DESIGN OF CROSS COUNTRY PIPELINE FOR LIQUID PETROLEUM

PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR

MASTER OF TECHNOLOGY

(PIPELINE ENGINEERING)

P.BALAJI

(R160205001)

UNDER THE GUIDENCE OF

Mr. R. P. Shriwas
Co-ordinator, M.Tech, (PLE)
UPES

UNIVERSITY OF PETROLEUM AND ENERGY STUDIES

DEHRADUN

2007

LIMAK GAMMON

CERTIFICATE

This is to certify that Mr.P.Balaji, a student of M.Tech (Pipeline Engineering) in University of Petroleum and Energy Studies, Dehradun has done his project on "Designing a Cross Country Pipeline For Liquid Petroleum" for the period Feb 28, 2007 to April 30, 2007.

His performance in the project was very good.

Sunil Kumar

N. Sunil Kumar,

(Const Manager)

LIMAK - GAMMON CONSORTIUM

GAMMON HOUSE, VEER SAVARKAR MARG, P. O. BOX NO. 9129, PRABHADEVI, MUMBAI-400 025. INDIA.
Telephone : 91- 22 - 5661 4000 • 2430 6761 • Fax : 91 - 22 - 56614196
E-Mail : pmi@gammonindia.com • Website : www.gammonindia.com

UNIVERSITY OF PETROLEUM & ENERGY STUDIES

CERTIFICATE

This is to certify that project work entitled **"DESIGN OF CROSS COUNTRY PIPELINE FOR LIQUID PETROLEUM"** is the bonafide work of **P. BALAJI** from **University of Petroleum & Energy Studies, M. Tech (Pipeline Engineering)** who carried out the work under joint supervision of Mr. Sunil Kumar, Gammon India Limited, Mumbai, and myself. This work has not been submitted anywhere else for a degree.

17.05.2007

Mr. R. P. SHRIWAS
CO-ORDINATOR
M.Tech, (PIPELINE ENGG)
UNIVERSITY OF PETROLEUM AND ENERGY STUDIES
DEHRADUN

17.05.07

Corporate Office :
Hydrocarbons Education & Research Society
3rd Floor, PHD House. 4/2, Siri Institutional Area
August Kranti Marg, New Delhi-11001 India
Ph + 91-11-41730151-53 Fax : +91-11 1730154

Main Campus :
Energy Acres, PO Bidholi, Via Prem Nagar,
Dehradun-248 007 (Uttaranchal) India
Ph. : +91-135-2261090-91, 2694201/203/208
Fax : +91-135-2694204

Regional Centre (NCR) :
SCO 9-12, Sector-14, Gurgaon 122 007
(Haryana), India
Ph : + 91-124-4540300
Fax : +91 124 4540 330

ACKNOWLEDGEMENT

This is to acknowledge with thanks the help, guidance and support that we have received during the training.

I am greatly indebted to my guide Mr. Sunil Kumar (Const Mgr.), Gammon India Limited, for his able guidance and support.

I have no words to express a deep sense of guidance to the management of Gammon India Limited for giving us an opportunity to pursue our project and in particular Mr. P. M. Jaccal (President, Pipeline department) Mr. B. Saravana Kumar (Sr. Mgr.), and Mr. D. C. Gupta (Dy. Mgr.) for their able guidance and support.

I must also thank Dr. B.P. Pandey, Dean, University of Petroleum and Energy Studies and Mr. R. P. Shriwas, Co-ordinator, Pipeline Engineering Department, UPES for his valuable support and guidance.

I also place on record our appreciation of the support provided by staff of various departments of Gammon India Limited.

P.BALAJI

M.Tech (Pipeline Engineering)
University of Petroleum and Energy Studies
Deharadun.

ABSTRACT

It is interesting to note that liquid – petroleum pipeline system have been in operation since the late 1800s, a number of different commodities are also transported via pipeline, with widely varying properties, and every design bring out a new facet towards technical and techno – commercial aspects.

This project is a hypothetical design on an oil pipeline systems, has been prepared as a basic guide to the design of cross country pipelines for liquid petroleum products, for 400 km cross country pipeline to transport crude oil from source to destination with an average flow rate of 30000 m^3/ day.

My work focused on the fundamentals of pipeline design, emphasizing practical guidelines for real systems. It provides a general overview of the system approach to hydraulic design aspects, pipeline system components such as number of pump station required and mechanical design aspects, in the design of a system, along with project economic analysis, in determining the preferred pipeline system.

CONTENTS

1.0 INTRODUCTION

In the design of an oil transportation system, it is necessary to consider many aspects of design and operation as well as project economics in determining the preferred pipeline system to transport commodity from a source to a destination. On a technical or engineering level, there are three aspects of design which are interrelated in the system approach to design

- Hydraulic
- Mechanical
- Operation and maintenance

Decisions in one area of design directly affect, or limit, the options in another area. For example, it may be necessary to locate a pump station such that it is accessible, for example, on a main road, near an electrical power source. Thus the pipeline route will have an intermediate location point set, in addition to the origin and terminal points. Likewise, preliminary design and cost estimating are not separate and independent procedures but are instead closely related and proceed concurrently.

The hydraulic design is the process of evaluating the physical characteristics of the commodity to be transported, the quantities to be transported, the pipeline route and topography, and the range of pressures, temperatures, and environmental conditions along the route. Identifying the number and location of pump stations with respect to the hydraulic characteristics of the system is also part of the hydraulic design. There may be several viable hydraulic designs for any given pipeline-design basis and route. The most feasible is identified in conjunction with the owner or operator of the system, giving consideration to early use requirements and future capacity plans for the system.

For any one hydraulic design there are a number of mechanical system designs that can be developed to meet the criteria of the design basis and deliver the commodity from origin to destination. The mechanical design is governed by the codes and standards developed from experience in operating petroleum pipeline systems, and focuses on selection of pipe material and specification of physical line-pipe properties such as pipe diameter and wall thickness as required by the stresses imposed on the system by the hydraulic and thermal conditions, yet with in the limits set by the code. Other aspects of the mechanical design include the type, size and power required of pumps and other equipment or ancillary facilities required to meet the hydraulic-thermal design, such as heating stations, and the support or burial requirements for the pipeline.

The final aspects of design take into consideration the day to day tasks of operating and maintaining the functional integrity of the system. These include the necessary control systems to operate the system within its design parameters and to promote safe and continuous operation.

The preferred pipeline system for a given set of conditions is selected through an economic comparison of several systems, seeking to identify the system that yields the best economic return on the investments, depending on the initial and subsequent capital costs, the method of financing, and the operating and maintenance cost for the economic life of investment. If alternatives require capital investments, example, for pumping stations, at different future dates, then these costs should be compared on a present value basis, discounted at a real interest rates, to ensure a valid, unbiased selection of a preferred system.

Concurrent with the hydraulic, mechanical, and operation and maintenance designs, the pipeline projects team will also be performing many tasks related to the construction of the pipeline. These include technical and environmental surveys of the pipeline route and surrounding areas, preparation of environmental impact reports, acquisition of permits and rights of way, procurement of construction materials, development of construction costs considering pipe diameter, wall thickness, grade of steel and welding procedures, and preparation of contract specifications and bidding papers.

The investigation of any pipeline system begins by establishing the design basis, for the commodity, then making a preliminary selection of pipe diameters and cost estimates for comparative economic attractiveness. If preliminary estimate indicates that further consideration is desirable, then preliminary feasibility begin by selecting possible routes and developing a preliminary design.

1.1 ROUTE SELECTION

Give the task of transportation a liquid commodity from one point to another whether it is from the point of production or storage to a processing plant, or from the process plant to distribution facilities, the first selection of route will logically be the shortest course, or a straight line.

