickness is increased, the frictional pressure drop will increase.

Pressure drop calculation for difference in elevation

The change in elevation affects the total pressure required directly by increasing the total pressure required for pumping the liquid. The difference in elevation between each section is taken into account and the pressure loss for each section is calculated and summed up to give the total pressure drop due to changes in elevation.

Total discharge pressure required

The total discharge pressure required overcoming the loss due to friction, elevation and the required delivery pressure is calculated and shown in a detailed way in APPENDIX 1.the total length of the pipeline is 1014 kilometer and is divided into 17 sections. Each section has a variable elevation and the placement of pumping station depends on the change in total pressure in each section of the pipeline.

Each pump has a entry pressure and it must be maintained in order to ensure the safe pumping of the crude oil. If the placement of pumping station is required before the location mentioned, then suitable pressure is deducted from the actual pressure pumped by the pump. So if the pump delivers less pressure than the pressure allocated to be pumped, then it means that the pumping station is placed before the location mentioned in the pipeline route.

The tabulations for the total discharge pressures for all the grades, thickness and diameters are shown in the following tables and hydraulic profiles.

Table 9: Discharge pressures for API 5L X56, D = 22 inch, Thickness = 0.250 inch, P_f = 7.54 psi/mile.

Location	Chainage km	chainage mile	Elevation feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0.00	49	0	0	0	916
Bhachau	93	57.76	138	89	32.75	435.54	448
Santalpur	198	122.98	49	-89	32.75	491.74	906
Dev	250	155.28	112	63	17.73	243.53	645
Juna raviyana	282	175.16	256	144	52.88	149.86	442
Bargaon	363	225.47	820	564	207.53	379.34	772
Bhadra	405	251.55	649	-171	62.93	196.70	638
Jhalwar	545	338.51	1050	401	147.5	655.65	751
Kantiya	643	399.38	1194	144	52.88	458.96	241
Sateran	699	434.16	728	-466	171.5	262.26	150
Kakra	732	454.66	1043	315	115	154.55	797
Shri Dungargarh	796	494.41	886	-157	57.77	299.73	556
Alsisar	824	511.80	945	59	21.71	131.13	403
Sawar	870	540.37	682	-263	96	215.43	284
Topariyan	934	580.12	623	-59	21.7	299.73	481
Maujakhera	960	596.27	754	131	48.2	121.76	311
Nakaura	963	598.14	705	-49	18.03	14.05	313
Bhatinda	1014	629.81	676	-29	10.67	238.84	85

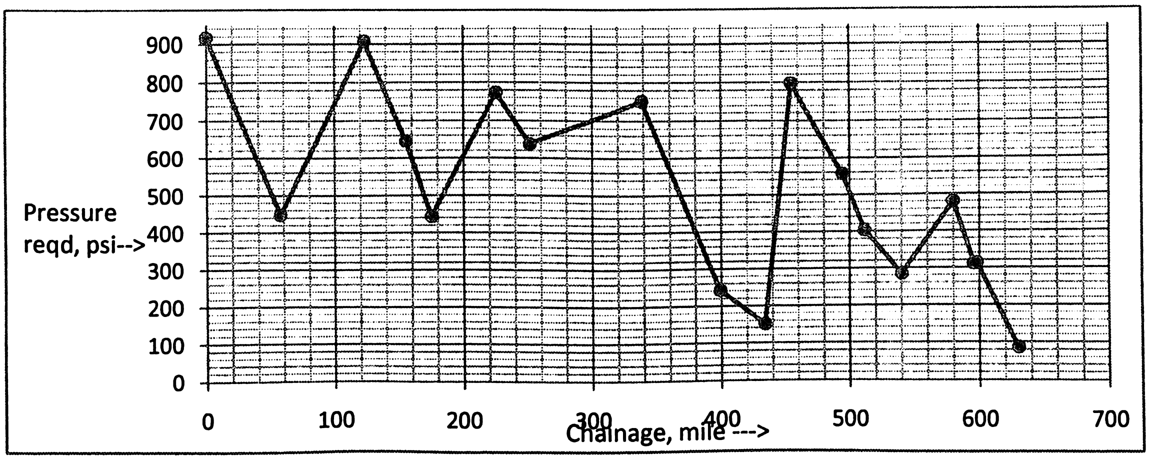

Figure 3: Hydraulic profile for API 5L X56, D = 22 inch, Thickness = 0.250 inch.

Table 10: Discharge pressures for API 5L, X56 grade, D = 22 inch, Thickness = 0.281 inch, P_f =7.63 psi/mile

location	Chainage km	chainage mile	Elevation feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr Reqd, psi
Mundra	0	0	49	0	0	0	1030
Bhachau	93	57.76	138	89	32.75	441.32	556
Santalpur	198	122.98	49	-89	32.75	498.26	91
Dev	250	155.28	112	63	17.73	246.76	857
Juna raviyana	282	175.16	256	144	52.88	151.85	652
Bargaon	363	225.47	820	564	207.53	384.37	61
Bhadra	405	251.55	649	-171	62.93	199.30	955
Jhalwar	545	338.51	1050	401	147.5	664.35	144
Kantiya	643	399.38	1194	144	52.88	465.04	657
Sateran	699	434.16	728	-466	171.5	265.74	563
Kakra	732	454.66	1043	315	115	156.60	291
Shri Dungargarh	796	494.41	886	-157	57.77	303.70	1030
Alsisar	824	511.80	945	59	21.71	132.87	875
Sawar	870	540.37	682	-263	96	218.29	752
Topariyan	934	580.12	623	-59	21.7	303.70	470
Maujakhera	960	596.27	754	131	48.2	123.38	299
Nakaura	963	598.14	705	-49	18.03	14.24	303
Bhatinda	1014	629.81	676	-29	10.67	242.01	72

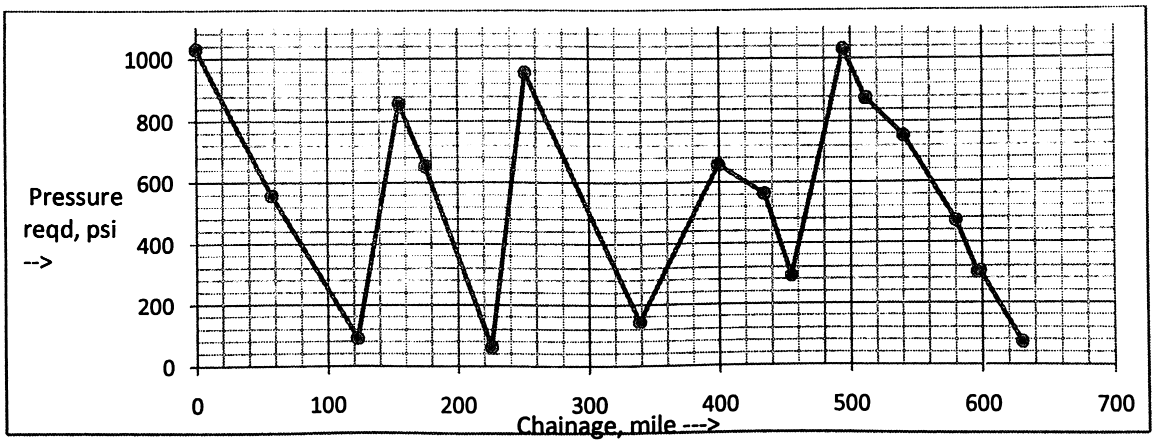

Figure 4: Hydraulic profile for API 5L X56, D = 22 inch, Thickness = 0.281 inch.

Table 11: Discharge pressures for API 5L, X56 grade, D = 22 inch, Thickness = 0.312 inch, P_f =7.75 psi/mile

location	Chainage km	chainage mile	Elevation feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr Reqd, psi
Mundra	0	0	49	0	0	0	1144
Bhachau	93	57.76	138	89	32.75	447.67	664
Santalpur	198	122.98	49	-89	32.75	505.43	191
Dev	250	155.28	112	63	17.73	250.31	1067
Juna raviyana	282	175.16	256	144	52.88	154.04	860
Bargaon	363	225.47	820	564	207.53	389.91	263
Bhadra	405	251.55	649	-171	62.93	202.17	124
Jhalwar	545	338.51	1050	401	147.5	673.91	447
Kantiya	643	399.38	1194	144	52.88	471.74	1067
Sateran	699	434.16	728	-466	171.5	269.57	969
Kakra	732	454.66	1043	315	115	158.85	695
Shri Dungargarh	796	494.41	886	-157	57.77	308.07	445
Alsisar	824	511.80	945	59	21.71	134.78	289
Sawar	870	540.37	682	-263	96	221.43	164
Topariyan	934	580.12	623	-59	21.7	308.07	489
Maujakhera	960	596.27	754	131	48.2	125.16	316
Nakaura	963	598.14	705	-49	18.03	14.44	320
Bhatinda	1014	629.81	676	-29	10.67	245.50	85

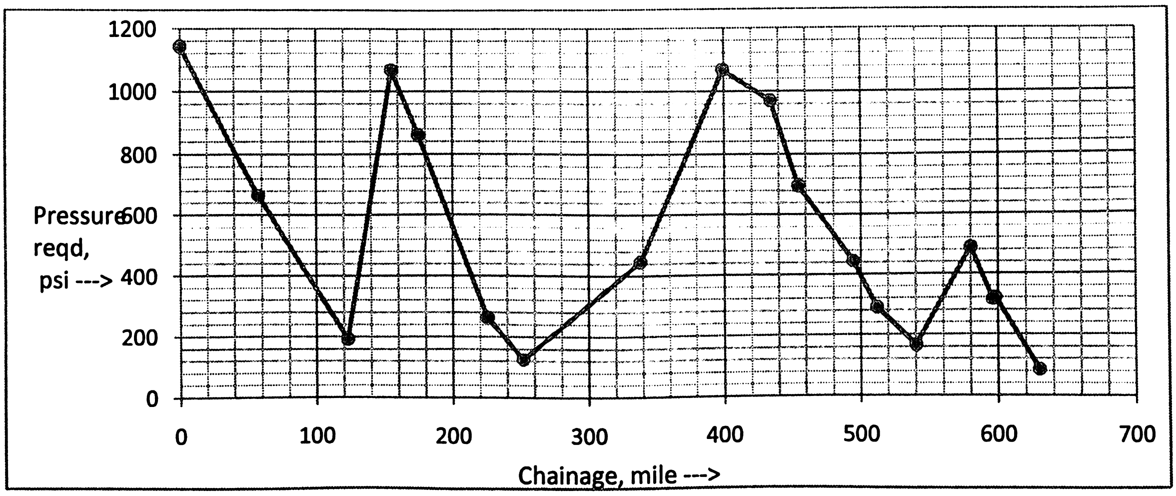

Figure 5: Hydraulic profile for API 5L X56, D = 22 inch, Thickness = 0.312 inch.

Table 12: Discharge pressures for API 5L, X56 grade, D = 24 inch, Thickness = 0.250 inch, P_f =4.92 psi/mile

Location	Chainage km	Chainage mile	Elevation feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	840
Bhachau	93	57.76	138	89	32.75	284.20	523
Santalpur	198	122.98	49	-89	32.75	320.87	235
Dev	250	155.28	112	63	17.73	158.91	60
Juna raviyana	282	175.16	256	144	52.88	97.79	750
Bargaon	363	225.47	820	564	207.53	247.53	295
Bhadra	405	251.55	649	-171	62.93	128.35	230
Jhalwar	545	338.51	1050	401	147.5	427.83	495
Kantiya	643	399.38	1194	144	52.88	299.48	143
Sateran	699	434.16	728	-466	171.5	171.13	143
Kakra	732	454.66	1043	315	115	100.84	810
Shri Dungargarh	796	494.41	886	-157	57.77	195.58	673
Alsisar	824	511.80	945	59	21.71	85.57	566
Sawar	870	540.37	682	-263	96	140.57	521
Topariyan	934	580.12	623	-59	21.7	195.58	348
Maujakhera	960	596.27	754	131	48.2	79.45	221
Nakaura	963	598.14	705	-49	18.03	9.17	230
Bhatinda	1014	629.81	676	-29	10.67	155.85	85

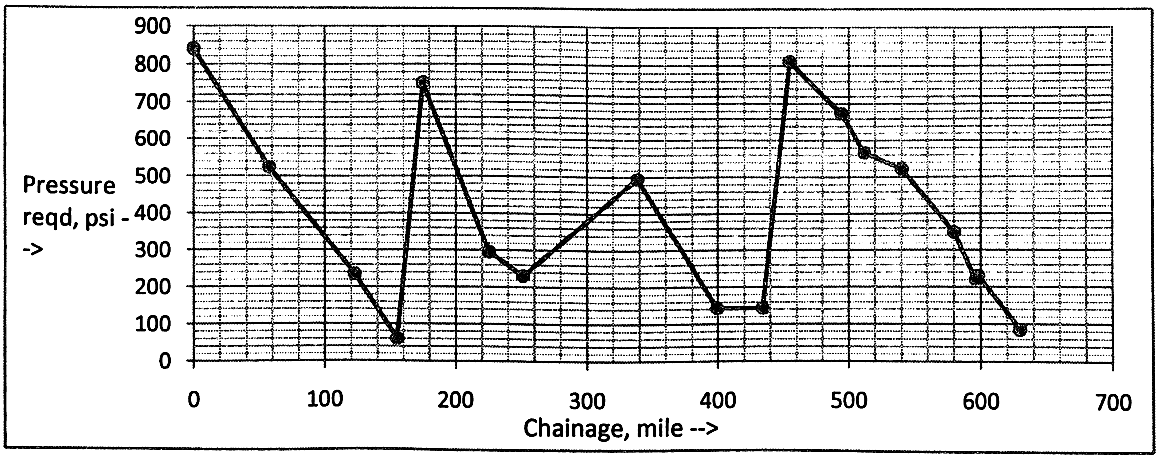

Figure 6: Hydraulic profile for API 5L X56, D = 24 inch, Thickness = 0.250 inch.

