Pipeline Systems- Designing, Construction, Maintenance and Asset Management

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IDC TECHNOLOGIES

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Pipeline Systems- Design, Construction, Maintenance and Asset Management

Revision 3.1

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Introduction and Overview

This chapter provides an introduction to the course and also a brief overview of the course topics. The objective of this chapter is to set the framework for the course and provide the reader with a good feel of the topics covered in the course.

Learning objectives

Fundamental aspects of the following topics:

- Pipeline Basics and factors influencing Pipeline Design.
- Pipeline Route Selection.
- Codes and Standards Affecting Pipeline Design, Construction, Operations and Maintenance.
- Pipeline Design Principles: Hydraulics, Mechanical Design and Materials Selection.
- Pipeline Construction Fundamentals.
- Pipeline Protection and Maintenance.
- Pipeline Economics.
- Physical Quantities and Units used in Pipeline Design.
- Practical Exercises.
- Comprehensive Case Study illustrating different aspects of pipeline design, operations and maintenance.

1.1 Pipeline Basics and Factors Influencing Pipeline Design

Pipelines play a vital role in the transmission of oil and gas from the source to the destination for further refining, processing and storage. Most of developed countries have an extensive pipeline network that help meet energy and product demands at different locations. Pipeline construction and use is increasing at a rapid pace in developing nations. Pipelines traverse large distances and can be above ground or below ground. Pipelines also cross bodies of water such as lakes and rivers. A picture of the Trans-Alaska pipeline is shown in Figure 1.1.

Figure 1.1
Trans-Alaska Pipeline

Facts on some well-known pipelines are presented in Table 1.1

Table 1.1

Facts on Some Well-Known Pipelines

Pipeline	Trans-Alaska	Baku-Tbilisi-Ceyhan (BTC)	West-East Gas
Location	Prudhoe Bay to Valdez	Caspian Sea to Mediterranean Sea	Xingjiang Uygur to Shanghai
Commodity	Crude Oil	Crude Oil	Natural Gas
Length	800 miles	1100 miles	2500 miles
Constr. Dates	1974 – 1977	2003 – 2005	2002 – 2004
Cost	$7.7 billion	$3.6 billion	$5.2 billion
Features	Extreme Terrain and Climate, Permafrost, Environment	Traverses mountain ranges, roads, railways, water bodies	Traverses three mountains, 37 rivers. Used remote sensing technology.
Status	2 million BPD at peak (1988). 890,000 BPD in 2005	150,000 BPD in June 2005. Will reduce by 350, the tankers through Bosphorus Strait	1.3 billion cubic meters of natural gas in 2004, its first year of operation

The design, construction, maintenance and operation of pipeline involve the use of several engineering, scientific and economic principles. The location of the pipeline depends on the location of the source of the commodity and its destination. The routing of the pipeline involves consideration of factors such as the terrain, topography, climate and the environment. Construction techniques are adopted to suit the terrain, the soil and the environment. Compressor stations support the operation of gas transmission lines and pumping stations support pipelines transporting liquids.

The major factors influencing the design and construction of pipelines are listed here.

- Nature of fluid being transported (gas or liquid) and fluid properties.
- Volume flow rate.
- Length of the pipeline.
- Terrain and medium (soil/water) traversed by the pipeline.
- Climatic conditions – extreme heat/cold.
- Environmental constraints and impact on the environment.
- Codes, standards and regulations governing the design, construction and operation of the pipeline.
- Seismic/volcanic conditions.
- Flood plains and potential for flooding.
- Economics.
- Materials.
- Construction, operation and maintenance of the pipeline.

The objective of pipeline design and engineering is to route, design and construct a pipeline that can operate safely with minimal impact on the environment and one that is cost effective both in terms of capital and operating costs. To achieve this objective, sophisticated engineering and economic studies are necessary to optimize variables such as pipeline routing, size (diameter), materials and compression/pumping requirements.

1.2 Pipeline Route Selection

The pipeline is routed to connect the supply and delivery points in an optimal, cost-effective manner keeping in mind the operational costs as well as the environmental impacts. The factors that influence pipeline routing are listed here.

- Location of supply and delivery points.
- Terrain and vegetation.
- Location of control points such as river crossings, mountain passes and densely populated areas.
- Location and nature of flood plains – usually pipelines should operate continuously under 1:50 year flood conditions and should not sustain major damage from a 1:100 year flood.
- Construction access and constructability issues such as the ease with which construction equipment can be moved in and out of suggested routing.
- Requirements and location of maintenance facilities such as pig launching and receiving stations.

Pipeline routing is an iterative process. The shortest route may not be the most cost effective. Engineering and design studies of the proposed alternative routes will have to be under taken to optimize conflicting variables. After a preliminary routing is established, it is assessed with respect to the factors mentioned earlier. Some of the tools and techniques used in the assessment of the preliminary routing are listed here.