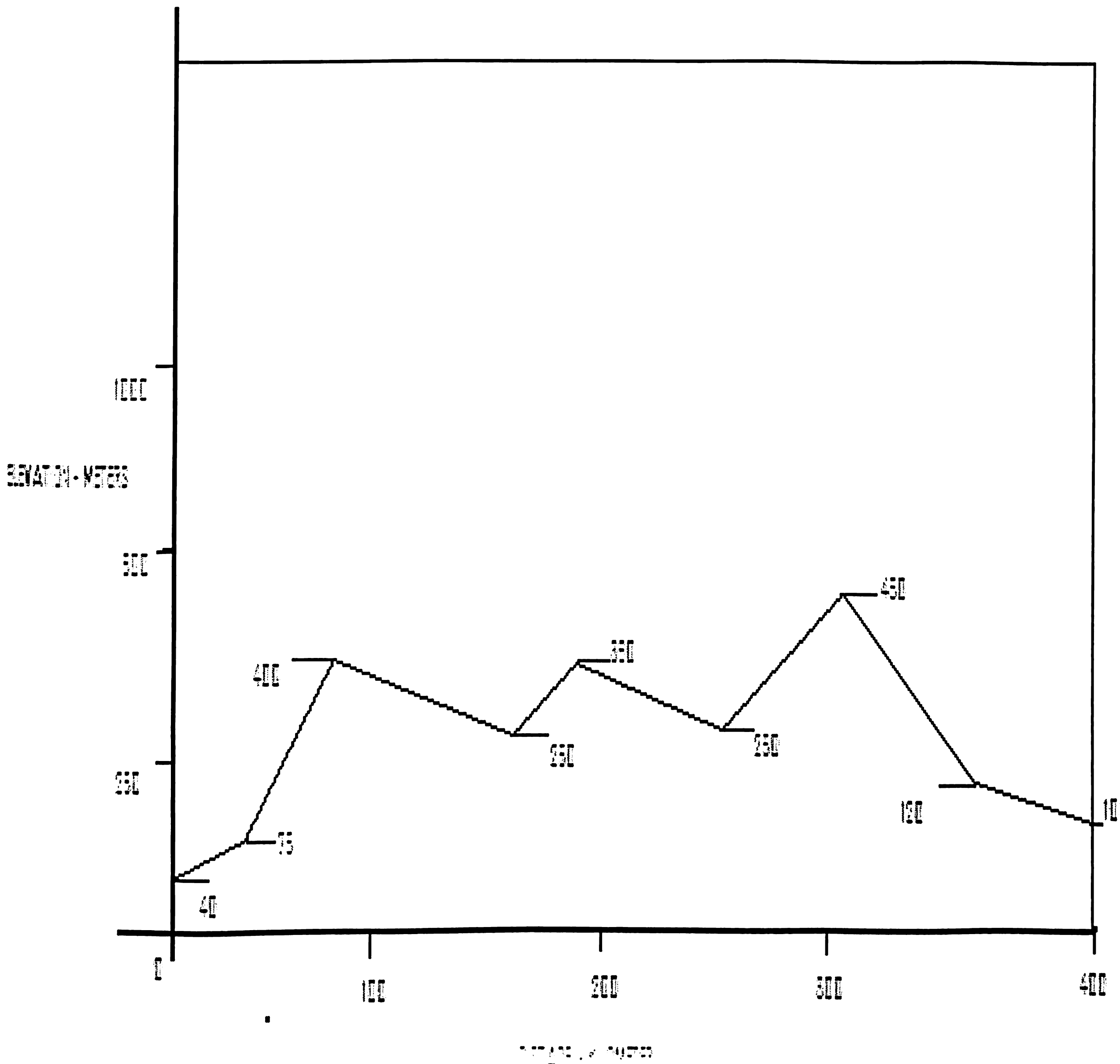
While a straight line route is a reasonable first approximation of the pipeline route, there are several common-sense reasons for deviation, including

- Significant natural obstacles such as mountain ranges, rivers, swamps, etc,
- Minimizing of control points in the hydraulic profile
- Access for construction equipment and materials.
- Permitting restrictions.

A preliminary route is determined using suitable maps of the area which need to show geographic feature such as contour lines as well as towns, roads, rivers, railroads, existing pipelines and utility corridors, etc., aerial photographs are also useful.

Several of the factors which will influence the selection of the design route may not readily identifiable or resolved until later phases of design, in particular, environmental and permitting requirements and land acquisition. However, a preliminary route can be selected and later modified when more information on the specific and final route is available. Once an initial route is identified, the ground profile is plotted for use in the hydraulic design

1.2 ROUTE PROFILE



GENERAL ASPECTS OF DESIGNING A PIPELINE FOR TRANSPORTING LIQUID PETROLEUM

2.0 LIQUID- PETROLEUM PIPELINE SYSTEM

There are number of different commodities are transported via pipeline, with widely varying properties. There fore to begin the discussion of liquid petroleum pipeline systems, it is useful to illustrate some of the characteristics of fluids covered by ASME B 31.4 code.

2.1 TYPES OF PETROLEUM COMMODITIES

ASME B 31.4 covers a wide range of petroleum liquid commodities like

- Crude oils
- Residuals
- Diesel oil
- Jet fuels
- Gasoline
- Natural gas liquid
- Oil water emulsion
- Anhydrous ammonia
- Alcohols
- Carbon dioxide

The physical properties of these commodities are also variable, and each pipeline system design is based on the specific properties of an identified commodity, or group of commodities in the case of multiproduct pipeline system.

2.2 HYDRAULIC DESIGN

The hydraulic design integrates the physical characteristics of the transported commodity along a given pipeline route, with in specified operating conditions as established in the design basis. The result of the hydraulic design is identification of the total system energy required to meet the design criteria. In addition, the hydraulic calculations indicate a range of feasible pipe diameters and preliminary spacing of pump stations along the route.

When the design is finalized, i.e., the route selected, pipeline size determined, and type of pipe selected, the hydraulic calculations are refined to determine the conditions for over pressure control during line shut of and surges during operation. Hydraulic calculations are also made for variables in the operating conditions (temperature, ranges of viscosities for products pipelines.etc, and for future expansion of system capacity.

2.2.1 DESIGN BASIS

When beginning the design basis of a pipeline system, it is necessary to define the basis of the design as completely as possible. The general parameters which are required for the design of the design include

- System operating parameters, such as design through put or flow rate, operating temperature of the system.
- Environmental conditions, such as ambient ground and air temperature (average and extremes)
- Properties of the transported fluid, such as viscosity, relative density, vapor pressure, and pour point temperature.

2.2.1.1 SYSTEM PARAMETERS

There are number of system parameters which are typically defined by the operating company or owner of the system. It is helpful for the design flow rate for the system to be defined as closely as possible. Maximum, minimum and forecast future daily or annual throughputs of the pipeline system are required for good design, resulting in selection of the economically preferred line size as early as possible. This limits the iterations of the design as well as the range of alternatives.

The design throughput of an oil pipeline may vary by year and is usually expressed as the average daily flow rate in barrels per day (BPD) or 1000 m3 per calendar day, or million tons per annum (MTA), which requires conversion to daily rates of computation. The actual flow rate that a system must be capable of attaining to compensate for last capacity from shutdowns and reduced flow conditions is the flow rate per operating day BPOD, or 1000m3 per day, which is greater than the flow rate per calendar day to operating day is the load factor.

Load factor = flow rate per calendar day/ flow rate per operating day

A well- operated pipeline can be expected to have a load factor of 92 to 95 percent. For domestic pipelines, this may be used in the design procedures unless special circumstances dictate a lower factor. Pipelines to be located in remote areas, more complex systems with many pump stations, or pipelines operated with expected flow variations would be more reasonably designed to a lower load factor, 85 to 90 percent, to account for greater system downtime, i.e., from interruptions in services as a result of operations and maintenance.

2.2.1.2 ENVIRONMENTAL PARAMETERS

The critical environmental parameter for the hydraulic design is the ambient temperature of the ground, for buried pipelines, or the air for above ground pipeline systems. Most location will have seasonal variations, and long pipeline system may have variations over the length of the system. It is important to identify the mean or average ambient temperature as well as the seasonal and local extremes.

2.2.1.3 PROPERTIES OF THE COMMODITIES

Specification of the commodity to be transported includes identification of viscosity, density, vapor pressure and pour point temperature. Some of these properties will have to be determined from laboratory test on specific commodity samples. However, design may proceed on the basis of typical commodity and include flexibility for a specified range of variation.

Viscosity is the physical property of fluids which resist flow and, for liquids, varies inversely with temperature. Besides density, viscosity is the key characteristic of the fluid to be considered in the design of liquid pipelines, having a significant effect on determining line size, station spacing, and pumping power requirements.

As per ASME B 31.4. Code the following are the characteristics for general crude.