Table 13: Discharge pressures for API 5L, X56 grade, D = 24 inch, Thickness = 0.281 inch, P_f =4.98psi/mile

location	Chainage km	Chainage mile	Elevation feet	Elevation difference feet	Pr. Loss due to elevation psi	P_f, psi	Total pr. Reqd psi
Mundra	0	0	49	0	0	0	945
Bhachau	93	57.76	138	89	32.75	287.66	625
Santalpur	198	122.98	49	-89	32.75	324.78	333
Dev	250	155.28	112	63	17.73	160.84	155
Juna raviyana	282	175.16	256	144	52.88	98.98	945
Bargaon	363	225.47	820	564	207.53	250.55	487
Bhadra	405	251.55	649	-171	62.93	129.91	420
Jhalwar	545	338.51	1050	401	147.5	433.04	785
Kantiya	643	399.38	1194	144	52.88	303.13	429
Sateran	699	434.16	728	-466	171.5	173.22	427
Kakra	732	454.66	1043	315	115	102.07	210
Shri Dungargarh	796	494.41	886	-157	57.77	197.96	613
Alsisar	824	511.80	945	59	21.71	86.61	575
Sawar	870	540.37	682	-263	96	142.29	529
Topariyan	934	580.12	623	-59	21.7	197.96	353
Maujakhera	960	596.27	754	131	48.2	80.42	224
Nakaura	963	598.14	705	-49	18.03	9.28	233
Bhatinda	1014	629.81	676	-29	10.67	157.75	85

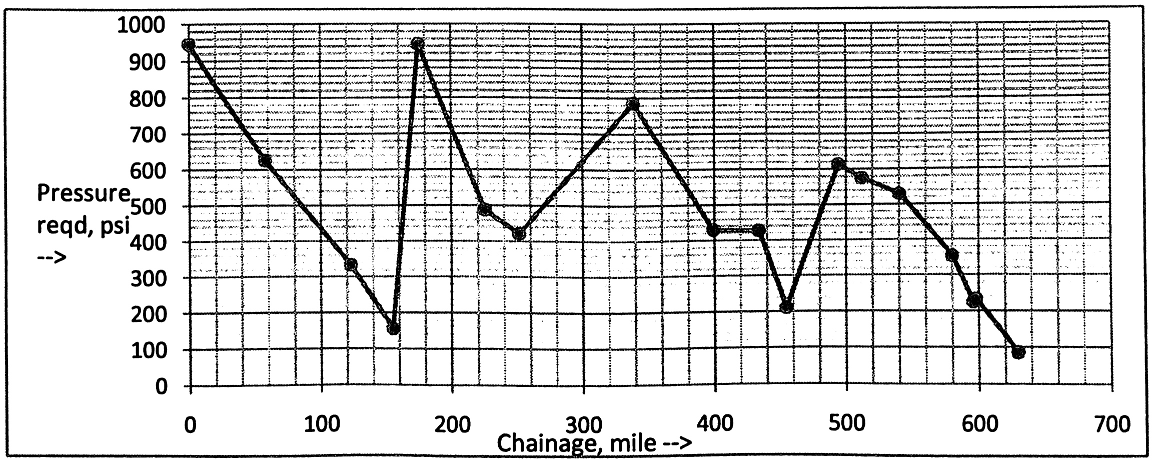

Figure 7: Hydraulic profile for API 5L X56, D = 24 inch, Thickness = 0.281 inch.

Table 14: Discharge pressures for API 5L, X56 grade, D = 24 inch, Thickness = 0.312 inch, P_f =5.05 psi/mile

location	Chainage km	Chainage mile	Elevation feet	Elevation difference feet	Pr. Loss due to elevation psi	P_f, psi	Total pr. Reqd, psi
.Mundra	0	0	49	0	0	0	1049
Bhachau	93	57.76	138	89	32.75	291.71	725
Santalpur	198	122.98	49	-89	32.75	329.35	429
Dev	250	155.28	112	63	17.73	163.11	248
Juna raviyana	282	175.16	256	144	52.88	100.37	95
Bargaon	363	225.47	820	564	207.53	254.07	683
Bhadra	405	251.55	649	-171	62.93	131.74	614
Jhalwar	545	338.51	1050	401	147.5	439.13	86
Kantiya	643	399.38	1194	144	52.88	307.39	717
Sateran	699	434.16	728	-466	171.5	175.65	713
Kakra	732	454.66	1043	315	115	103.51	495
Shri Dungargarh	796	494.41	886	-157	57.77	200.75	352
Alsisar	824	511.80	945	59	21.71	87.83	243
Sawar	870	540.37	682	-263	96	144.29	195
Topariyan	934	580.12	623	-59	21.7	200.75	356
Maujakhera	960	596.27	754	131	48.2	81.55	226
Nakaura	963	598.14	705	-49	18.03	9.41	235
Bhatinda	1014	629.81	676	-29	10.67	159.97	85

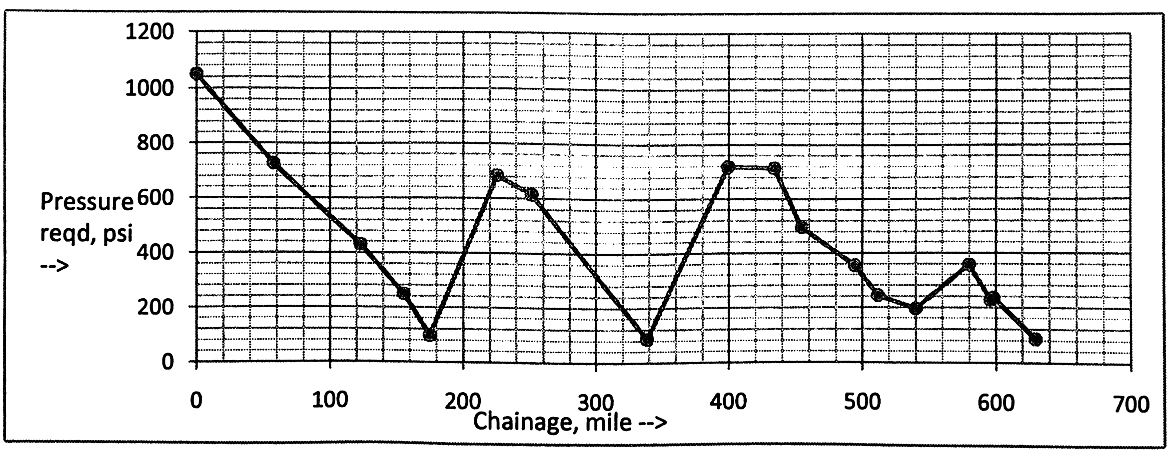

Figure 8: Hydraulic profile for API 5L X56, D = 24 inch, Thickness = 0.312 inch.

Table 15: Discharge pressures for API 5L, X56 grade, D = 26 inch, Thickness = 0.250 inch, P_f =3.33 psi/mile

location	Chainage km	Chainage mile	Elevation feet	Elevation difference feet	Pr. Loss due to elevation psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	776
Bhachau	93	57.76	138	89	32.75	192.35	551
Santalpur	198	122.98	49	-89	32.75	217.17	367
Dev	250	155.28	112	63	17.73	107.55	242
Juna raviyana	282	175.16	256	144	52.88	66.19	123
Bargaon	363	225.47	820	564	207.53	167.53	544
Bhadra	405	251.55	649	-171	62.93	86.87	520
Jhalwar	545	338.51	1050	401	147.5	289.57	83
Kantiya	643	399.38	1194	144	52.88	202.70	584
Sateran	699	434.16	728	-466	171.5	115.83	641
Kakra	732	454.66	1043	315	115	68.25	458
Shri Dungargarh	796	494.41	886	-157	57.77	132.37	383
Alsisar	824	511.80	945	59	21.71	57.91	303
Sawar	870	540.37	682	-263	96	95.14	304
Topariyan	934	580.12	623	-59	21.7	132.37	111
Maujakhera	960	596.27	754	131	48.2	53.78	168
Nakaura	963	598.14	705	-49	18.03	6.20	180
Bhatinda	1014	629.81	676	-29	10.67	105.48	85

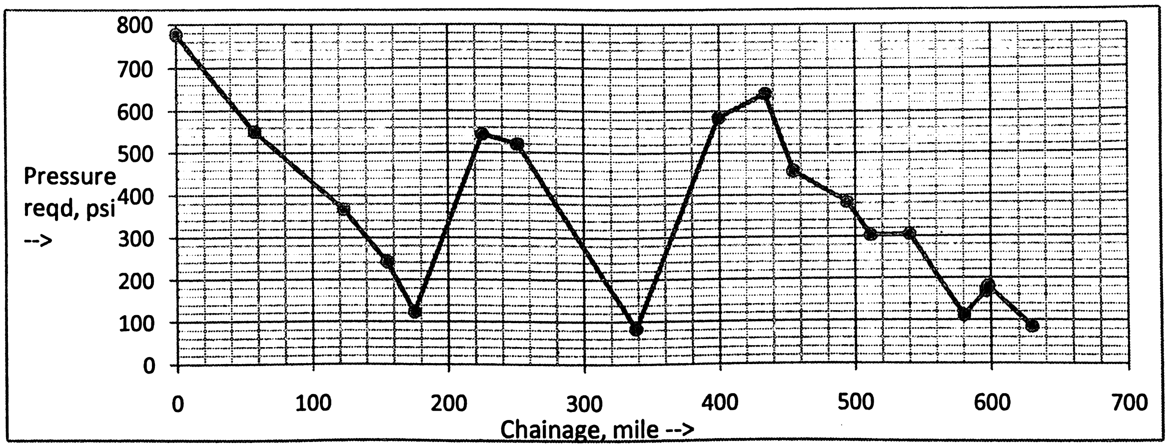

Figure 9: Hydraulic profile for API 5L X56, D = 26 inch, Thickness = 0.250 inch.

Table 16: Discharge pressures for API 5L, X56 grade, D = 26 inch, Thickness = 0.281 inch, P_f =3.37 psi/mile

location	Chainage km	Chainage mile	Elevation feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	872
Bhachau	93	57.76	138	89	32.75	194.66	645
Santalpur	198	122.98	49	-89	32.75	219.78	458
Dev	250	155.28	112	63	17.73	108.84	332
Juna raviyana	282	175.16	256	144	52.88	66.98	212
Bargaon	363	225.47	820	564	207.53	169.55	622
Bhadra	405	251.55	649	-171	62.93	87.91	597
Jhalwar	545	338.51	1050	401	147.5	293.04	157
Kantiya	643	399.38	1194	144	52.88	205.13	677
Sateran	699	434.16	728	-466	171.5	117.22	729
Kakra	732	454.66	1043	315	115	69.07	545
Shri Dungargarh	796	494.41	886	-157	57.77	133.96	469
Alsisar	824	511.80	945	59	21.71	58.61	383
Sawar	870	540.37	682	-263	96	96.29	383
Topariyan	934	580.12	623	-59	21.7	133.96	271
Maujakhera	960	596.27	754	131	48.2	54.42	169
Nakaura	963	598.14	705	-49	18.03	6.28	181
Bhatinda	1014	629.81	676	-29	10.67	106.75	85

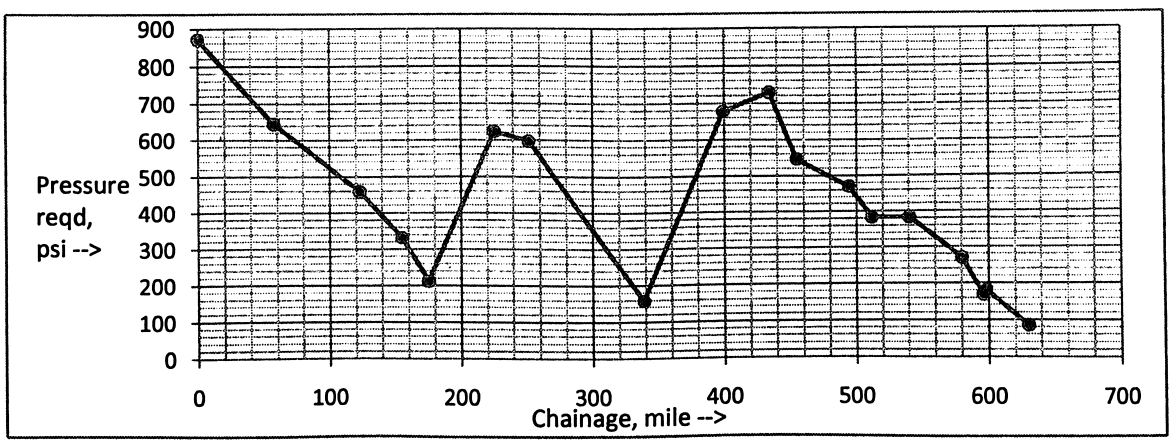

Figure 10: Hydraulic profile for API 5L X56, D = 26 inch, Thickness = 0.281 inch.