- Geographical Information Systems (GIS).
- Detailed Surveying and its results.
- Land and soil data.
- Hydrological data (riverbed depth and flooding).
- Aerial reconnaissance and photographs.
- Satellite imaging and data.
- Site visits.
- Environmental impact studies and their findings.

The preliminary routing is refined and adjusted as necessary based on the results of the route assessment studies.

1.3 Codes and Standards Affecting Pipeline Design, Construction, Operation and Maintenance

Several codes and standards have been developed as guidelines for the design, construction and operation of pipelines. The objective of these codes and standards is to ensure the safety of the personnel and the general public by minimizing the risks of high-pressure pipelines. In addition to codes and standards, pipelines must follow governmental regulations at different levels – federal, state (provincial) and local. Some of the international codes and standards that affect pipeline design, construction and operation are listed here. In some cases a brief description is also provided.

- ASME B 31.8 – Gas Transmission and Distribution Piping Systems: This Code covers the design, fabrication, installation, inspection, and testing of pipeline facilities used for the transportation of gas. This Code also covers safety aspects of the operation and maintenance of those facilities.
- ASME B 31.4 – Pipeline Transportation Systems for Liquid Hydrocarbons and other Liquids: This Code prescribes requirements for the design, materials, construction, assembly, inspection, and testing of piping transporting liquids such as crude oil, condensate, natural gasoline, natural gas liquids, liquefied petroleum gas, carbon dioxide, liquid alcohol, liquid anhydrous ammonia and liquid petroleum products between producers' lease facilities, tank farms, natural gas processing plants, refineries, stations, ammonia plants, terminals (marine, rail and truck) and other delivery and receiving points.
- AS 2885 - Australian Standard 2885 "Pipelines – Gas and Liquid petroleum." This code combines the features of many international and national standards including ASME B31.8, CSA Z662, ISO 13623, API 1104, and ISO 13847.
  It has explicit requirements for the design, documentation, and approval of key processes such as prevention of external interference, control of fracture, and welding procedure qualification.
  It uses an integral risk assessment and threat mitigation process in design and in operation and maintenance.

It adopts the requirements to suit the specific needs of Australian conditions of longer distances, terrain and population densities

- API 5L – API (American Petroleum Institute) Specifications for Line Pipe: Covers welded and seamless pipe suitable for use in conveying gas, water, oil in both the oil and natural gas industries.
- API 6D – Specifications for Pipeline Valves, End Closures, Connectors and Swivels: API 6D is the primary standard for valves used in pipeline service, including gate, plug, ball and check valves. This standard has more stringent testing requirements.
- API 1104 – Welding of Pipeline and Related Facilities.
- ASTM A106 – Seamless Carbon Steel Pipe for High Temperature Service.
- NACE RP-01-92 – Control of External Corrosion on Underground or Submerged Piping System.
- ISO 9001 – Quality Systems for Design/Development, Production, Installation and Servicing.
- API RP 5L2 – Recommended Practice for Internal Coating of Line Pipe for Gas Transmission Service.

1.4 Pipeline Design Principles – Hydraulics, Mechanical Design and Materials of Construction

The design and detailed engineering of pipelines requires the knowledge and application of fluid mechanics (hydraulics), stress analysis and materials science.

The temperature and pressure of the fluid flowing in the pipeline are important parameters that affect the fluid properties as well as the wall thickness and the insulation requirements.

Principles of fluid mechanics are used in the calculation of friction losses, pressure drop, and pumping requirements. Additionally, they are also used in the measurement and metering of flow through the pipelines.

Pipelines are subjected to forces resulting from internal pressure as well as other factors such as wind, thermal expansion, displacements, seismic movements and soil loads. These forces create stresses in the pipeline walls. The mechanical design of pipelines uses the principles of stress analysis to calculate stresses within the pipeline and to ensure that they are well within the allowable limits specified by the codes.

The subject matter of thermodynamics covers topics related to principles of gas compression, pressure - temperature relationships for gas compression, energy and Power requirements for pumps and compressors.

The nature of the commodity flowing in the pipeline and the surrounding environment (soil, water or above ground) determine the material to be used in the pipeline. Different grades of steel can be used depending on cost, wall thickness, welding requirements and toughness. The subject matter of materials science covers the topics related to: selection of appropriate materials for pipeline systems including pipe, valves, fittings, flanges, pumps and compressors, selection of appropriate insulation materials, principles of corrosion, techniques to minimize corrosion including cathodic protection.

1.5 Pipeline Construction Fundamentals

The techniques used in the construction of pipelines depend on the nature of the route traversed by the pipeline – above ground or below ground, the terrain, and crossing of bodies of water, if any. Also, construction techniques are dependant on the season – techniques that are effective during summer may not be appropriate during winter. Construction operations and activities must comply with the regulations in effect along the pipeline route. Most of these regulations are intended to protect the environment and to promote public safety. Regulatory agencies conduct inspections to ensure compliance. Restoration of the environment to pre-construction status constitutes an important part of construction activities. The optimization of construction costs takes place during the route selection process. Common procedures and operations used during the construction process are listed here.