- Commodity : General crude oil
- Temperature range : 4°C to 70°C
- Relative density : 0.84
- API gravity : 12 – 40
- Viscosities at 20° C : 11 cSt
  at 50° C : 4.1 cSt
- Pour point temperature : 13°C
- Vapor pressure : 15 kPa

2.3 HYDRAULIC GRADIENT

The hydraulic gradient is a profile representing the static head at any point in the system, relative to a common datum elevation, which is usually mean see level. Ground elevation is represented by the route elevation profile to the same datum. Energy added to the system through a pump station is plotted above the elevation profile. Head losses from friction, etc, are also shown graphically. For a pipeline system with constant parameters along with the system, such as viscosity, relative density and diameter, the hydraulic gradient will be a straight line with a slop equal to the friction loss per unit of length for specific flow rate. Therefore, the actual pressure in the pipeline at any point is the difference between the hydraulic gradient and the ground elevation.

The graph illustrates the slop of hydraulic gradients based on the 30000 m^3/ day flow rate and the three diameters, where an assumed pump station discharge head of 1000 m is shown at origin. The hydraulic gradient, being the available head at any point along the pipeline route, cannot be less than the elevation of the pipeline route profile. Therefore, where the gradient intersects the pipeline elevation, a pump station is required. It is obvious from the graph that unrealistically high station discharge heads would be required for only one pump station using NPS 16 or NPS 20 pipe. However, one station could be used on the [illegible]
sufficiently to clear the ground profile at kilometer post 325. the station discharge head is usually selected on the basis of the maximum allowable pressure rating for valves and fittings, or the MAOP of the selected pipe, which ever provides the required operating flexibility, and is the most attractive economically.

2.4 MECHANICAL DESIGN

Mechanical design of a pipeline system is the selection of materials, including type of steel and diameter, wall thickness of the pipe. Selected also are methods of support and restraint for the system in response to the loadings and stresses imposed on the pipeline system by physical pressure and forces such as the internal and external design pressures, static loadings and weight effects of the pipe, fluid, and soil, dynamic loadings from wind, waves, earthquakes, and other natural forces and relative motion of connected components. These factors impose loadings on the pipe and result in longitudinal, hoop, and radial stresses which must be evaluated in the mechanical design of the piping system.

In addition to the mechanical factors that affect the allowable stress levels for design, the grade of steel and wall thickness determine welding procedures and affect construction cost. Section 434.8 of the code prescribes the requirements for welding. Section 434.8.3 specifies welding qualifications with reference to API 1104 and sec IX of the ASME boiler and pressure vessel code.

The mechanical design of the pipeline, with respect to restraint against longitudinal, or axial, and radial motions, considers the pipeline as a unit and must provide sufficient flexibility in the system to ensure that expansion or contraction, as a result of the internal or external loadings, do not cause excessive stresses in the piping material, bending moments at joints, or excessive forces or moments at points of connection to equipment or at supports.

Mechanical piping system design primarily utilizes computer programs, many of which operate on personal computers. In most cases, the code requirements are built into the programs, so for a set of internal pressures and external loadings, the program will give the optimum wall thickness, pump locations and maximum stress values on the basis of parameters input by the engineer. However, this does not preclude the possibility of error. The engineer must be able to determine accurately the required loadings and pressure and to analyze the computer results, verifying their validity to the overall system.

2.4.1 LINE PIPE, FITTINGS AND VALVES

Specifications for the line pipe and for fittings, valves, and flanges are given in various API, ANSI, and ASME standards and specifications including

- ANSI/ASME B36.10M Welded and Seamless Steel Pipe
- ANSI/ASME B36.19M Welded and Stainless Steel Pipe
- API 5L, 5LU, Line Pipe

- ANSI B16.5, B16.9, B16.10, B16.11, B16.25, B16.28, Fittings, Valves, Flanges
- API 6D Pipeline Valves, Gate, Plug, Ball, and Check Valves
- API 600, 602, 603, Valves

Line pipe is manufactured by several methods, the most common being seamless (SMLS), electric resistance welded (ERW), and submerged are welded (SAW) in the form of longitudinal and spiral welds.

With respect to the mechanical design of a pipeline, the characteristic of line pipe which is of critical interest is the specified minimum yield strength (SMYS) of the material. API 5L, Specifications for Line pipe, is available in various strength grades, ranging from Grade B, rated at 35,000 psi (241 MPa) to Grade X80, rated at 80,000 psi (551 MPa), where the grade X80 refers to the SMYS in ksi, which is defined as kips per square inch, a kip being 1,000 pounds.

There is some advantage to the higher strength grades; principally that wall thickness may be reduced. In some cases this may have an economic impact on the project, as thinner walls translate into lower steel tonnage for entire pipeline system, and this may be a significant factor, even though higher grades of pipe cost more per ton. Cost savings can also result from reduced time required to field weld the thinner wall sections. There are other considerations which will affect the decision to use higher strength, thinner wall pipe. These include aspects of construction which are result of experience in the field, such as the way the pipe handles with regard to field bending, laying stresses, tendency to go out of round. In addition there may be limitations placed on the grade of pipe and wall thickness used for a particular project, particularly for a system which will be in sour or corrosive service.

Valves, pipe flanges, and fittings are described by class ratings, which are not the same as the rated pressure for a particular class. For example, API 6D, Specification for pipeline valves, class 300 (PN 50) valves, standard flanged end and standard weld end, have a nominal pressure rating of 720 psig at - 20 to 100F° (-29 to 38 °C), not 300 psig. Metric designations, PN for nominal pressure and DN for nominal pipe size replace class and nominal pipe diameter respectively.

Few pipelines now in operation utilize fittings heavier than Class 600 (PN100), rated at 1,440 psig (9930 kPa), although the trend is toward higher pressure ratings. Deep-water subsea pipelines which have heavier wall thickness due to laying stresses and high external pressures may have fittings and flanges rated at class 1,500 (PN 250), rated at 3600 psi (24,000 kPa).

2.4.2 ALLOWABLE PIPE STRESS

Paragraph 402.3.1 of the code establishes for the allowable stress value, S_A in psi, to be used in the temperature range -20°F to 250°F(-30°C to 120°C) for design calculations:

S_A= (design factor) X (SMYS) X (joint weld factor)

Paragraph 402.3.1 describes application of above equation for allowable stress values of S_A depending on new, used, or or reclaimed straight pipe of known or unknown specification. Sub Paragraph 402.3.1

Reference paragraph	Application for straight pipe	formulations
402.3.1 (a)	New pipe of known specification.	S_A= 0.72 x Ex SMYS psi (MPa) Where E= joint factor
402.3.1 (b)	Used or reclaimed pipe of known specification	S_A= 0.72 x E x SMYS psi (MPa) Where E= joint factor
402.3.1 (c)	New, Used or reclaimed pipe of unknown or ASTM A120 specification	S_A= 0.72 x E x minimum yield strength of pipe, psi (MPa) Where E= joint factor
402.3.1 (d)	Pipe cold worked in order to meet specified minimum yield strength and subsequently heated to 600°F (300°C) or more except welding	S_A= 75% of applicable allowable stress value

Table 402.3.1 (a) of the code tabulates allowable stress values for various grades of material specifications and manufacturing processes.

Specified minimum yield strength of a pipe material is used as the basis of design because it is a property which can be determined for a specific material. Further more; steel generally behaves elastically below this stress level. Ultimate yield strength has also been used as the basis for design and may still be used in other countries.

A particular batch of steel line pipe may be tested and determined that its elastic yield strength is higher than the nominal value; however, 402.3.1 (g) of the code specifies, " in no case where the code refers to the specified minimum value of a physical property shall a higher value of the property be used in establishing the allowable stress value".

402.3.1 (a) also includes the joint weld factor E in calculating allowable stress as a consideration to the way the line pipe is manufactured. In most cases, the joint weld factor is 1.00, but it may be 0.80 or 0.60 for specific grades of steel and welding method of the manufacturing process.

it is useful at this point to clarify a question that arises periodically as to whether the mechanical stress calculations are based on a particular design temperature, that is if S_A is temperature dependent. Section 401.3.1 of the code states "it is not necessary to vary allowable design stress for metal temperatures -20° F(-30° C) and 250°F(120°C)." however, for applications where ground or air temperature is expected to be extremely low, seasonally or locally, the properties of pipe component materials should be considered to verify that the design will be adequate.

Allowable stress limits for shear and bearing are given in section 402.3.1 (e) of the code. For shear S_A shall not be exceed 45% of SMYS. For bearing S_A is limited to 90% of SMYS. Limits on calculated stress due to sustained loads and thermal expansion and due to occasional loads in operation and test condition are specified in section 402.3.2 and 402.3.3 of the code. In general, this limits fall within the definition of allowable stress given previously. However, special circumstances may apply, and the engineer is encouraged to verify the stresses and relevant limitations.