Table 17: Discharge pressures for API 5L, X56 grade, D = 26 inch, Thickness = 0.312 inch, P_f =3.40 psi/mile

location	Chainage, km	chainage, mile	Elevation, feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	968
Bhachau	93	57.76	138	89	32.75	196.40	739
Santalpur	198	122.98	49	-89	32.75	221.74	550
Dev	250	155.28	112	63	17.73	109.81	423
Juna raviyana	282	175.16	256	144	52.88	67.58	303
Bargaon	363	225.47	820	564	207.53	171.06	893
Bhadra	405	251.55	649	-171	62.93	88.70	867
Jhalwar	545	338.51	1050	401	147.5	295.65	424
Kantiya	643	399.38	1194	144	52.88	206.96	165
Sateran	699	434.16	728	-466	171.5	118.26	218
Kakra	732	454.66	1043	315	115	69.69	546
Shri Dungargarh	796	494.41	886	-157	57.77	135.16	469
Alsisar	824	511.80	945	59	21.71	59.13	388
Sawar	870	540.37	682	-263	96	97.14	387
Topariyan	934	580.12	623	-59	21.7	135.16	274
Maujakhera	960	596.27	754	131	48.2	54.91	171
Nakaura	963	598.14	705	-49	18.03	6.34	183
Bhatinda	1014	629.81	676	-29	10.67	107.70	86

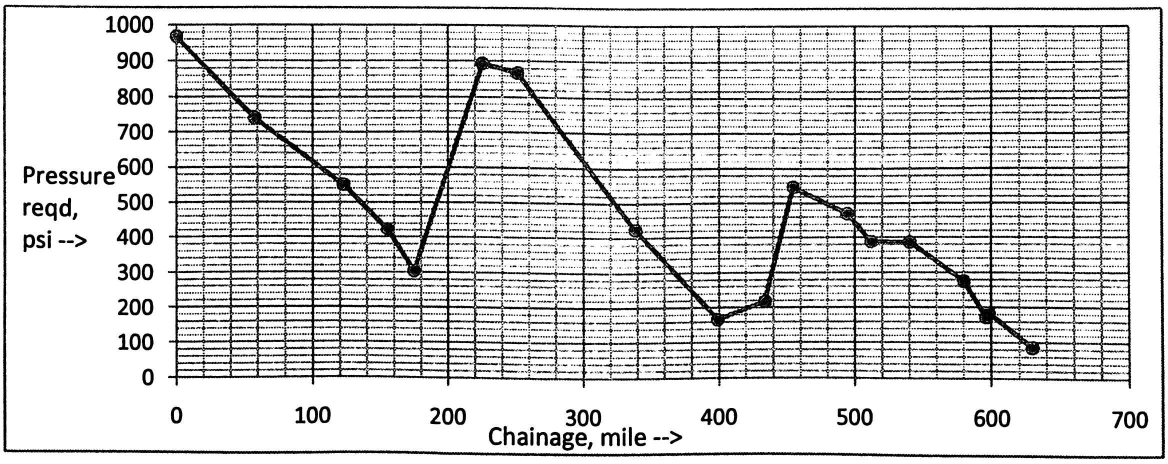

Figure 11: Hydraulic profile for API 5L X56, D = 26 inch, Thickness = 0.312 inch.

Table 18: Discharge pressures for API 5L, X60 grade, D = 22 inch, Thickness = 0.250 inch, P_f =7.54 psi/mile

location	Chainage km	chainage, mile	Elevation, feet	Elevation difference feet	Pr. Loss due to elevation psi	P_f, psi	Total pr. Reqd psi
Mundra	0	0	49	0	0	0	982
Bhachau	93	57.76	138	89	32.75	435.54	514
Santalpur	198	122.98	49	-89	32.75	491.74	982
Dev	250	155.28	112	63	17.73	243.53	721
Juna raviyana	282	175.16	256	144	52.88	149.86	519
Bargaon	363	225.47	820	564	207.53	379.34	915
Bhadra	405	251.55	649	-171	62.93	196.70	781
Jhalwar	545	338.51	1050	401	147.5	655.65	962
Kantiya	643	399.38	1194	144	52.88	458.96	451
Sateran	699	434.16	728	-466	171.5	262.26	360
Kakra	732	454.66	1043	315	115	154.55	90
Shri Dungargarh	796	494.41	886	-157	57.77	299.73	831
Alsisar	824	511.80	945	59	21.71	131.13	677
Sawar	870	540.37	682	-263	96	215.43	560
Topariyan	934	580.12	623	-59	21.7	299.73	292
Maujakhera	960	596.27	754	131	48.2	121.76	112
Nakaura	963	598.14	705	-49	18.03	14.05	314
Bhatinda	1014	629.81	676	-29	10.67	238.84	85

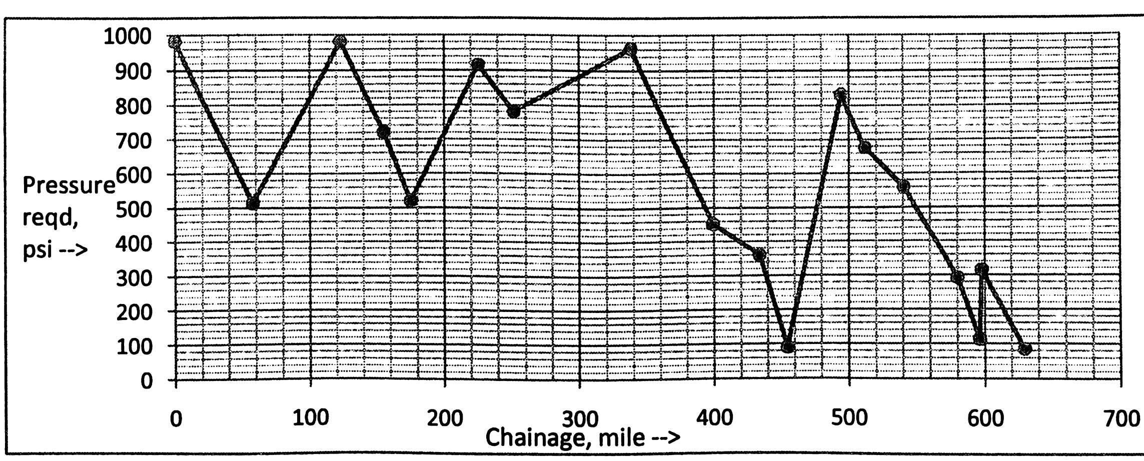

Figure 12: Hydraulic profile for API 5L X60, D = 22 inch, Thickness = 0.250 inch.

Table 19: Discharge pressures for API 5L, X60 grade, D = 22 inch, Thickness = 0.281 inch, P_f =7.64 psi/mile

location	Chainage km	chainage, mile	Elevation, feet	Elevation difference feet	Pr. Loss due to elevation psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	1104
Bhachau	93	57.76	138	89	32.75	441.32	630
Santalpur	198	122.98	49	-89	32.75	498.26	165
Dev	250	155.28	112	63	17.73	246.76	1005
Juna raviyana	282	175.16	256	144	52.88	151.85	800
Bargaon	363	225.47	820	564	207.53	384.37	208
Bhadra	405	251.55	649	-171	62.93	199.30	1104
Jhalwar	545	338.51	1050	401	147.5	664.35	293
Kantiya	643	399.38	1194	144	52.88	465.04	880
Sateran	699	434.16	728	-466	171.5	265.74	786
Kakra	732	454.66	1043	315	115	156.60	514
Shri Dungargarh	796	494.41	886	-157	57.77	303.70	268
Alsisar	824	511.80	945	59	21.71	132.87	114
Sawar	870	540.37	682	-263	96	218.29	765
Topariyan	934	580.12	623	-59	21.7	303.70	483
Maujakhera	960	596.27	754	131	48.2	123.38	312
Nakaura	963	598.14	705	-49	18.03	14.24	316
Bhatinda	1014	629.81	676	-29	10.67	242.01	85

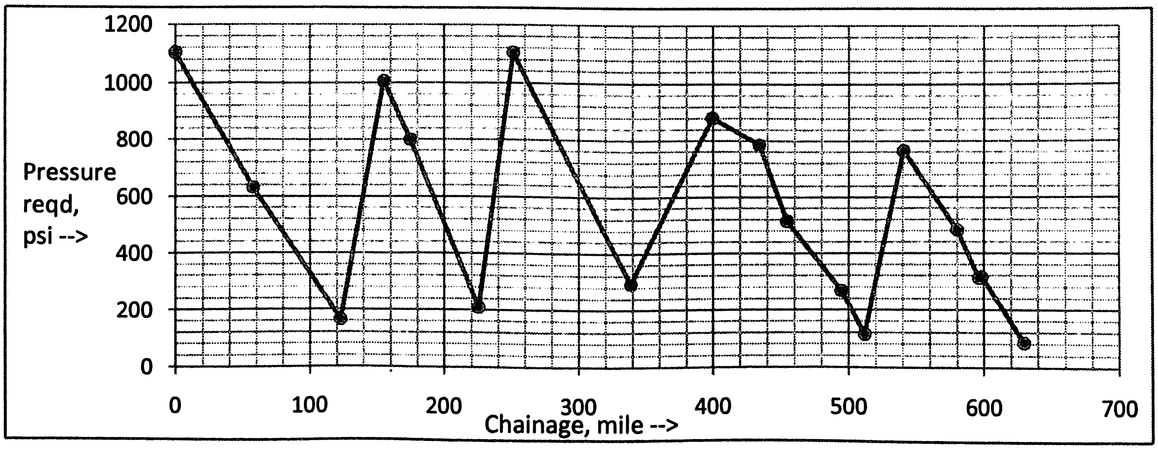

Figure 13: Hydraulic profile for API 5L X60, D = 22 inch, Thickness = 0.281 inch.

Table 20: Discharge pressures for API 5L, X60 grade, D = 22 inch, Thickness = 0.312 inch, P_f =7.75 psi/mile

location	Chainage, km	chainage, mile	Elevation, feet	Elevation difference feet	Pr. Loss due to elevation psi	P_f, psi	Total pr. Reqd , psi
Mundra	0	0	49	0	0	0	1226
Bhachau	93	57.76	138	89	32.75	447.67	746
Santalpur	198	122.98	49	-89	32.75	505.43	273
Dev	250	155.28	112	63	17.73	250.31	1226
Juna raviyana	282	175.16	256	144	52.88	154.04	1019
Bargaon	363	225.47	820	564	207.53	389.91	422
Bhadra	405	251.55	649	-171	62.93	202.17	283
Jhalwar	545	338.51	1050	401	147.5	673.91	688
Kantiya	643	399.38	1194	144	52.88	471.74	164
Sateran	699	434.16	728	-466	171.5	269.57	1226
Kakra	732	454.66	1043	315	115	158.85	953
Shri Dungargarh	796	494.41	886	-157	57.77	308.07	703
Alsisar	824	511.80	945	59	21.71	134.78	547
Sawar	870	540.37	682	-263	96	221.43	422
Topariyan	934	580.12	623	-59	21.7	308.07	136
Maujakhera	960	596.27	754	131	48.2	125.16	316
Nakaura	963	598.14	705	-49	18.03	14.44	320
Bhatinda	1014	629.81	676	-29	10.67	245.50	85

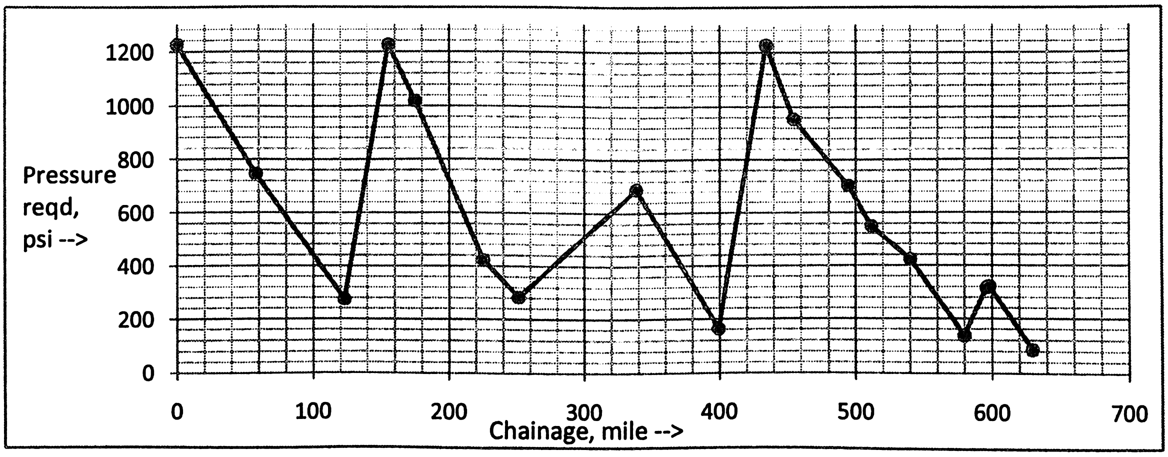

Figure 14: Hydraulic profile for API 5L X60, D = 22 inch, Thickness = 0.312 inch.

Table 21: Discharge pressures for API 5L, X60 grade, D = 24 inch, Thickness = 0.250 inch, P_f =4.92 psi/mile

location	Chainage, km	chainage, mile	Elevation, feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	900
Bhachau	93	57.76	138	89	32.75	284.20	583
Santalpur	198	122.98	49	-89	32.75	320.87	295
Dev	250	155.28	112	63	17.73	158.91	119
Juna raviyana	282	175.16	256	144	52.88	97.79	868
Bargaon	363	225.47	820	564	207.53	247.53	413
Bhadra	405	251.55	649	-171	62.93	128.35	348
Jhalwar	545	338.51	1050	401	147.5	427.83	673
Kantiya	643	399.38	1194	144	52.88	299.48	321
Sateran	699	434.16	728	-466	171.5	171.13	322
Kakra	732	454.66	1043	315	115	100.84	106
Shri Dungargarh	796	494.41	886	-157	57.77	195.58	675
Alsisar	824	511.80	945	59	21.71	85.57	568
Sawar	870	540.37	682	-263	96	140.57	523
Topariyan	934	580.12	623	-59	21.7	195.58	349
Maujakhera	960	596.27	754	131	48.2	79.45	221
Nakaura	963	598.14	705	-49	18.03	9.17	230
Bhatinda	1014	629.81	676	-29	10.67	155.85	85

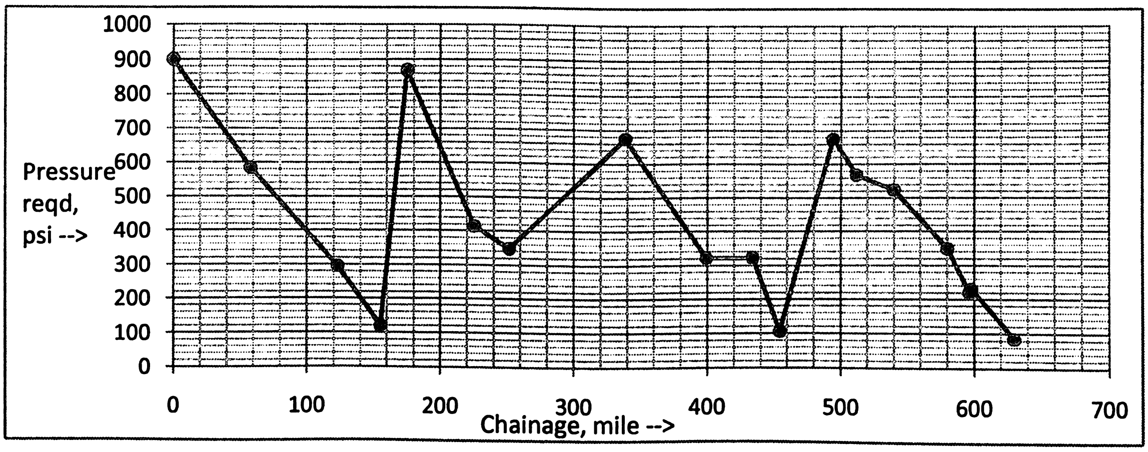

Figure 15: Hydraulic profile for API 5L X60, D = 24 inch, Thickness = 0.250 inch.

Table 22: Discharge pressures for API 5L, X60 grade, D = 24 inch, Thickness = 0.281 inch, P_f =4.98 psi/mile

location	Chainage km	chainage, mile	Elevation, feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	1012
Bhachau	93	57.76	138	89	32.75	287.66	692
Santalpur	198	122.98	49	-89	32.75	324.78	400
Dev	250	155.28	112	63	17.73	160.84	221
Juna raviyana	282	175.16	256	144	52.88	98.98	1012
Bargaon	363	225.47	820	564	207.53	250.55	554
Bhadra	405	251.55	649	-171	62.93	129.91	487
Jhalwar	545	338.51	1050	401	147.5	433.04	919
Kantiya	643	399.38	1194	144	52.88	303.13	563
Sateran	699	434.16	728	-466	171.5	173.22	561
Kakra	732	454.66	1043	315	115	102.07	344
Shri Dungargarh	796	494.41	886	-157	57.77	197.96	204
Alsisar	824	511.80	945	59	21.71	86.61	575
Sawar	870	540.37	682	-263	96	142.29	529
Topariyan	934	580.12	623	-59	21.7	197.96	353
Maujakhera	960	596.27	754	131	48.2	80.42	224
Nakaura	963	598.14	705	-49	18.03	9.28	233
Bhatinda	1014	629.81	676	-29	10.67	157.75	86

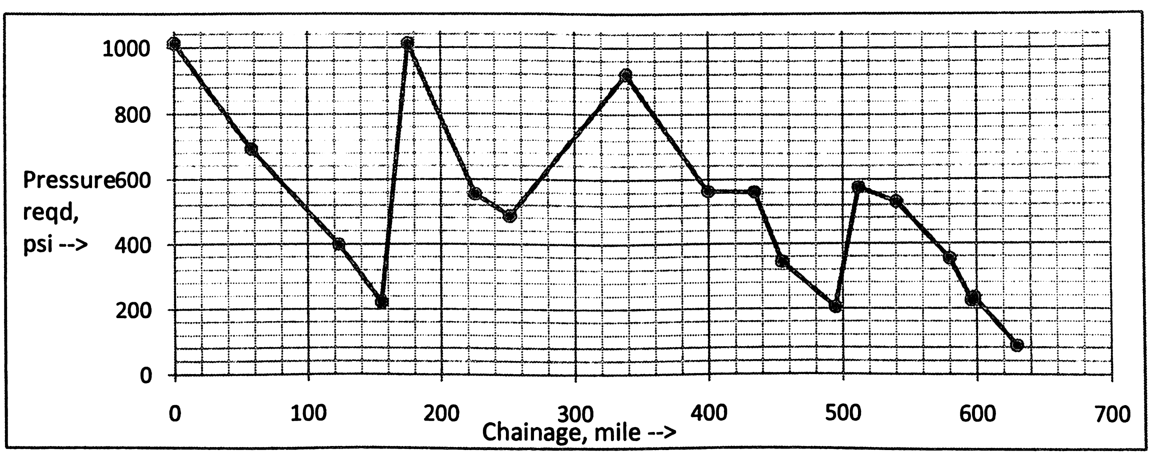

Figure 16: Hydraulic profile for API 5L X60, D = 24 inch, Thickness = 0.281 inch.

Table 23: Discharge pressures for API 5L, X60 grade, D = 24 inch, Thickness = 0.312 inch, P_f =5.05 psi/mile

location	Chainage km	chainage, mile	Elevation, feet	Elevation difference feet	Pr. Loss due to elevation psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	1123
Bhachau	93	57.76	138	89	32.75	291.71	799
Santalpur	198	122.98	49	-89	32.75	329.35	502
Dev	250	155.28	112	63	17.73	163.11	321
Juna raviyana	282	175.16	256	144	52.88	100.37	168
Bargaon	363	225.47	820	564	207.53	254.07	830
Bhadra	405	251.55	649	-171	62.93	131.74	761
Jhalwar	545	338.51	1050	401	147.5	439.13	175
Kantiya	643	399.38	1194	144	52.88	307.39	1055
Sateran	699	434.16	728	-466	171.5	175.65	1051
Kakra	732	454.66	1043	315	115	103.51	833
Shri Dungargarh	796	494.41	886	-157	57.77	200.75	690
Alsisar	824	511.80	945	59	21.71	87.83	581
Sawar	870	540.37	682	-263	96	144.29	533
Topariyan	934	580.12	623	-59	21.7	200.75	354
Maujakhera	960	596.27	754	131	48.2	81.55	225
Nakaura	963	598.14	705	-49	18.03	9.41	234
Bhatinda	1014	629.81	676	-29	10.67	159.97	85

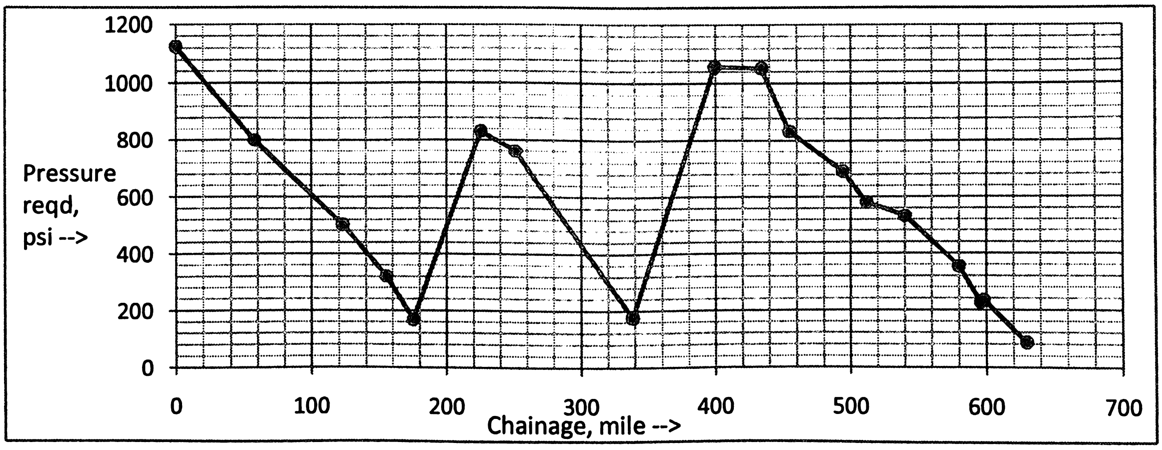

Figure 17: Hydraulic profile for API 5L X60, D = 24 inch, Thickness = 0.312 inch.

Table 24: Discharge pressures for API 5L, X60 grade, D = 26 inch, Thickness = 0.250 inch, P_f =3.33 psi/mile

location	Chainage km	chainage, mile	Elevation, feet	difference in elevation, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	831
Bhachau	93	57.76	138	89	32.75	192.35	606
Santalpur	198	122.98	49	-89	32.75	217.17	422
Dev	250	155.28	112	63	17.73	107.55	297
Juna raviyana	282	175.16	256	144	52.88	66.19	178
Bargaon	363	225.47	820	564	207.53	167.53	634
Bhadra	405	251.55	649	-171	62.93	86.87	610
Jhalwar	545	338.51	1050	401	147.5	289.57	173
Kantiya	643	399.38	1194	144	52.88	202.70	660
Sateran	699	434.16	728	-466	171.5	115.83	716
Kakra	732	454.66	1043	315	115	68.25	533
Shri Dungargarh	796	494.41	886	-157	57.77	132.37	459
Alsisar	824	511.80	945	59	21.71	57.91	380
Sawar	870	540.37	682	-263	96	95.14	381
Topariyan	934	580.12	623	-59	21.7	132.37	270
Maujakhera	960	596.27	754	131	48.2	53.78	168
Nakaura	963	598.14	705	-49	18.03	6.20	180
Bhatinda	1014	629.81	676	-29	10.67	105.48	86

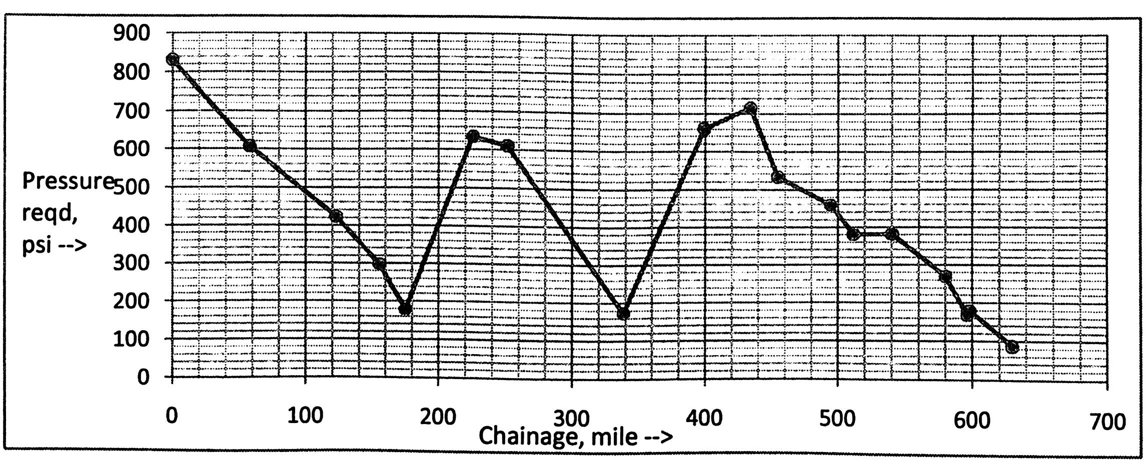

Figure 18: Hydraulic profile for API 5L X60, D = 26 inch, Thickness = 0.250 inch.