2.4.3 PIPE DIAMETER

In the hydraulic design of a pipeline system, line size is initially based on a preliminary choice of diameter and wall thickness from experience and from simplified charts. Further calculations are needed to verify the selection and finalize the system design based on the code requirements as well as on considerations for project cost and material availability.

For most pipeline systems, the pipe cost, which is based on the diameter and wall thickness, will be the highest material cost in the system. In addition, the size of pipe will have a direct effect on the cost of installation. Therefore, total project cost is impacted by the selection of pipe size. For this reason, it is important to optimize the pipe diameter, wall thickness, and grade of steel to be used so that the overall project cost is contained.

As discussed earlier in the hydraulic design part, the diameter of pipe is based n the design flow rate; the mechanical design considerations have little effect on diameter selection. However, internal and external pressure, allowable stress, and other considerations do affect the final design of the wall thickness for the selected diameter.

2.4.4 WALL THICKNESS

In the hydraulic design the preliminary design of wall thickness is based on experience for the preliminary selection of the pipe diameter and grade of steel. The actual design of a system must reflect code requirements for the wall thickness, which is based on internal design pressure and dditional loads at the design temperature.

2.4.5 WALL THICKNESS CALCULATION

Minimum wall thickness, t is a function of internal pressure, P_i, nominal diameter, D, on the allowable stress, S_A , as specified by section 404.1.2 of the code. The actual wall thickness used in the system will be equal to or greater than this calculated value. API 5L, specification for line pipe table 6.2, lists commonly manufactured wall thickness for various grades of materials.

With respect to construction and installation of a pipeline, there is also a practical minimum wall thickness, based on handling during installation, as the pipe wall must be able to resist damage and maintain roundness during construction.

Good judgment should be used in balancing higher strength steel materials versus heavier wall thickness.

It is not a requirement that wall thickness be constant for the entire length of the system. Specific sections of the system may have different wall thickness requirements as determined by the internal pressure and other imposed stresses, and making use of the hydraulic grade in developed in the hydraulic design. Thinner wall may be installed at some distance downstream of pumping stations as the operating pressure in the system declaims. There are economic benefits to utilizing the minimum wall thickness allowed under code design, however, there are other considerations, such as complications in construction, that is field welding, of a system with frequent variation in wall thickness. Practically speaking, changes in wall thickness should be limited. Furthermore, anticipated growths are expansion of the system capacity should be considered carefully.

2.4.6 PUMP SELECTION

The concept of pump curves and preliminary pump selection was discussed above. Expanding on that discussion, it is assumed that the hydraulic and pipe design are essentially completed. The next step is to choose the pumps and drives. The first decision is what type of driver – diesel, turbine, or electric. This is preliminary an economic decision influenced by the availability of fuel and cost electric power. When electric power is readily available, electric motors provide simple operation, low cost and low maintenance, where the natural gas or other unrefined fuels are available, gas turbines may give low fuel costs, and occasionally a steam turbine or some combination of some machines proves the best choice. It may even be possible to draw off commodity from the system, to fuel the pump drivers themselves, for example, with the diesel transport system.

3.0 RELEVENT EXCERPTS FROM CODES

3.1 SCOPE

There are three basic codes developed by the American Society of Mechanical Engineers (ASME) which govern the design of piping systems in chemical, liquid petroleum, and gas.

- ASME B 31.3, covering piping inside the boundaries of a chemical plant, refinery, or gas processing plant.
- ASME B 31.8, covering gas transmission and distribution piping system.
- ASME B 31.4, covering pipeline transportation systems for liquid hydrocarbons and other liquids.

3.2 CODES, STANDARDS, SPECIFICATIONS, AND RECOMMENDED PRACTICES

In general, pipelines which are designed in accordance with the code will meet the requirements in the USA for liquid petroleum pipelines and associated facilities.

In addition to the ASME B 31.4, ASME b 31.8, ASME B 31.3, the following codes, standards, specifications, and recommended practices may be applicable to a proposed pipeline system.

- API (RP) 1102 - recommend practice for liquid petroleum pipelines crossing railroads and highways.
- API 1104 - Welding of pipelines and related facilities.
- API 5L - Specification for line pipe.

- API 6D - Pipeline valves (Gate, Plug, Ball, and Check valves)
- ASME B 16.5 - Pipe flanges and flanged fittings.
- ASME B 16.34 - Valves-flanged ,threaded, and welding end
- ISO 3183-1-2-3. 1996- Petroleum and natural gas industries- Steel pipe for pipelines- Technical delivery condition.

4.0 SYSTEMATIC APPROACH FOR DESIGNING A PIPELINE

STEP 1: DESIGN BASIS

STEP 2: PIPE SIZING

STEP 3: PIPE ROUGHNESS

STEP 4: REYNOLDS NUMBER

STEP 5: FRICTION LOSS CALCULATIONS

STEP 6: MAXIMUM ALLOWABLE OPERATING PRESSURE

STEP 7: NUMBER OF PUMP STATION REQUIRED

STEP 8: PUMPING POWER REQUIREMENT

CALCULATIONS

5.1 DESIGN BASIS

The crude oil sample having following characteristics

- Commodity : General crude oil
- Temperature range : 4°C to 70°C
- Ambient design temperature : 4°C
- Relative density based on water at 15°C : 0.8623
- API gravity at 15°C : 32.6
- Viscosities at 15° C : 23 cSt
  at 54° C : 6 cSt
- Pour point temperature : 13°C
- Vapor pressure : 15 kPa

The design temperature for average operation differs from the measurement standard of the design crude. Consequently it is necessary to make adjustments from the values given here at standard conditions at 15°C to the operating condition.

The corrected values are

- Relative density at 4°C : 0.8701
- Viscosity at 4°C : 37 cSt

The final design basis is

- Commodity : General crude oil
- Distance : 400 km
- Temperature range : 4°C to 70°C

- Ambient design temperature : 4°C
- Relative density at 4°C : 0.8701
- Viscosity at 4°C : 37 cSt
- Pour point temperature : 13°C
- Vapor pressure : 15 kPa
- Average flow rate : 30000 m^3/ day
- Minimum flow rate : 20000 m^3/ day
- Maximum flow rate : 40000 m^3/ day

5.2 PIPE SIZING

The pipe size can be calculated arithmetically by using the following formula

Cross sectional area (A) = Volumetric flow rate (V) / Flow velocity (u)

V = Volumetric flow rate (m^3/ sec)
U = flow velocity (m/ s)

As per piping hand book velocities for preliminary estimates of line size are typically in the range of 1 to 3 m/ s.

So initially I take minimum velocity as 1m/s, average velocity as 2 m/ s and maximum velocity as 3 m/s and precede my calculation for all velocities and all flow rates.