Table 25: Discharge pressures for API 5L, X60 grade, D = 26 inch, Thickness = 0.281 inch, P_f =3.37 psi/mile

location	Chainage km	chainage, mile	Elevation, feet	Elevation difference feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	934
Bhachau	93	57.76	138	89	32.75	194.66	707
Santalpur	198	122.98	49	-89	32.75	219.78	520
Dev	250	155.28	112	63	17.73	108.84	393
Juna raviyana	282	175.16	256	144	52.88	66.98	273
Bargaon	363	225.47	820	564	207.53	169.55	830
Bhadra	405	251.55	649	-171	62.93	87.91	805
Jhalwar	545	338.51	1050	401	147.5	293.04	365
Kantiya	643	399.38	1194	144	52.88	205.13	107
Sateran	699	434.16	728	-466	171.5	117.22	162
Kakra	732	454.66	1043	315	115	69.07	542
Shri Dungargarh	796	494.41	886	-157	57.77	133.96	466
Alsisar	824	511.80	945	59	21.71	58.61	386
Sawar	870	540.37	682	-263	96	96.29	385
Topariyan	934	580.12	623	-59	21.7	133.96	273
Maujakhera	960	596.27	754	131	48.2	54.42	171
Nakaura	963	598.14	705	-49	18.03	6.28	183
Bhatinda	1014	629.81	676	-29	10.67	106.75	86

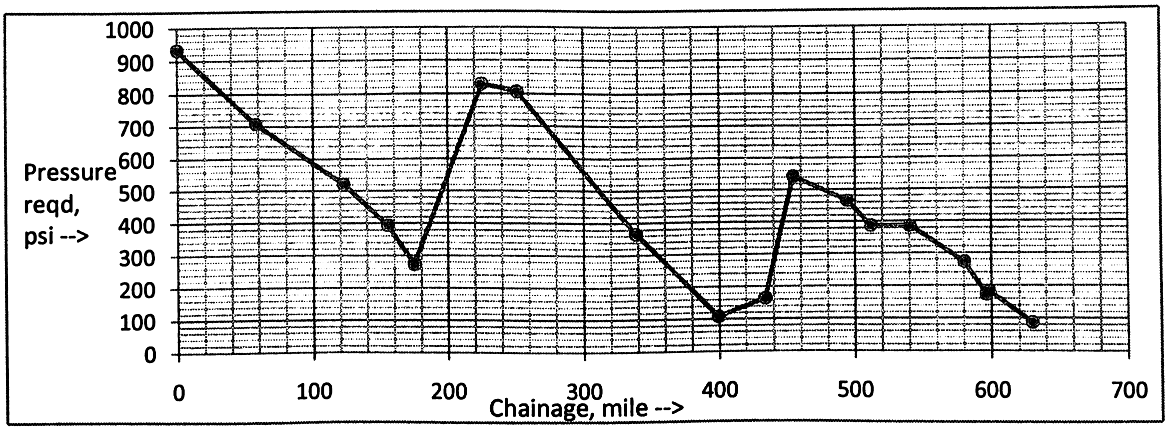

Figure 19: Hydraulic profile for API 5L X60, D = 26 inch, Thickness = 0.281 inch.

Table 26: Discharge pressures for API 5L, X60 grade, D = 26 inch, Thickness = 0.312 inch, P_f =3.40 psi/mile

location	Chainage km	chainage, mile	Elevation, feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	1037
Bhachau	93	57.76	138	89	32.75	196.40	808
Santalpur	198	122.98	49	-89	32.75	221.74	619
Dev	250	155.28	112	63	17.73	109.81	492
Juna raviyana	282	175.16	256	144	52.88	67.58	372
Bargaon	363	225.47	820	564	207.53	171.06	1030
Bhadra	405	251.55	649	-171	62.93	88.70	1004
Jhalwar	545	338.51	1050	401	147.5	295.65	561
Kantiya	643	399.38	1194	144	52.88	206.96	301
Sateran	699	434.16	728	-466	171.5	118.26	354
Kakra	732	454.66	1043	315	115	69.69	170
Shri Dungargarh	796	494.41	886	-157	57.77	135.16	470
Alsisar	824	511.80	945	59	21.71	59.13	389
Sawar	870	540.37	682	-263	96	97.14	388
Topariyan	934	580.12	623	-59	21.7	135.16	275
Maujakhera	960	596.27	754	131	48.2	54.91	172
Nakaura	963	598.14	705	-49	18.03	6.34	184
Bhatinda	1014	629.81	676	-29	10.67	107.70	86

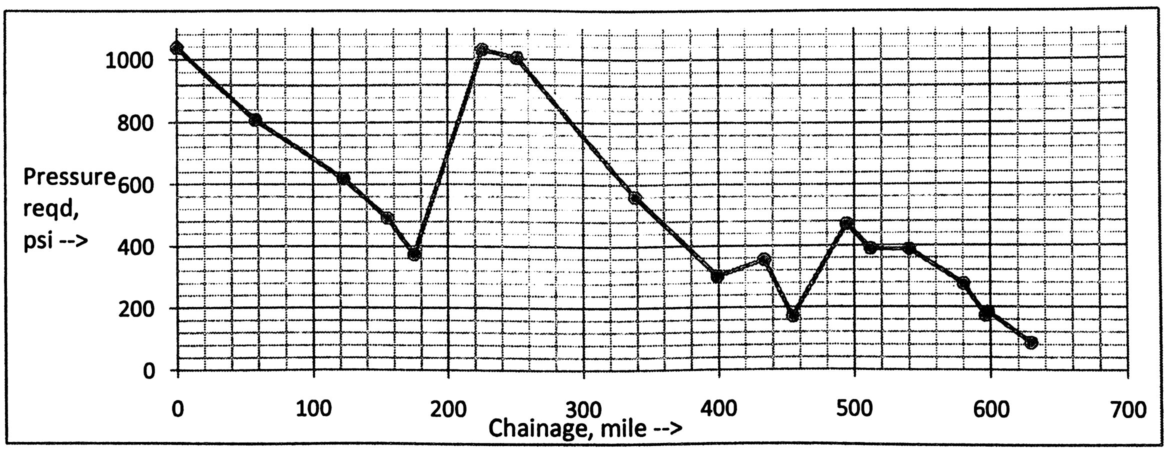

Figure 20: Hydraulic profile for API 5L X60, D = 26 inch, Thickness = 0.312 inch.

Table 27: Discharge pressures for API 5L, X65 grade, D = 22 inch, Thickness = 0.250 inch, P_f =7.54 psi/mile

location	Chainage km	chainage, mile	Elevation, feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	1064
Bhachau	93	57.76	138	89	32.75	435.54	596
Santalpur	198	122.98	49	-89	32.75	491.74	137
Dev	250	155.28	112	63	17.73	243.53	975
Juna raviyana	282	175.16	256	144	52.88	149.86	772
Bargaon	363	225.47	820	564	207.53	379.34	185
Bhadra	405	251.55	649	-171	62.93	196.70	1064
Jhalwar	545	338.51	1050	401	147.5	655.65	261
Kantiya	643	399.38	1194	144	52.88	458.96	814
Sateran	699	434.16	728	-466	171.5	262.26	723
Kakra	732	454.66	1043	315	115	154.55	454
Shri Dungargarh	796	494.41	886	-157	57.77	299.73	212
Alsisar	824	511.80	945	59	21.71	131.13	877
Sawar	870	540.37	682	-263	96	215.43	758
Topariyan	934	580.12	623	-59	21.7	299.73	480
Maujakhera	960	596.27	754	131	48.2	121.76	310
Nakaura	963	598.14	705	-49	18.03	14.05	314
Bhatinda	1014	629.81	676	-29	10.67	238.84	85

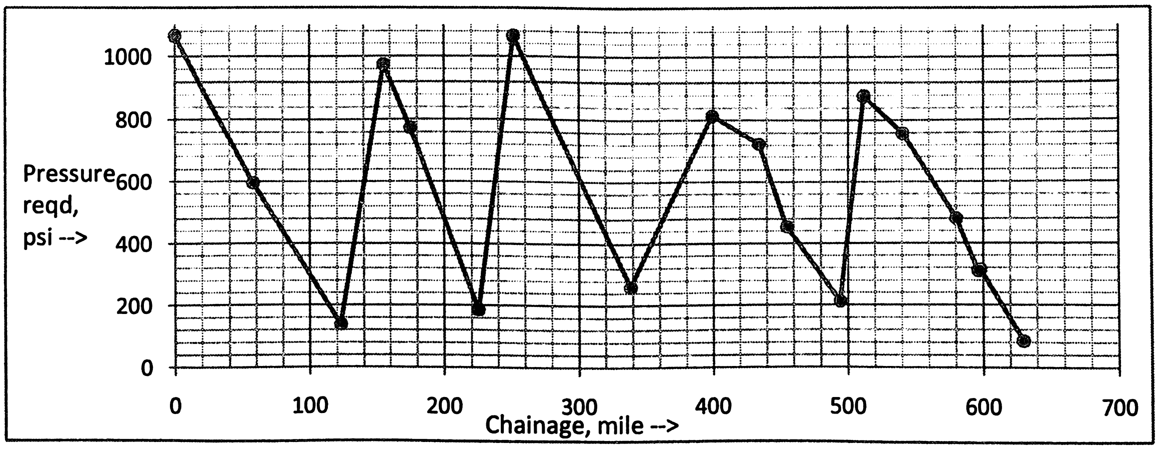

Figure 21: Hydraulic profile for API 5L X65, D = 22 inch, Thickness = 0.250 inch.

Table 28: Discharge pressures for API 5L, X65 grade, D = 22 inch, Thickness = 0.281 inch, P_f =7.64 psi/mile

location	Chainage, km	chainage, mile	Elevation feet	difference in elevation, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	1196
Bhachau	93	57.76	138	89	32.75	441.32	722
Santalpur	198	122.98	49	-89	32.75	498.26	257
Dev	250	155.28	112	63	17.73	246.76	1189
Juna raviyana	282	175.16	256	144	52.88	151.85	984
Bargaon	363	225.47	820	564	207.53	384.37	392
Bhadra	405	251.55	649	-171	62.93	199.30	256
Jhalwar	545	338.51	1050	401	147.5	664.35	640
Kantiya	643	399.38	1194	144	52.88	465.04	123
Sateran	699	434.16	728	-466	171.5	265.74	1196
Kakra	732	454.66	1043	315	115	156.60	924
Shri Dungargarh	796	494.41	886	-157	57.77	303.70	678
Alsisar	824	511.80	945	59	21.71	132.87	523
Sawar	870	540.37	682	-263	96	218.29	401
Topariyan	934	580.12	623	-59	21.7	303.70	119
Maujakhera	960	596.27	754	131	48.2	123.38	313
Nakaura	963	598.14	705	-49	18.03	14.24	317
Bhatinda	1014	629.81	676	-29	10.67	242.01	85

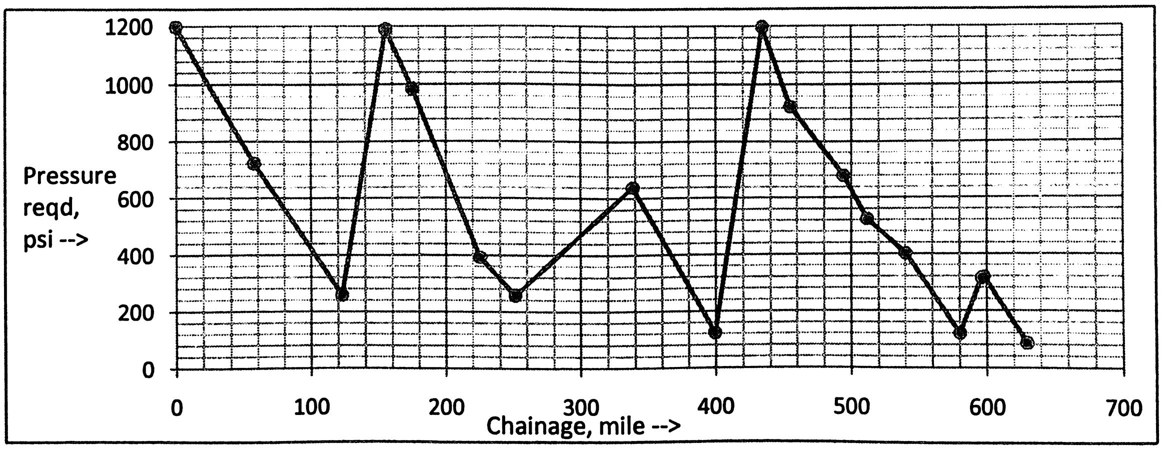

Figure 22: Hydraulic profile for API 5L X65, D = 22 inch, Thickness = 0.281 inch.