(a) For 20000 m^3/ day flow rate with different velocities

For 20000 m^3/ day with maximum velocity
$A=V / u$
$A= \pi d^2/ 4$

$V = 20000\ m^3/\ day$

$= 0.23148\ m^3/\ s$

$U = 3\ m/\ s$

$d^2 = 0.098243$

$d = 0.3134\ m$

d = 313.4 mm

For 20000 m^3/ day with average velocity

$A = V / u$

$A = \pi d^2 / 4$

$V = 20000\ m^3/\ day$

$= 0.23148\ m^3/\ s$

$U = 2\ m/\ s$

$d^2 = 0.14736$

$d = 0.3838\ m$

d = 383.8 mm

For 20000 m^3/ day with minimum velocity

$A = V / u$

$A = \pi d^2 / 4$

$V = 20000\ m^3/\ day$

$= 0.23148\ m^3/\ s$

$U = 1\ m/\ s$

$d^2 = 0.29472$

$d = 0.54288\ m$

d = 542.88 mm

(b) For 30000 m^3/ day flow rate with different velocities

For 30000 m^3/ day with maximum velocity

A=V / u

A= πd^2/ 4

V= 30000 m^3/ day

= 0.34722 m^3/ s

U= 3 m/ s

d^2 = 0.14736

d = 0.3838 m

d = 383.88 mm

For 30000 m^3/ day with average velocity

A=V / u

A= πd^2/ 4

V= 30000 m^3/ day

= 0.34722 m^3/ s

U= 2 m/ s

d^2 = 0.22104

d = 0.47015 m

d = 470.15 mm

For 30000 m^3/ day with minimum velocity

A=V / u

A= πd^2/ 4

V= 30000 m^3/ day

= 0.34722 m^3/ s

U= 2 m/ s

$d^2 = 0.44209$

$d = 0.66490$ m

d = 664.90 mm

3. For 40000 m^3/ day flow rate with different velocities

For 40000 m^3/ day with maximum velocity

$A = V / u$

$A = \pi d^2 / 4$

$V = 40000$ m^3/ day

$= 0.46296$ m^3/ s

$U = 3$ m/ s

$d^2 = 0.19648$

$d = 0.44326$ m

d = 443.26 mm

For 40000 m^3/ day with average velocity

$A = V / u$

$A = \pi d^2 / 4$

$V = 40000$ m^3/ day

$= 0.46296$ m^3/ s

$U = 2$ m/ s

$d^2 = 0.29472$

$d = 0.54288$ m

d = 542.88 mm

For 40000 m^3/ day with minimum velocity

$A = V / u$

$A = \pi d^2 / 4$

$V = 40000\ m^3/\ day$

$= 0.46296\ m^3/\ s$

$U = 1\ m/\ s$

$d^2 = 0.58945$

$d = 0.7677\ m$

d = 767.7 mm

Pipe size summary for different velocities and different flow rates:

(a) For maximum velocity

For 20000 m^3/day with max velocity of 3 m/ s the out side diameter (d) = 313.4 mm
For 30000 m^3/day with max velocity of 3 m/ s the out side diameter (d) = 383.8 mm
For 40000 m^3/day with max velocity of 3 m/ s the out side diameter (d) = 443.2 mm

(b) For average velocity

For 20000 m^3/day with max velocity of 2 m/ s the out side diameter (d) = 383.8 mm
For 30000 m^3/day with max velocity of 2 m/ s the out side diameter (d) = 470.1 mm
For 40000 m^3/day with max velocity of 2 m/ s the out side diameter (d) = 542.8 mm

(c) For minimum velocity

For 20000 m^3/day with max velocity of 1 m/ s the out side diameter (d) = 542.8 mm
For 30000 m^3/day with max velocity of 1 m/ s the out side diameter (d) = 664.9 mm
For 40000 m^3/day with max velocity of 1 m/ s the out side diameter (d) = 767.7 mm

I assumed that the velocity is average and according to that I selected the pipe diameter. As per API 5L for line pipe the diameter which I selected is the next standard size compare to the calculated value. This is because there are some standard sizes mentioned in API 5L and we can not go down than the calculated values. (See Appendix II)

Now I select three diameters with minimum wall thickness

Outside diameter (mm)	Inside diameter (mm)	Wall thickness (mm)	Line Pipe Grade
406.4	393.6	6.4	API 5l X 60
508	495.2	6.4	
610	597.2	6.4	

5.3 Pipe roughness (ε)

The pipe roughness is taken from standard tables, and for commercial steel pipe would generally be taken as 0.0457.

Pipe roughness (ε) = 0.0457 mm

5.4 Reynolds number (Re)

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

The Reynolds number can be calculated for any given liquid and pipe size as follows

$$Re = VD/\mu$$

Re = Reynolds number (dimensionless)
V = average velocity (m/ sec)
D = internal diameter (m)
μ = viscosity of the fluid (m^2/ sec)

It has been shown that for values of Re less than approximately 2000, the flow is laminar. For values of Re number more than 4000 the flow is consider turbulent. If the value is between 2000 and 4000 it is known as critical zone where the flow is unpredictable.

It is more practical to express the calculation of the Re number in oil filed units as follows.

$$Re = 3.536777 \text{ X } 10^5 \, (Q/ d v)$$

Where,

Q = flow rate, m^3/ hr
d = inside diameter, mm
v = kinematic viscosity, cSt

According to the above formula I have calculated the Re number for three flow rates.

Diameter, Wall thickness (mm)	Flow rate m^3 / day	Reynolds number
406.4 X 6.4	20000	20240
	30000	30357
	40000	40480
508.0 X 6.4	20000	16085
	30000	24129
	40000	32170
610.0 X 6.4	20000	13335
	30000	20008
	40000	26670

5.5 UNIT FRICTION LOSS

Unit friction losses can be stated in terms of pressure or head loss per unit length. In pipelining the unit length is almost a mile or kilometer. For that reason the unit friction loss equation herein will be based on the km or kft. Head loss will be expressed in terms of unit length, so in MKS units it is expressed in m/km.
Unit friction loss can be determined from the moody chart and the friction head loss can be calculated by relevant Darcy equation.

5.5.1 MOODY CHART

The unit friction loss is generally calculated by using Moody chart which is derived from coefficient of friction, Reynolds number and relative roughness. (see appendix I)

The Unit friction loss can be calculated arithmetically. In industry the working equation for unit friction loss in terms of head is as follows

$$S_f = 6.377707 \times 10^9 f_{Darcy} (Q^2 / d^2)$$

S_f = head loss (m/km)

Q = flow rate (m^3/ hr)

d = inside diameter of the pipe (mm)

Where,

$f_{Darcy} = 4 / (T_{Oil})^2$

$T_{Oil} = 3.6 \log (N_{Re}/8)$

By the application of the above formulas I get the following values for different flow rates

Pipe Dia(mm)	Flow rate m^3 / day	Reynolds number	Darcy- Weisbach friction factor	Unit friction loss (m/km)
406.4	20000	20240	0.026	12.22
	30000	30357	0.024	25.31
	40000	40480	0.022	41.78
508	20000	16085	0.028	4.09
	30000	24129	0.025	8.35
	40000	32170	0.023	13.90
610	20000	13335	0.029	1.68
	30000	20008	0.027	3.54
	40000	26670	0.024	5.67

Summing the friction losses for a specific set of pipeline diameters along the system results in the net friction head that must be overcome by the pump stations of the system. In addition, the positive or negative static head due to the elevation difference between the inlet and outlet must be considered in determining the pumping requirements of the system. Minor losses at valves and fittings between stations are normally ignored, initially, or an added length of pipe may be added to the scaled length to determine the estimated total system friction head losses.

5.6 MAXIMUM ALLOWABLE OPERATING PRESSURE

As per ASME B 31.4 section 404.1.2 of the code expresses the required wall thickness for the internal wall thickness for the internal wall thickness for the internal design pressure for straight pipe by the following equation

$t = P_i * D / (2*S)$

Where,

P_i = maximum allowable internal gauge pressure, KPa

D = outside diameter, mm

S_A = allowable stress, MPa

t = wall thickness, mm

Expressing the above equation in the following form for calculating the internal design pressure,

$P_i = B * S_A * (t/D)$

The constant B is determined by the units of the allowable stress S_A, and the units of pressure to be determined using the ratio of t/D in consistent units.

Where,

The value of B in Metric unit is 2000 if allowable stress in MPa and Pressure in kPa.

S_A = (design factor) X (SMYS) X (joint weld factor)

SMYS = 413 MPa (per tables in API Spec 5L).

Design factor = 0.72 (ASME B 31.4)

Joint weld factor = 1 (ASME B 31.4)

By all the above formula the following values occurred

Pipe diameter, mm	406.4	508	610
Pipe wall thickness, mm	6.4	6.4	6.4
MAOP, kPa	9366	7493	6240
MAOH, m^2	1097	878	731

The MAOP is used in the development of the system hydraulic design as a limit on the internal pressure component of the hydraulic gradient. When plotted above the route profile, the hydraulic gradient may not exceed this limit and still be designed to the ASME B 31.4 code. MAOP is also used in determining the approximate number of pump stations.

5.7 PUMP STATIONS

The calculated system head to achieve a given flow rate through a pipeline system with a selected diameter, which includes the total friction component and the static elevation difference between inlet and outlet, determines the pumping requirements of the system. As seen in the graph, at least one intermediate pump station is required for this system and pipe diameter illustrated. This station discusses a method of determining how many pump stations are required and locating them on the basis of hydraulic balance and a graphical method.

5.7.1 NUMBER OF PUMP STATIONS

A rough number of pumping stations is found by dividing the total system pressure or head required to overcome elevation changes and friction, by the maximum allowable operating pressure or head, MAOP or MAOH, for a specific diameter, wall thickness and pipe material, using consistent units.

Number of pump stations = total system head / (MAOH – NPSH)

The first step to determining the number of pump stations is to determine the pressure head required to overcome the frictional resistance caused by the flow of the oil.

(a) For 406.4 X 6.4 Diameter pipe:

1. Using 406.4 mm diameter pipe size with 6.4 mm wall thickness with the Darcy-Weisbach equation, the unit head friction loss, for the flow of 30,000 m^3/ day is 25.31. Summing the friction head loss over the 400 kilometers measured length of the system yields 3340 m of total head loss H_f

2. There is also a static head loss H_s, of 110 m to be pumped against due to a change in elevation between the initial point and the head required at the terminal.

The total head (H) = Friction head (H_f) + Friction head (H_s)

H = 10124 + 110

H = 10234 m

The MAOP of API 5L Grade X60 pipe DN 500 with wall thickness 6.4 mm, expressed in units of head is 1097 m. Assuming 25 m of head loss in station piping, the available head per station is

Number of pump stations = 10234 / (1097 – 25)

= 9.44

(b) For 508 X 6.4 Diameter pipeline:

1. Using DN 500 diameter pipe size with 6.4 mm wall thickness with the Darcy-Weisbach equation, the unit head friction loss, for the flow of 30,000 m^3/ day is 8.35. Summing the friction head loss over the 400 kilometers measured length of the system yields 3340 m of total head loss H_f

2. There is also a static head loss H_s, of 110 m to be pumped against due to a change in elevation between the initial point and the head required at the terminal.

The total head (H) = Friction head (H_f) + Friction head (H_s)

H = 3340 + 110

H = 3450 m

The MAOP of API 5L Grade X60 pipe DN 500 with wall thickness 6.4 mm, expressed in units of head is 878 m. Assuming 25 m of head loss in station piping, the available head per station is

Number of pump stations = 3450 / (878 – 25)
= 4.04

(c) For 610 X 6.4 Diameter pipeline:

1. Using 610 mm diameter pipe size with 6.4 mm wall thickness with the Darcy-Weisbach equation, the unit head friction loss, for the flow of 30,000 m^3/ day is 3.54. Summing the friction head loss over the 400 kilometers measured length of the system yields 3340 m of total head loss H_f

2. There is also a static head loss H_s, of 110 m to be pumped against due to a change in elevation between the initial point and the head required at the terminal.

The total head (H) = Friction head (H_f) + Friction head (H_s)

H = 1416 + 110

H = 1526 m

The MAOP of API 5L Grade X60 pipe DN 500 with wall thickness 6.4 mm, expressed in units of head is 731 m. Assuming 25 m of head loss in station piping, the available head per station is

Number of pump stations = 1526 / (731 – 25)

= 2.09

Fractional stations may be accounted for by using heavier wall pipe for a limited length, or by installing a booster station.

5.8 PUMPING POWER REQUIREMENT

Pumping power requirements for the entire system can be calculated using the following formula, where H_T and P_T refer to the total system head and pressure requirements.

Power = flow X H_T X (relative density/ 8810 X efficiency)

Where,

Power= kW

Flow = m^3/day

H_T = m

Pump efficiency in percent typically ranges from 70 to 80 percent for centrifugal pumps to 90 percent for reciprocating pumps. Determination of pumping power for individual stations and pumps is similar, using the head or pressure requires for the downstream section between one station and the next. As motor power is provided in standardized increments, the power provided by the motor will exceed the required pumping power.

(a) For 406.4 X 6.4 Diameter pipeline:

:

Using 406.4 mm dia pipeline, assuming 82 percent efficiency for the pumps, the required system operating power at the design temperature is

Power = 30000 X 10126 X 0.8701/ (8810 X 0.82)
= 36584 kW

(b) For 508 X 6.4 Diameter pipe:

Using 508 mm dia pipeline, assuming 82 percent efficiency for the pumps, the required system operating power at the design temperature is

Power = 30000 X 3450 X 0.8701/ (8810 X 0.82)
= 12460 kW

(c) For 610 X 6.4 Diameter pipe:

Using 610 mm dia pipeline, assuming 82 percent efficiency for the pumps, the required system operating power at the design temperature is

Power = 30000 X 1478 X 0.8701/ (8810 X 0.82)
= 5340 kW

Specification for the mail line pumps should stress performance, efficiency and ease of maintenance, because over the life of the pipeline, the cost of fuel and power will be the major operating or annual expense. Therefore, a percent or two on pump or driver efficiency has a major impact. Consideration should also me given to variable speed centrifugal pumps, on the basis of economics, in order to satisfy varying flow and pressure or head requirements over the life of pipeline system. It may be that the added cost of a variable speed pumping unit is favorable versus controlling station discharge pressure by throttling.

CONCLUSION

The following are the final results I got for three diameters with the flow rate of 30000 m^3/ day.

Pipe size X Wall thickness, mm	406.4 X 6.4	508 X 6.4	610 X 6.4
Line pipe grade	API 5L X60	API 5L X60	API 5L X60
Unit friction loss, m/km	25.04	8.35	3.42
Length, km	400	400	400
Pipe friction loss, m	10016	3340	1368
Static head, m	110	110	110
Total head, m	10126	3450	1478
Total pressure, kPa	86406	29439	12612
MAOP, kPa	9366	7493	6240
MAOH less NPSH, m	1073	853	706
Number of pump stations	9.44	4.04	2.09
Operating power at 82% efficiency, kW	36584	12464	5340

Finally for this pipeline project I preferred 610 mm X 6.4 mm pipeline for transport the crude from source to destination. By seeing the results obtained here, we can find that, the number of pump station, operating power, pipe friction loss all are less compare to other diameter pipelines

Appendix I

Moody chart

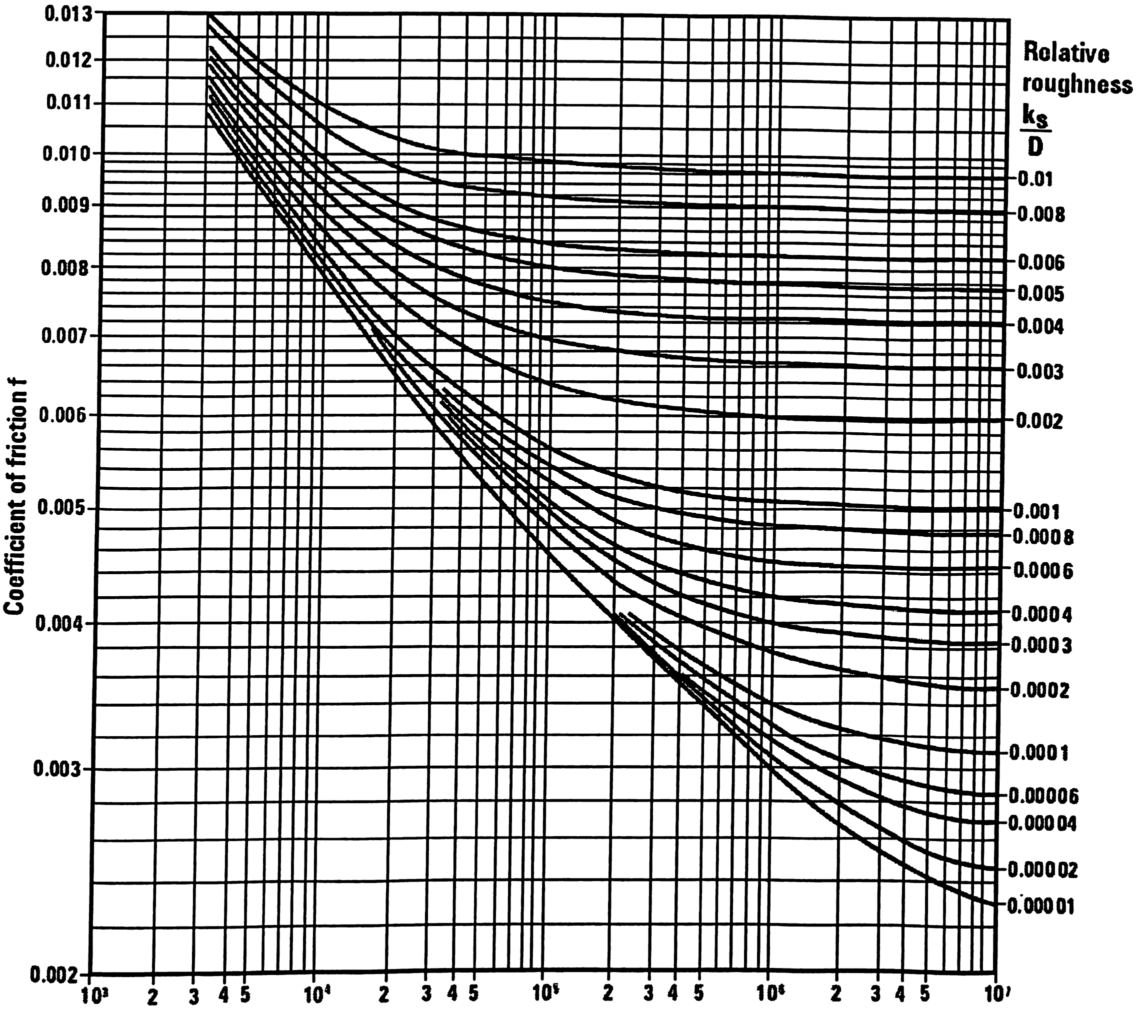


Fig. 10.2.4 'SI based' Moody chart (abridged)