Table 29: Discharge pressures for API 5L, X65 grade, D = 22 inch, Thickness = 0.312 inch, P_f =7.75 psi/mile

location	Chainage km	chainage, mile	Elevation, feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	1327
Bhachau	93	57.76	138	89	32.75	447.67	847
Santalpur	198	122.98	49	-89	32.75	505.43	374
Dev	250	155.28	112	63	17.73	250.31	106
Juna raviyana	282	175.16	256	144	52.88	154.04	1226
Bargaon	363	225.47	820	564	207.53	389.91	629
Bhadra	405	251.55	649	-171	62.93	202.17	490
Jhalwar	545	338.51	1050	401	147.5	673.91	996
Kantiya	643	399.38	1194	144	52.88	471.74	471
Sateran	699	434.16	728	-466	171.5	269.57	373
Kakra	732	454.66	1043	315	115	158.85	100
Shri Dungargarh	796	494.41	886	-157	57.77	308.07	1058
Alsisar	824	511.80	945	59	21.71	134.78	902
Sawar	870	540.37	682	-263	96	221.43	777
Topariyan	934	580.12	623	-59	21.7	308.07	491
Maujakhera	960	596.27	754	131	48.2	125.16	318
Nakaura	963	598.14	705	-49	18.03	14.44	322
Bhatinda	1014	629.81	676	-29	10.67	245.50	86

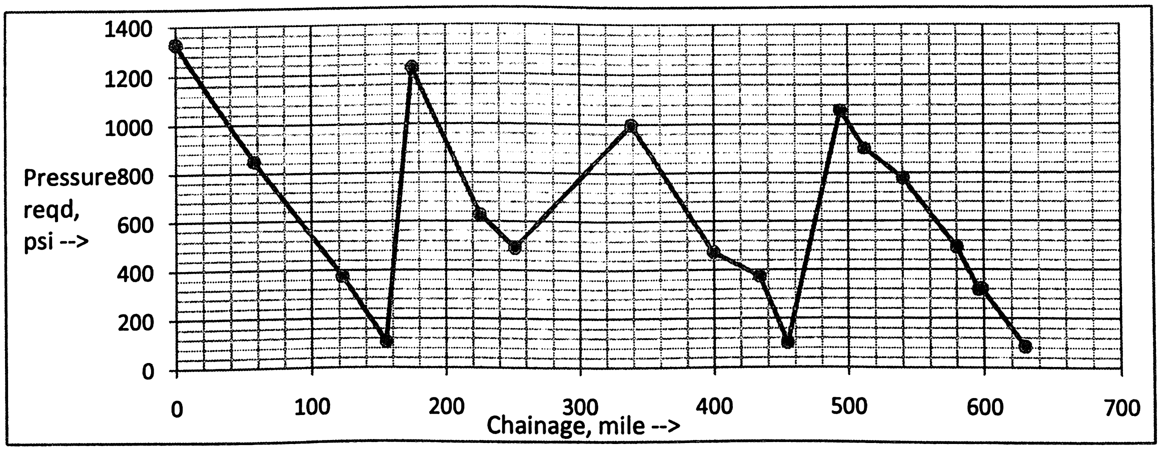

Figure 23: Hydraulic profile for API 5L X65, D = 22 inch, Thickness = 0.312 inch.

Table 30: Discharge pressures for API 5L, X65 grade, D = 24 inch, Thickness = 0.250 inch, P_f =4.92 psi/mile

location	Chainage km	chainage mile	Elevation, feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	975
Bhachau	93	57.76	138	89	32.75	284.20	658
Santalpur	198	122.98	49	-89	32.75	320.87	370
Dev	250	155.28	112	63	17.73	158.91	194
Juna raviyana	282	175.16	256	144	52.88	97.79	975
Bargaon	363	225.47	820	564	207.53	247.53	520
Bhadra	405	251.55	649	-171	62.93	128.35	455
Jhalwar	545	338.51	1050	401	147.5	427.83	855
Kantiya	643	399.38	1194	144	52.88	299.48	503
Sateran	699	434.16	728	-466	171.5	171.13	503
Kakra	732	454.66	1043	315	115	100.84	288
Shri Dungargarh	796	494.41	886	-157	57.77	195.58	151
Alsisar	824	511.80	945	59	21.71	85.57	570
Sawar	870	540.37	682	-263	96	140.57	525
Topariyan	934	580.12	623	-59	21.7	195.58	351
Maujakhera	960	596.27	754	131	48.2	79.45	223
Nakaura	963	598.14	705	-49	18.03	9.17	232
Bhatinda	1014	629.81	676	-29	10.67	155.85	85

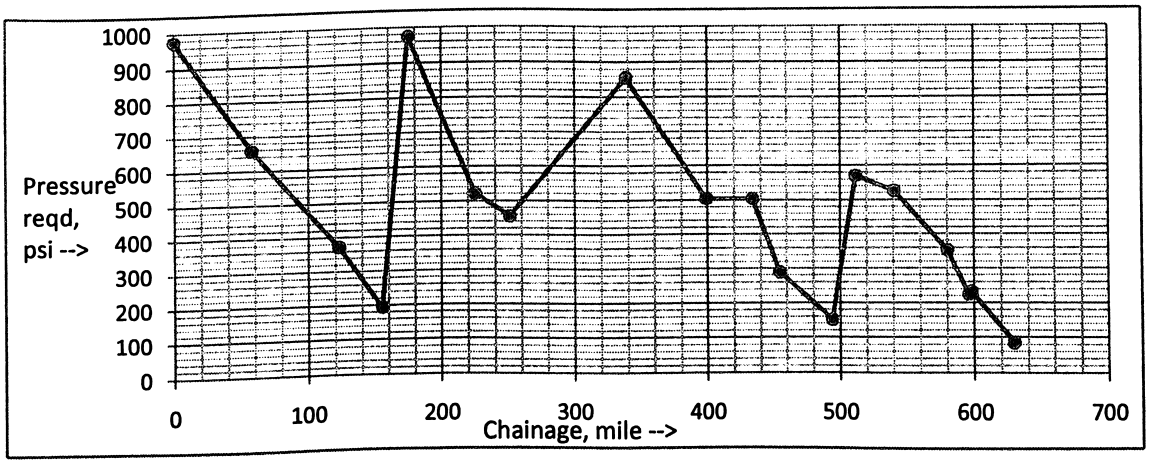

Figure 24: Hydraulic profile for API 5L X65, D = 24 inch, Thickness = 0.250 inch.

Table 31: Discharge pressures for API 5L, X65 grade, D = 24 inch, Thickness = 0.281 inch, P_f =4.98 psi/mile

location	Chainage km	chainage, mile	Elevation, feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	1096
Bhachau	93	57.76	138	89	32.75	287.66	776
Santalpur	198	122.98	49	-89	32.75	324.78	484
Dev	250	155.28	112	63	17.73	160.84	305
Juna raviyana	282	175.16	256	144	52.88	98.98	153
Bargaon	363	225.47	820	564	207.53	250.55	791
Bhadra	405	251.55	649	-171	62.93	129.91	724
Jhalwar	545	338.51	1050	401	147.5	433.04	144
Kantiya	643	399.38	1194	144	52.88	303.13	884
Sateran	699	434.16	728	-466	171.5	173.22	882
Kakra	732	454.66	1043	315	115	102.07	665
Shri Dungargarh	796	494.41	886	-157	57.77	197.96	525
Alsisar	824	511.80	945	59	21.71	86.61	417
Sawar	870	540.37	682	-263	96	142.29	371
Topariyan	934	580.12	623	-59	21.7	197.96	195
Maujakhera	960	596.27	754	131	48.2	80.42	225
Nakaura	963	598.14	705	-49	18.03	9.28	234
Bhatinda	1014	629.81	676	-29	10.67	157.75	85

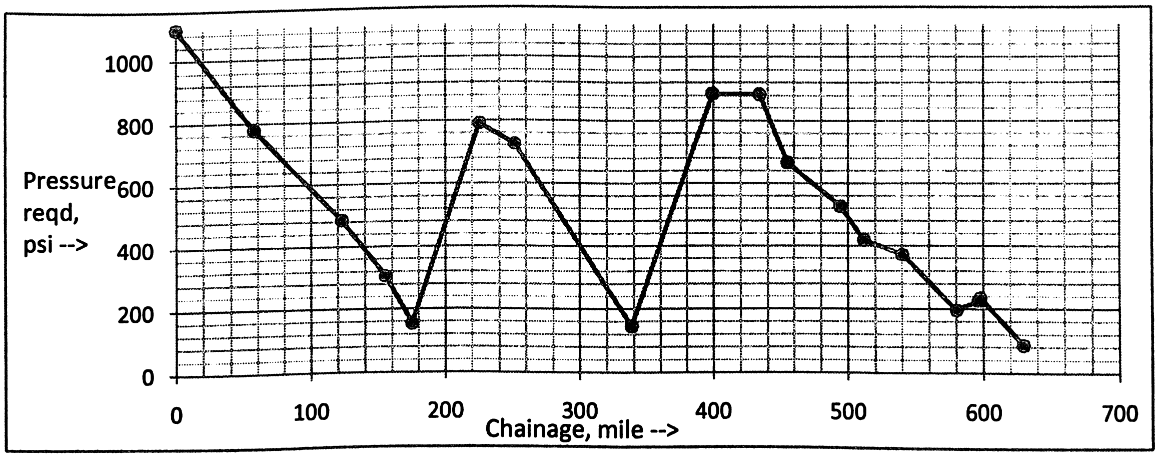

Figure 25: Hydraulic profile for API 5L X65, D = 24 inch, Thickness = 0.281 inch.

Table 32: Discharge pressures for API 5L, X65 grade, D = 24 inch, Thickness = 0.312 inch, P_f =5.05 psi/mile

location	Chainage km	chainage, mile	Elevation, feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	1217
Bhachau	93	57.76	138	89	32.75	291.71	893
Santalpur	198	122.98	49	-89	32.75	329.35	596
Dev	250	155.28	112	63	17.73	163.11	415
Juna raviyana	282	175.16	256	144	52.88	100.37	262
Bargaon	363	225.47	820	564	207.53	254.07	1017
Bhadra	405	251.55	649	-171	62.93	131.74	948
Jhalwar	545	338.51	1050	401	147.5	439.13	362
Kantiya	643	399.38	1194	144	52.88	307.39	1058
Sateran	699	434.16	728	-466	171.5	175.65	1054
Kakra	732	454.66	1043	315	115	103.51	836
Shri Dungargarh	796	494.41	886	-157	57.77	200.75	693
Alsisar	824	511.80	945	59	21.71	87.83	584
Sawar	870	540.37	682	-263	96	144.29	536
Topariyan	934	580.12	623	-59	21.7	200.75	357
Maujakhera	960	596.27	754	131	48.2	81.55	228
Nakaura	963	598.14	705	-49	18.03	9.41	237
Bhatinda	1014	629.81	676	-29	10.67	159.97	87

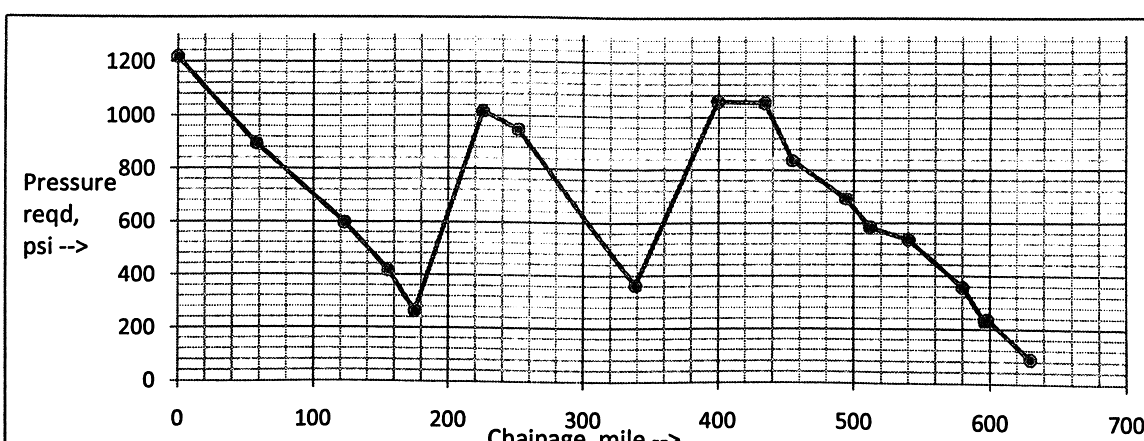

Figure 26: Hydraulic profile for API 5L X65, D = 24 inch, Thickness = 0.312 inch.