Appendix II

(a) Table 1(Specification of line pipe, API 5L)

Table E-6C (Continued)—Plain-End Line Pipe Dimensions, Weights per Unit Length, and Test Pressures for Sizes $6^5/_8$ through 80 (SI Units)

(1)	(2)	(3)	(4)	(5)		(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	Specified Outside Diameter	Specified Wall Thickness	Plain-End Weight per Unit Length	Calculated Inside Diameter[a]		Minimum Test Pressure[b] (kPa × 100)[c]									
Size	D (mm)	t (mm)	w_{pe} (kg/m)	d (mm)		Grade A	Grade B	Grade X42	Grade X46	Grade X52	Grade X56	Grade X60	Grade X65	Grade X70	Grade X80
14[d]	355.6	7.1	61.02	341.4	Std.	50	58	98	108	122	131	141	152	164	187
					Alt.	62	72	98	108	122	131	141	152	164	187
14	355.6	7.9	67.74	339.8	Std.	55	64	110	120	136	146	156	169	182	207
					Alt.	69	80	110	120	136	146	156	169	182	208
14	355.6	8.7	74.42	338.2	Std.	61	71	121	132	149	161	172	186	201	207
					Alt.	76	88	121	132	149	161	172	186	201	230
14	355.6	9.5	81.08	336.6	Std.	66	77	132	144	163	175	188	203	207	207
					Alt.	83	97	132	144	163	175	188	203	219	251
14	355.6	10.3	87.71	335.0	Std.	72	84	143	156	177	190	204	207	207	207
					Alt.	90	105	143	156	177	190	204	221	238	272
14	355.6	11.1	94.30	333.4	Std.	78	90	154	168	191	205	207	207	207	207
					Alt.	97	113	154	168	191	205	220	238	256	293
14	355.6	11.9	100.86	331.8	Std.	83	97	165	180	204	207	207	207	207	207
					Alt.	104	121	165	180	204	220	236	255	275	314
14	355.6	12.7	107.39	330.2	Std.	89	103	176	192	207	207	207	207	207	207
					Alt.	111	129	176	192	218	234	251	272	293	335
14	355.6	14.3	120.36	327.0	Std.	100	116	198	207	207	207	207	207	207	207
					Alt.	125	145	198	217	245	264	283	306	330	377
14	355.6	15.9	133.19	323.8	Std.	111	129	207	207	207	207	207	207	207	207
					Alt.	139	162	220	241	273	293	315	341	367	420
14	355.6	17.5	145.91	320.6	Std.	122	142	207	207	207	207	207	207	207	207
					Alt.	153	178	243	265	300	323	346	375	404	462
14	355.6	19.1	158.49	317.4	Std.	133	155	207	207	207	207	207	207	207	207
					Alt.	167	193	265	289	328	352	378	409	441	500
14	355.6	20.6	170.18	314.4	Std.	144	168	207	207	207	207	207	207	207	207
					Alt.	180	193	286	312	354	380	408	441	476	500
14	355.6	22.2	182.52	311.2	Std.	155	181	207	207	207	207	207	207	207	207
					Alt.	193	193	308	336	381	410	439	475	500	500
14	355.6	23.8	194.74	308.0	Std.	166	193	207	207	207	207	207	207	207	207
					Alt.	193	193	330	361	408	439	471	500	500	500
14	355.6	25.4	206.83	304.8	Std.	177	193	207	207	207	207	207	207	207	207
					Alt.	193	193	352	385	436	469	500	500	500	500
14	355.6	27.0	218.79	301.6	Std.	189	193	207	207	207	207	207	207	207	207
					Alt.	193	193	374	409	463	498	500	500	500	500
14	355.6	28.6	230.63	298.4	Std.	193	193	207	207	207	207	207	207	207	207
					Alt.	193	193	397	433	491	500	500	500	500	500
14	355.6	31.8	253.92	292.0	Std.	193	193	207	207	207	207	207	207	207	207
					Alt.	193	193	441	482	500	500	500	500	500	500
16[d]	406.4	4.8	47.54	396.8	Std.	29	34	58	64	72	78	83	90	97	111
					Alt.	37	43	58	64	72	78	83	90	97	111
16[d]	406.4	5.2	51.45	396.0	Std.	32	37	63	69	78	84	90	97	105	120
					Alt.	40	46	63	69	78	84	90	97	105	120
16[d]	406.4	5.6	55.35	395.2	Std.	34	40	68	74	84	90	97	105	113	129
					Alt.	43	50	68	74	84	90	97	105	113	129
16[d]	406.4	6.4	63.13	393.6	Std.	39	46	78	85	96	103	111	120	129	148
					Alt.	49	57	78	85	96	103	111	120	129	148
16[d]	406.4	7.1	69.91	392.2	Std.	43	51	86	94	107	115	123	133	143	164
					Alt.	54	63	86	94	107	115	123	133	143	164
16	406.4	7.9	77.63	390.6	Std.	48	56	96	105	119	128	137	148	160	182
					Alt.	60	70	96	105	119	128	137	148	160	182

(b) Table 2(Specification of line pipe, API 5L)

Table E-6C (Continued)—Plain-End Line Pipe Dimensions, Weights per Unit Length, and Test Pressures for Sizes $6^5/_8$ through 80 (SI Units)

(1)	(2)	(3)	(4)	(5)		(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	Specified Outside Diameter	Specified Wall Thickness	Plain-End Weight per Unit Length	Calculated Inside Diameter[a]		Minimum Test Pressure[b] (kPa × 100)[c]									
Size	D (mm)	t (mm)	w_{pe} (kg/m)	d (mm)		Grade A	Grade B	Grade X42	Grade X46	Grade X52	Grade X56	Grade X60	Grade X65	Grade X70	Grade X80
18	457.0	10.3	113.46	436.4	Std.	56	65	111	121	138	148	159	172	185	207
					Alt.	70	81	111	121	138	148	159	172	185	211
18	457.0	11.1	122.05	434.8	Std.	60	70	120	131	148	159	171	185	199	207
					Alt.	75	88	120	131	148	159	171	185	199	228
18	457.0	11.9	130.62	433.2	Std.	65	75	128	140	159	171	183	198	207	207
					Alt.	81	94	128	140	159	171	183	198	214	244
18	457.0	12.7	139.15	431.6	Std.	69	80	137	150	170	182	196	207	207	207
					Alt.	86	100	137	150	170	182	196	212	228	250
18	457.0	14.3	156.11	428.4	Std.	78	90	154	169	191	205	207	207	207	207
					Alt.	97	113	154	169	191	205	220	238	250	250
18	457.0	15.9	172.95	425.2	Std.	86	101	172	187	207	207	207	207	207	207
					Alt.	108	126	172	187	212	228	245	250	250	250
18	457.0	17.5	189.67	422.0	Std.	95	111	189	206	207	207	207	207	207	207
					Alt.	119	138	189	206	234	250	250	250	250	250
18	457.0	19.1	206.25	418.8	Std.	104	121	206	207	207	207	207	207	207	207
					Alt.	130	151	206	225	250	250	250	250	250	250
18	457.0	20.6	221.69	415.8	Std.	112	130	207	207	207	207	207	207	207	207
					Alt.	140	163	222	243	250	250	250	250	250	250
18	457.0	22.2	238.03	412.6	Std.	121	140	207	207	207	207	207	207	207	207
					Alt.	151	176	239	250	250	250	250	250	250	250
18	457.0	23.8	254.25	409.4	Std.	129	151	207	207	207	207	207	207	207	207
					Alt.	162	188	250	250	250	250	250	250	250	250
18	457.0	25.4	270.34	406.2	Std.	138	161	207	207	207	207	207	207	207	207
					Alt.	173	193	250	250	250	250	250	250	250	250
18	457.0	27.0	286.30	403.0	Std.	147	171	207	207	207	207	207	207	207	207
					Alt.	183	193	250	250	250	250	250	250	250	250
18	457.0	28.6	302.14	399.8	Std.	155	181	207	207	207	207	207	207	207	207
					Alt.	193	193	250	250	250	250	250	250	250	250
18	457.0	30.2	317.85	396.6	Std.	164	191	207	207	207	207	207	207	207	207
					Alt.	193	193	250	250	250	250	250	250	250	250
18	457.0	31.8	333.44	393.4	Std.	173	193	207	207	207	207	207	207	207	207
					Alt.	193	193	250	250	250	250	250	250	250	250
20[d]	508.0	5.6	69.38	496.8	Std.	27	32	58	63	71	77	82	89	96	110
					Alt.	34	40	58	63	71	77	82	89	96	110
20[d]	508.0	6.4	79.16	495.2	Std.	31	36	66	72	81	88	94	102	110	125
					Alt.	39	46	66	72	81	88	94	102	110	125
20[d]	508.0	7.1	87.70	493.8	Std.	35	40	73	80	90	97	104	113	122	139
					Alt.	43	51	73	80	90	97	104	113	122	139
20	508.0	7.9	97.43	492.2	Std.	39	45	81	89	100	108	116	125	135	155
					Alt.	48	56	81	89	100	108	116	125	135	155
20	508.0	8.7	107.12	490.6	Std.	43	50	89	98	111	119	128	138	149	170
					Alt.	53	62	89	98	111	119	128	138	149	170
20	508.0	9.5	116.78	489.0	Std.	46	54	98	107	121	130	139	151	163	186
					Alt.	58	68	98	107	121	130	139	151	163	186
20	508.0	10.3	126.41	487.4	Std.	50	59	106	116	131	141	151	164	176	201
					Alt.	63	73	106	116	131	141	151	164	176	201
20	508.0	11.1	136.01	485.8	Std.	54	63	114	125	141	152	163	176	190	207
					Alt.	68	79	114	125	141	152	163	176	190	217
20	508.0	11.9	145.58	484.2	Std.	58	68	122	134	151	163	175	189	204	207
					Alt.	73	85	122	134	151	163	175	189	204	233

(c) Table 3(Specification of line pipe, API 5L)

Table E-6C (Continued)—Plain-End Line Pipe Dimensions, Weights per Unit Length, and Test Pressures for Sizes 6$^5/_8$ through 80 (SI Units)

(1)	(2)	(3)	(4)	(5)		(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	Specified Outside Diameter	Specified Wall Thickness	Plain-End Weight per Unit Length	Calculated Inside Diameter[a]		Minimum Test Pressure[b] (kPa × 100)[c]									
Size	D (mm)	t (mm)	w_{pe} (kg/m)	d (mm)		Grade A	Grade B	Grade X42	Grade X46	Grade X52	Grade X56	Grade X60	Grade X65	Grade X70	Grade X80
22	559.0	14.3	192.08	530.4	Std.	64	74	134	146	165	178	191	206	207	207
					Alt.	79	92	134	146	165	178	191	206	222	250
22	559.0	15.9	212.95	527.2	Std.	71	82	148	162	184	198	207	207	207	207
					Alt.	88	103	148	162	184	198	212	229	247	250
22	559.0	17.5	233.68	524.0	Std.	78	91	163	179	202	207	207	207	207	207
					Alt.	97	113	163	179	202	218	233	250	250	250
22	559.0	19.1	254.30	520.8	Std.	85	99	178	195	207	207	207	207	207	207
					Alt.	106	124	178	195	221	237	250	250	250	250
22	559.0	20.6	273.51	517.8	Std.	92	107	192	207	207	207	207	207	207	207
					Alt.	114	133	192	210	238	250	250	250	250	250
22	559.0	22.2	293.87	514.6	Std.	99	115	207	207	207	207	207	207	207	207
					Alt.	123	144	207	227	250	250	250	250	250	250
22	559.0	23.8	314.11	511.4	Std.	106	123	207	207	207	207	207	207	207	207
					Alt.	132	154	222	243	250	250	250	250	250	250
22	559.0	25.4	334.23	508.2	Std.	113	131	207	207	207	207	207	207	207	207
					Alt.	141	164	237	250	250	250	250	250	250	250
22	559.0	27.0	354.22	505.0	Std.	120	140	207	207	207	207	207	207	207	207
					Alt.	150	175	250	250	250	250	250	250	250	250
22	559.0	28.6	374.08	501.8	Std.	127	148	207	207	207	207	207	207	207	207
					Alt.	159	185	250	250	250	250	250	250	250	250
22	559.0	30.2	393.81	498.6	Std.	134	156	207	207	207	207	207	207	207	207
					Alt.	168	193	250	250	250	250	250	250	250	250
22	559.0	31.8	413.42	495.4	Std.	141	165	207	207	207	207	207	207	207	207
					Alt.	177	193	250	250	250	250	250	250	250	250
22	559.0	33.3	431.69	492.4	Std.	148	172	207	207	207	207	207	207	207	207
					Alt.	185	193	250	250	250	250	250	250	250	250
22	559.0	34.9	451.06	489.2	Std.	155	181	207	207	207	207	207	207	207	207
					Alt.	193	193	250	250	250	250	250	250	250	250
22	559.0	36.5	470.30	486.0	Std.	162	189	207	207	207	207	207	207	207	207
					Alt.	193	193	250	250	250	250	250	250	250	250
22	559.0	38.1	489.41	482.8	Std.	169	193	207	207	207	207	207	207	207	207
					Alt.	193	193	250	250	250	250	250	250	250	250
24[d]	610.0	6.4	95.26	597.2	Std.	26	30	55	60	68	73	78	85	91	104
					Alt.	33	38	55	60	68	73	78	85	91	104
24[d]	610.0	7.1	105.56	595.8	Std.	29	34	61	66	75	81	87	94	101	116
					Alt.	36	42	61	66	75	81	87	94	101	116
24	610.0	7.9	117.30	594.2	Std.	32	37	68	74	84	90	97	104	113	129
					Alt.	40	47	68	74	84	90	97	104	113	129
24	610.0	8.7	129.00	592.6	Std.	35	41	74	81	92	99	106	115	124	142
					Alt.	44	52	74	81	92	99	106	115	124	142
24	610.0	9.5	140.68	591.0	Std.	39	45	81	89	101	108	116	126	135	155
					Alt.	48	56	81	89	101	108	116	126	135	155
24	610.0	10.3	152.32	589.4	Std.	42	49	88	96	109	117	126	136	147	168
					Alt.	52	61	88	96	109	117	126	136	147	168
24	610.0	11.1	163.93	587.8	Std.	45	53	95	104	118	126	136	147	158	181
					Alt.	57	66	95	104	118	126	136	147	158	181
24	610.0	11.9	175.51	586.2	Std.	48	56	102	111	126	136	145	157	170	194
					Alt.	61	71	102	111	126	136	145	157	170	194
24	610.0	12.7	187.06	584.6	Std.	52	60	109	119	135	145	155	168	181	207
					Alt.	65	75	109	119	135	145	155	168	181	207

REFERENCE

[1] Oil and Gas Pipelines by Thomas O.Miesner and William L. Liffler

[2] Design and Construction by Mohitpur

[3] Hydraulics for Pipeliners by C.B.Lester, Vol I

[4] API (RP) 1102 - recommend practice for liquid petroleum pipelines crossing railroads and highways.

[5] API 1104 - Welding of pipelines and related facilities.

[6] API 5L - Specification for line pipe.

[7] API 6D - Pipeline valves (Gate, Plug, Ball, and Check valves)

[8] ASME B 16.5 - Pipe flanges and flanged fittings.

[9] ASME B 16.34 - Valves-flanged ,threaded, and welding end

[10] ISO 3183-1-2-3. 1996 - Petroleum and natural gas industries- Steel pipe for pipelines- Technical delivery condition.