Table 33: Discharge pressures for API 5L, X65 grade, D = 26 inch, Thickness = 0.250 inch, P_f =3.33 psi/mile

location	Chainage km	chainage, mile	Elevation, feet	difference in elevation, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	900
Bhachau	93	57.76	138	89	32.75	192.35	675
Santalpur	198	122.98	49	-89	32.75	217.17	491
Dev	250	155.28	112	63	17.73	107.55	366
Juna raviyana	282	175.16	256	144	52.88	66.19	247
Bargaon	363	225.47	820	564	207.53	167.53	772
Bhadra	405	251.55	649	-171	62.93	86.87	748
Jhalwar	545	338.51	1050	401	147.5	289.57	311
Kantiya	643	399.38	1194	144	52.88	202.70	662
Sateran	699	434.16	728	-466	171.5	115.83	718
Kakra	732	454.66	1043	315	115	68.25	535
Shri Dungargarh	796	494.41	886	-157	57.77	132.37	460
Alsisar	824	511.80	945	59	21.71	57.91	381
Sawar	870	540.37	682	-263	96	95.14	382
Topariyan	934	580.12	623	-59	21.7	132.37	271
Maujakhera	960	596.27	754	131	48.2	53.78	169
Nakaura	963	598.14	705	-49	18.03	6.20	181
Bhatinda	1014	629.81	676	-29	10.67	105.48	86

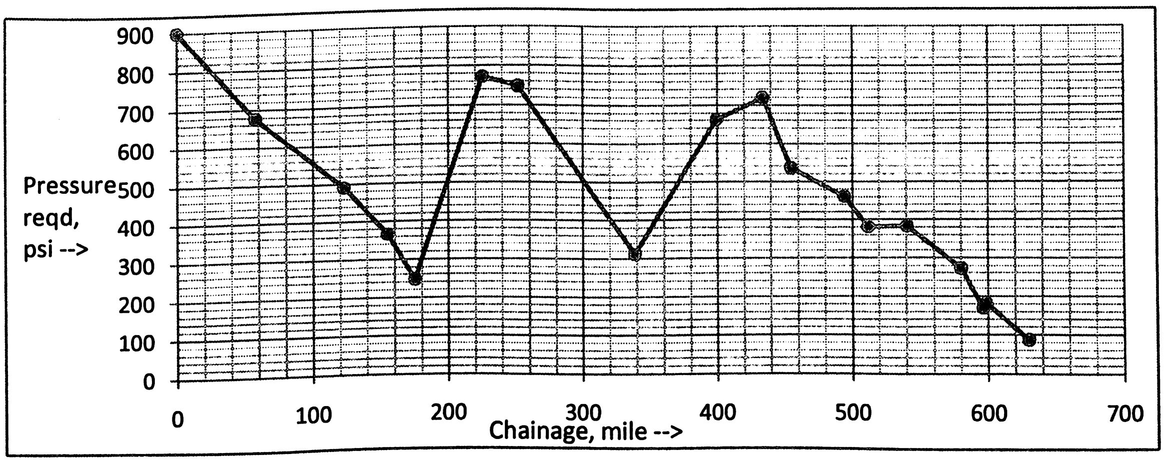

Figure 27: Hydraulic profile for API 5L X65, D = 26 inch, Thickness = 0.250 inch.

Table 34: Discharge pressures for API 5L, X65 grade, D = 26 inch, Thickness = 0.281 inch, P_f =3.37 psi/mile

location	Chainage km	chainage, mile	Elevation, feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f,psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	1012
Bhachau	93	57.76	138	89	32.75	194.66	785
Santalpur	198	122.98	49	-89	32.75	219.78	598
Dev	250	155.28	112	63	17.73	108.84	471
Juna raviyana	282	175.16	256	144	52.88	66.98	351
Bargaon	363	225.47	820	564	207.53	169.55	985
Bhadra	405	251.55	649	-171	62.93	87.91	960
Jhalwar	545	338.51	1050	401	147.5	293.04	520
Kantiya	643	399.38	1194	144	52.88	205.13	262
Sateran	699	434.16	728	-466	171.5	117.22	316
Kakra	732	454.66	1043	315	115	69.07	132
Shri Dungargarh	796	494.41	886	-157	57.77	133.96	472
Alsisar	824	511.80	945	59	21.71	58.61	391
Sawar	870	540.37	682	-263	96	96.29	390
Topariyan	934	580.12	623	-59	21.7	133.96	277
Maujakhera	960	596.27	754	131	48.2	54.42	174
Nakaura	963	598.14	705	-49	18.03	6.28	183
Bhatinda	1014	629.81	676	-29	10.67	106.75	86

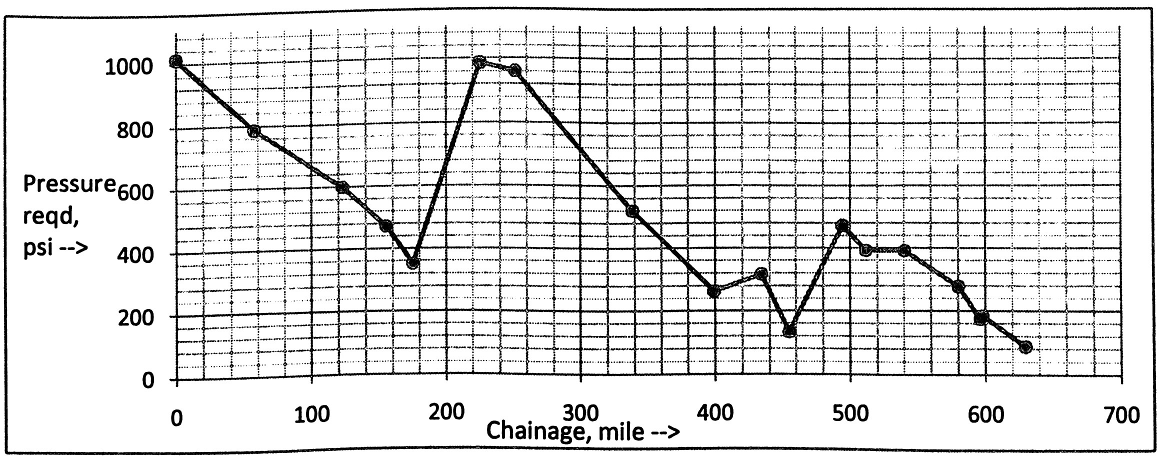

Figure 28: Hydraulic profile for API 5L X65, D = 26 inch, Thickness = 0.281 inch.

Table 35: Discharge pressures for API 5L, X65 grade, D = 26 inch, Thickness = 0.312 inch, P_f =3.40 psi/mile

location	Chainage km	chainage, mile	Elevation, feet	Elevation difference, feet	Pr. Loss due to elevation, psi	P_f, psi	Total pr. Reqd, psi
Mundra	0	0	49	0	0	0	1123
Bhachau	93	57.76	138	89	32.75	196.40	894
Santalpur	198	122.98	49	-89	32.75	221.74	705
Dev	250	155.28	112	63	17.73	109.81	578
Juna raviyana	282	175.16	256	144	52.88	67.58	457
Bargaon	363	225.47	820	564	207.53	171.06	79
Bhadra	405	251.55	649	-171	62.93	88.70	1123
Jhalwar	545	338.51	1050	401	147.5	295.65	680
Kantiya	643	399.38	1194	144	52.88	206.96	420
Sateran	699	434.16	728	-466	171.5	118.26	473
Kakra	732	454.66	1043	315	115	69.69	288
Shri Dungargarh	796	494.41	886	-157	57.77	135.16	211
Alsisar	824	511.80	945	59	21.71	59.13	130
Sawar	870	540.37	682	-263	96	97.14	129
Topariyan	934	580.12	623	-59	21.7	135.16	276
Maujakhera	960	596.27	754	131	48.2	54.91	172
Nakaura	963	598.14	705	-49	18.03	6.34	184
Bhatinda	1014	629.81	676	-29	10.67	107.70	86

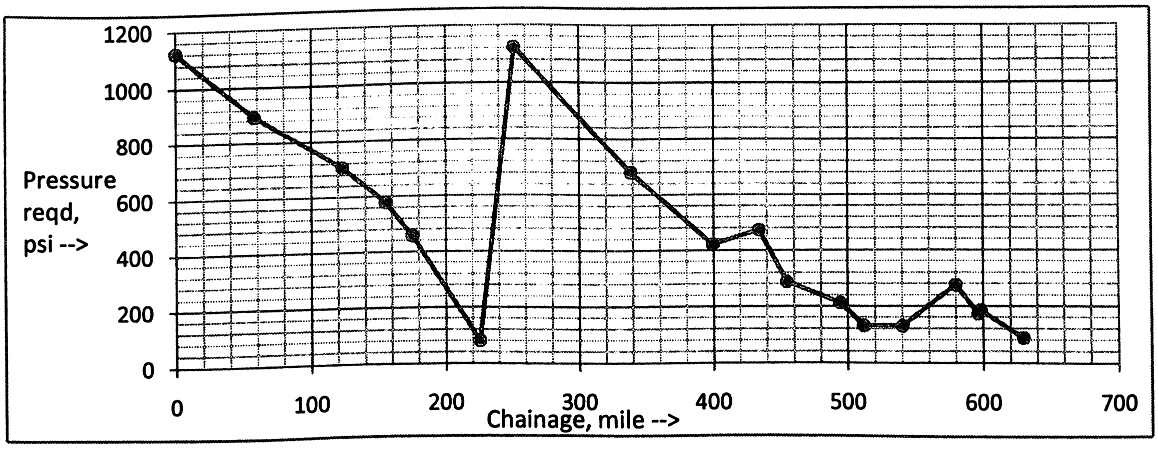

Figure 29: Hydraulic profile for API 5L X65, D = 26 inch, Thickness = 0.312 inch.

3.6.3 Profile analysis

Depending on the discharge pressure and the hydraulic profiles for all the grades and pipe sizes, the number of pumping stations required is determined so that the fluid can be transferred at a required velocity and pressure from the beginning to the end of the pipeline. The pipeline which requires the least number of pumping stations are selected and the remaining options are rejected from design. Almost all the grades and thickness in the diameter 22 inch require more number of pumping stations and hence they are removed. The selected grades and pipe sizes are given in table 36 below.

Table 36: Pipe sizes and grades which requires least number of pumping stations

Grade	Diameter, inch	Thickness, inch	Pumping stations required
X56	26	0.281	3
X56	26	0.312	3
X60	24	0.312	3
X60	26	0.250	3
X60	26	0.281	3
X60	26	0.312	3
X65	24	0.312	3
X65	26	0.250	3
X65	26	0.281	3
X65	26	0.312	3

Now the pump power required for all the above mentioned grades and pipe sizes are calculated.

3.7 Pump power calculation

The hydraulic horse power required is the power that has to be supplied to the pump by means of a prime mover so that the crude oil can be transported from source to the destination at the desired pressure. The power required for pumping one pump is given by the formula,

$$\text{Power required, } P = (Q * p) / (3600 * E)$$

Where,

Q = 1323 m^3/hour in our case

E = Combined efficiency, in our case it is taken as 0.75.

The pump power calculations are done as shown in APPENDIX 2. Each pump has an entry pressure of 6 kg/cm^2.The tabulation which includes the pump power for all the selected grades and sizes are shown in table 37.

Table 37: Pump power for selected grades and pipe sizes

Grades	Diameter, inch	Thickness, inch	Pumped pressure, kpa	Pump power, kw/hour
X56	26	0.281	5536	7467
X56	26	0.312	6212	7678
X60	24	0.312	7307	10742
X60	26	0.250	5249	7127
X60	26	0.281	5974	7431
X60	26	0.312	6700	7893
X65	24	0.312	7966	11162
X65	26	0.250	5736	7611
X65	26	0.281	6522	7726
X65	26	0.312	7307	7820

Upon analyzing the above table, it is clear that the power required for the diameter 24 inch for all grades is high which would directly increase the operational expenses of the pipeline. Hence these two options API 5L X60 D =24 and API 5L X65 D = 24 is taken off the consideration for design purpose.

3.8 Cathodic protection

Cathodic protection is the protection of the pipeline from being corroded. The term corrosion is discussed in following section clearly.

3.8.1 Corrosion & its mechanism

Corrosion can be generally defined as the degradation of material through environmental interaction. Corrosion is a natural phenomenon and cannot be completely eliminated but controlled to acceptable levels.

Corrosion occurs in aqueous environment and is electro chemical in nature. Corrosion process involves oxidation as well as reduction reaction and proceeds as follows:

$Fe \rightarrow Fe^{++} + 2e^-$

$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$

Oxidation reaction is generally known as anodic and reduction reaction is known as cathodic reaction. Corrosion can occur only when the conditions like presence of an anode, presence of a cathode, presence of a metallic path connecting the anode with cathode and finally the anode and cathode must be immersed in a electrically conductive electrolyte.

3.8.2 Cathodic protection

It is the technique to reduce the corrosion rate of a metal surface by making it cathode of the electrochemical cell. At the anode areas current flows from pipeline and gets corroded. At cathodic areas, the current flows from the electrolyte on to the pipe surface and corrosion is reduced.

Cathodic protection is carried out in two ways which are cathodic protection with galvanic anodes and cathodic protection with impressed current. In the galvanic anode method a very active metal is connected electrically with the underground pipeline to be protected. The active metal being at higher potential with respect to pipeline metal shall discharge current on the pipeline and thus making the anodic area cathodic. Galvanic anodes are made of materials like alloys of magnesium, zinc or aluminum.

Whereas in impressed current cathodic protection system, the only difference is that a current source is used to facilitate the driving voltage. The most common power source is a rectifier in which alternating current is converted to direct current. The current can be altered to required levels. Materials used for impressed current cathodic protection are graphite, silver alloy and so on.

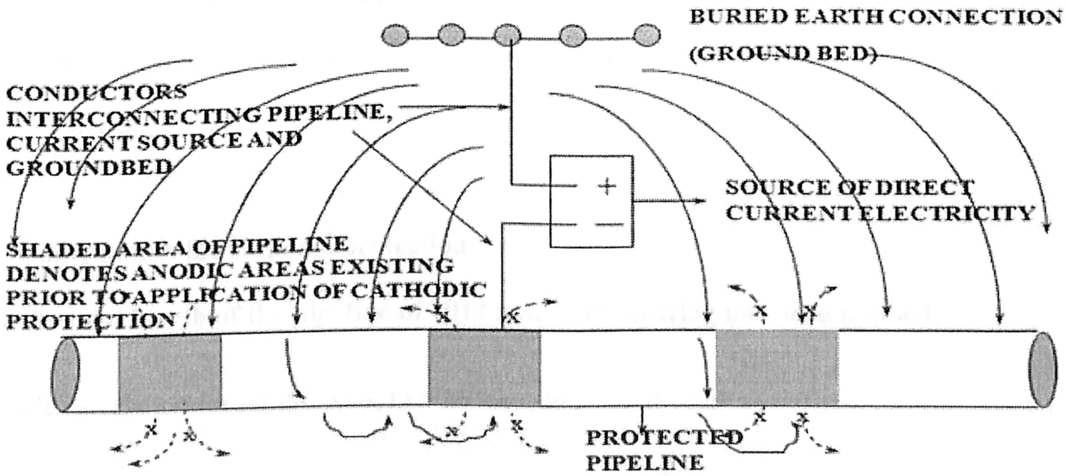

Figure 30: Impressed current cathodic protection system

3.8.3 Criteria for cathodic protection

According to a number of research for decades, the NACE committee has landed up with certain norms that have been listed in section 6 of NACE standard RP-01-69 and must be followed for a cross country pipeline impressed current cathodic protection. The following mentioned below are the criteria for protection of steel structures as per NACE.

- A negative potential of at least 850 mV with the cathodic protection must be applied to the structure and this has to be measured with respect to Cu/CuSO4 reference electrode containing the electrolyte. Voltage drops other than those across the structure to electrolyte boundary must be considered for valid interpretation of the voltage measurement.
- A negative polarized potential of minimum of 850 mV as measured between the structure surface and a saturated Cu/CuSO4 reference electrode contacting the electrolyte.
- A minimum of 100 mV of cathodic polarization should be present when measured between the structure surface and a stable Cu/CuSO4 half cell containing the electrolyte. This decay of polarization can be found out, which would satisfy the above mentioned criterion.

3.8.4 Calculation for cathodic protection

For the total length of the pipeline of 1014 km, 3LPE coating has been applied.

Sample calculation for API5L X56, D = 26 inch, WT = 0.281inch.

Outer diameter of pipeline = 0.6604 meter.

Thickness of pipeline = 7.1mm.

R_L = Coating leakage resistance per meter = $1/(ga_l Lp)$

Where, g = Coating leakage conductance = 50 Micro mhos/m^2, a_l=Unit surface area per meter of pipe, Lp = Unit length of pipe = 1 meter.

$R_L = 1/(50 \times 10^{-6} \times 0.6604 \times 1 \times \pi) = 9640$ Ohms.

$R_S = \rho Lp/a$, where, ρ = Steel resistivity $= 2.2 \times 10^{-7}$

$Rs = 2.2 \times 10^{-7} \times 1/(\pi/4(0.6604^2-0.6462^2)) = 1.50 \times 10^{-5}$ Ohms.

α = Attenuation constant = square root $(Rs/R_L) = 3.94 \times 10^{-5}$.

$L = Log_n(E_A/E_T)/\alpha$

Taking potential at drainage = E_A = -1.25 V

Potential at the end of drainage point E_T = -0.45V, potential from both directions = 0.225.

$L = (Logn\ E_A/E_T)/\alpha$ = 44 Km.

Hence the CP stations must be placed at a distance of 44 km from each other.

Therefore for a length of 1014 km, 23 CP stations have been used.

CHAPTER 4

COST ESTIMATION OF THE CRUDE OIL PIPELINE

4.0 Cost estimation

In any pipeline design, the cost of the pipeline must be determined after the design phase to check whether the given pipeline design is feasible or not. Pipeline expenses not only include the initial cost for laying the pipeline but also consist of the operational costs. So both installation and the operating or maintenance expense must be considered in choosing the optimum design. Often a design having a lower installation cost than another alternative will be more expensive to operate. When compared based on economic indicators over the life of the system, the design with the lowest cost may not be the best solution.

Capital costs mainly consists of the pipeline cost along with its coating expenses, pipeline laying labor cost, pump stations and related equipments, valves and fittings, ROW acquisition, field surveys, line pipe materials, SCADA and telecommunication, tanks and manifold piping, and other project costs.

Operating costs mainly consists of pump operation cost, pipeline maintenance costs including line rider cost, CP survey, consumption of power and water, intelligent pigging, spare parts, man power used and so on.

After analyzing the capital costs and the operating costs together, we could complete the design part of the pipeline by selecting the suitable pipeline with less number of pumping stations and which operates at an optimum expense which could satisfy the conditions of profits to the organization and meeting the required demand.

The details of the capital costs and operating costs for all the grades and dimensions of pipeline are shown in table 40 and table 41.

Table 40: Capital costs in Rupees

Capital costs	Comment	Cost for X56,WT= 0.281×10^6	Cost for X56,WT= 0.312×10^6	Cost for X60,WT= 0.25×10^6	Cost for X60,WT= 0.281×10^6	Cost for X60,WT= 0.312×10^6	Cost for X65,WT= 0.25×10^6	Cost for X65,WT= 0.281×10^6	Cost for X65,WT= 0.312×10^6
Pipeline cost(coated)	1200$ for X56, 1400$ for X60, 1500$ for X65 Grades. 1$=INR 44	6778	7516	7043	7907	8769	7547	8472	9396
Pipe labour cost	Depends on the contractor	7100	7100	7100	7100	7100	7100	7100	7100
Pump station & equipment	3 pump stations	1200	1200	1200	1200	1200	1200	1200	1200
Valves & fittings	15% of line pipe	1016	1127	1056	1186	1315	1132	1270	1409
ROW acquisition	500 acres at 3 lakhs per acre	150	150	150	150	150	150	150	150
Field surveys		70	70	70	70	70	70	70	70
Line pipe materials		205	215	225	250	275	230	255	280
SCADA & telecommunication		264	264	264	264	264	264	264	264
Tanks & Manifold piping		7000	7000	7000	7000	7000	7000	7000	7000
Other project costs	20% of pipe cost	1355	1503	1408	1581	1753	1509	1694	1879
Total capital cost(sum)		2513	2614	2551	2670	2789	2620	2747	2874

Table 41: Operating cost in Rupees

Operating cost	Comment	Cost for X56,WT = 0.281 $\times 10^6$	Cost for X56,WT= 0.312 $\times 10^6$	Cost for X60,WT = 0.250 $\times 10^6$	Cost for X60,WT = 0.281 $\times 10^6$	Cost for X60,WT = 0.312 $\times 10^6$	Cost for X65,WT = 0.250 $\times 10^6$	Cost for X65,WT = 0.281 $\times 10^6$	Cost for X65,WT = 0.312 $\times 10^6$
Pump operation cost	8000 hours of operation at Rs.5/kwh	298.6	307.1	285.0	297.2	315.7	304.4	309.0	312.8
Pipeline maintenance cost, line rider, cp survey		25	25	25	25	25	25	25	25
Consumption of power, water	Utility & others	30	30	30	30	30	30	30	30
Intelligent Pigging operation	Once in ten years at Rs.6500/m	6591	6591	6591	6591	6591	6591	6591	6591
Spare parts		25	25	25	25	25	25	25	25
Man power		30	30	30	30	30	30	30	30
Total Operating cost		6999	7008	6986	6998	7016	7005	7010	7013

Table 42: Total cost for all grades and sizes

Grades & pipe sizes API 5L	Total capital cost, Rupees	Total operating cost, Rupees	Total cost, Rupees in crores
X56,D=26,WT=0.281	25139478784	6999680000	3213.9158784
X56,D=26,WT=0.312	26146716054	7008120000	3315.4836054
X60,D=26,WT=0.250	25518275979	6986080000	3250.4355979
X60,D=26,WT=0.281	26709558581	6998240000	3370.7798581
X60,D=26,WT=0.312	27898002063	7016720000	3491.4722063
X65,D=26,WT=0.250	26202509978	7005440000	3320.7949978
X65,D=26,WT=0.281	27477098479	7010040000	3448.7138479
X65,D=26,WT=0.312	28748645068	7013800000	3576.2445068

CHAPTER 5

CONCLUSION

5.0 Conclusion

The pipeline design and cost estimation is done for API 5L X56, X60, X65 grades of pipeline of different diameter and thickness and the following results have been deduced from our calculations and analysis.

After determining the costs for the pipelines, it is clearly seen that for API 5L X56 grade pipeline with a diameter of 26 inches and wall thickness of 0.281 inches, the capital and operating expenses are optimum.

Hence for the proposed project for laying of a crude oil pipeline from Mundra (Gujarat) to Bhatinda (Punjab) for a length of 1014 kilometers, we use API 5L X56 pipe grade of diameter 26 inches and wall thickness 0.281 inches. The location of pumping stations from Mundra to Bhatinda is shown in table 43.

Table 43: Location of pumping stations for Mundra-Bhatinda crude oil pipeline

Pumping station	Location	Location(State)
Pumping station 1	Mundra	Gujarat
Pumping station 2	Bargaon	Rajasthan
Pumping station 3	Kantiya	Rajasthan

5.1 Future work and recommendations

- The current project work is a basic design of a crude oil pipeline and there is a lot of scope for refinement. The design of canals, river, rail and road crossings are to be carried out individually in a detailed manner.
- The pipeline is designed with a safety factor of 0.72 for whole length as per ASME B31.4 which may vary for various crossings and other locations.
- The cost estimation can be done in a more detailed manner for better decision making. Some values taken into account for the cost analysis is approximate values taken from earlier pipeline projects and industries.
- The pipeline design has the same wall thickness and grade throughout the length. Telescoping pipe wall thickness and Grade tapering can be done to further reduce the pipeline project costs.

APPENDIX 1

Calculation of Total Discharge Pressure

The total discharge pressure calculation for API 5L X56 grade pipe, with Diameter 22 inches and thickness 0.250 inches .three sections Mundra, Bhachau and Santalpur are considered to illustrate the calculation of total discharge pressure.

Table 44: Sample table for total discharge pressure calculation

Location	Chainage (mile)	Elevation(feet)	Elevation difference (feet)
Mundra	0	49	0
Bhachau	57.76	138	89
Santalpur	122.98	49	-89

The MAOP of the pipe is 916 psi and hence this is the total pressure at Mundra.

At Bhachau the pressure will be reduced considering the frictional pressure loss and pressure drop due to elevation, hence total pressure at Bhachau is given by:

Pressure drop due to elevation = (138-49)*0.85/2.31= 32.75 psi .This is done to convert the difference in elevation to change in pressure .i.e. to convert feet to psi.

Pressure drop due to friction = (7.54 * 57.76) = 435.51 psi for that section of pipe.

Total pressure at Bhachau = 916 – (32.75 + 435.51) =447.75 = 448

At Santalpur, pressure drops due to friction and a considerable pressure increases due to reduction in elevation.

Pressure gained due to elevation = (138-49) *0.85/2.31= 32.75 psi

Pressure lost due to friction = (7.54 * 65.22) = 491.74 psi

Total pressure at Santalpur = 448+32.75 – 491.74 = -10.99 psi.

But pressure value cannot be in negative, so a pump is used at some distance before Santalpur and the pressure is again increased to the MAOP of the pipe. Hence total pressure at Santalpur is 906 psi.

Similarly calculations are done for the entire length of the pipeline and the locations where the total pressure reduces to the required pressure at the inlet of the pump i.e. pump entry pressure, in our case it is 6 kg/cm^2, next pump is deployed. Similar calculations are done for all the grades of pipe and all the dimensions of the pipeline.

APPENDIX 2

Pump Power Calculations

The pump power required for API 5L X 56 grade with diameter 26 inches and thickness 0.281 inches is calculated and shown. The calculation is similar for other grades and pipe sizes.

Let us assume that each pump has an entry pressure of 6 kg/cm^2.Hence this value must be deducted from the total pressure being pumped.

Power Required, P = (Q * p)/ (3600 * E)

Where,

Q = Flow rate, m^3/hour = 1323 m^3/hour in our case.

p = Pressure, kPa. In our case, 61.36 – 6 = 55.36 kg/cm^2 = 5536 kPa.

P = (1323 * 5536)/ (3600 * 0.75) = 2713. This value is for one pump, for two pumps it is (2713 * 2) = 5425 kw /hour.

Total number of pumps is three, but the last pump is not pumping at full power. Calculating pump power for the last pump, depending on the pressure required from that pump.

Last pump pressure = 47.66 – 6 = 41.66 kg/cm^2 = 4166 kPa.

P = (1323 * 4166)/(3600 * 0.75) = 2041.34 kw/hour.

Total Pump Power = 5425 + 2041.34 = 7467 kw/hour.

REFERENCES

1) E.Shashi Menon, "Liquid Pipeline Hydraulics", Marcel Dekker, Inc, New York, 2004.

2) E.Shashi Menon, "Gas Pipeline Hydraulics", Taylor and Francis Group, France, 2005.

3) Henry Liu, "Pipeline Engineering", 2nd Edition, Lewis Publishers, New York, 2003.

4) API Specification 5L, "Specification for Line Pipe", 41st Edition, American Petroleum Institute, Washington, 2001.

5) ASME B31.4- "Pipeline Transportation System for Liquid Hydrocarbons and other Liquids", American society of Mechanical Engineers, 2006.

6) Mohitpour. M, Golshan. H, Murray. A, "Pipeline Design and Construction- A Practical Approach", 2nd Edition. McGraw- Hill, New York, 2000.

7) Moser.A.P, "Buried Pipe Design", 2nd Edition. McGraw- Hill, New York, 2001.

8) Peabody,"Control of Pipeline Corrosion", 2nd Edition, NACE international corrosion society, 2001.

9) Google Earth- Wikimapia.