- Construction Surveying.
- Trenching (if below ground).
- Clearing and grading the pipeline path (Right Of Way - ROW).
- Placing the pipe spools on the ROW.
- Stringing the pipe.
- Bending.
- Welding.
- Inspection of pipeline and welds using Non Destructive Testing (NDT) methods.
- Backfilling of trenches and restoring the site and the environment (re-vegetation).

1.6 Pipeline Protection and Maintenance

Pipelines are valuable assets that need to be protected and maintained for optimum performance. The primary issue of concern for buried pipelines is external corrosion due to the surrounding soil. The common methods of protecting buried pipelines are external coating and cathodic protection. External coatings are plastic materials placed on the exterior of the pipe using one of the following methods – wrapping, extrusion or fusion bonding. External coatings not only serve as barriers for corrosion attack but also prevent damage to pipeline during transportation, handling and backfilling. Insulation, rock shield and concrete are also used as external coatings. Cathodic protection involves the use of a sacrificial anode or an impressed current that makes the pipeline the cathode. The method of protection employed depends on the nature and composition of the soil. This is determined by an analysis of the soil. During the design phase, the different types of external coatings and cathodic systems are evaluated and an appropriate protection strategy is chosen based on soil conditions and economics.

Corrosive substances, such as sour gas, being transported in the pipeline can also damage pipelines on the inside. The major problem is sulphide stress cracking (hydrogen embrittlement) caused by the presence of hydrogen sulphide (H_2S). A better understanding of the corrosion mechanism and the selection of appropriate material that will resist the corrosion will minimize internal corrosion problems.

Despite all the care taken during the design and construction of pipelines, there is always the risk of damage to the pipelines. The damage can be mechanical damage due to other equipment or forces due to soil movement. The damage could also be due to corrosion, mechanical defects and operational factors. This necessitates the monitoring of the pipeline to ensure the structural integrity and the operability of the pipeline. The techniques used in assessing the integrity of pipelines are listed here.

- Ultrasonic inspection.
- Radiography.
- Dye penetration tests.
- Magnetic particle testing.
- Cathodic protection survey.
- Magnetic flux.
- Visual inspection.

1.7 Pipeline Economics

The design, engineering and construction of pipelines require significant investment of capital and manpower. Further, the operating expenses of the pipeline also need to be considered. The capital costs and the operating costs are the two principal cost elements in owning and operating a pipeline system. In the initial stages, an economic feasibility study of the pipeline project is required to justify the investment in the pipeline. During such feasibility studies, alternative means of transporting the oil/gas by road or rail will also be considered. The oil/gas can also be fed into an existing line. The alternative that offers the best return on the investment will be chosen. A sample problem involving economic analysis of alternative means of transporting oil is illustrated in Practical Exercise 1.1.

Practical Exercise 1.1
The following data is available on three alternative methods for transporting oil. The cost figures are in millions of dollars. If the transmission company requires a minimum 6% return on investment, which alternative is most economically feasible? Use an analysis period of 30 years for comparison.

Alternative	Initial Investment	Annual Costs
Rail Transport	-	$50M
Lease an Existing Line	-	$60M
New Pipeline	$600M	$5M

Practical Exercise 1.2 illustrates the calculations of return on invested capital and payback period for a pipeline project.

Practical Exercise 1.2
A pipeline project has an estimated capital investment of $600 M. The pipeline will be operational in two years from the start of the construction. Once operational, the pipeline will have projected annual revenue of $105 M for a period of 15 years. Annual operation costs are expected to be $5 M.

Determine:
A. The rate of return for this pipeline project.
B. The pay back period.

Once the feasibility of a pipeline project is proven, further economic analysis is carried out to determine the optimum value of variables such as pipeline diameter, material, wall thickness, routing and pumping/compression requirements. Economics affects almost all design and construction parameters. The results of economic analysis are also used in determining the tariffs to be charged for transmission of commodities through the pipeline.

Further details on the different cost factors and on pipeline economics are presented in Chapter 6.

1.8 Physical Quantities and Units Used in Pipeline Design

The design of pipelines involves engineering and design calculations. It is therefore important to understand the physical quantities (variables) used in pipeline design and engineering calculations.
The key to understanding the physical quantities is to know the definitions of **force, pressure and engineering stress.**

Definitions of Force: Force is vector quantity that represents mass times acceleration.

$$F = m \times a$$

The unit of force in the metric system is *kilogram force* (kg_f), which is defined as the force required to accelerate 1 kilogram mass (kg_m) at the rate of 9.81m/s^2.

The unit of force in the SI system is *Newton (N)*, which is defined as the force required to accelerate 1 kilogram mass (kg_m) at the rate of 1m/s^2.

The unit of force in the imperial or US Customary System (USCS) is *pound force* (lb_f), which is defined as the force required to accelerate 1 pound mass (lb_m) at 32.2 ft/sec^2.
Note that subscripts “m” is used for mass units and subscript “f” is used for force units.

Units of Force:

$$1\ \text{N} = 1\ \text{kg} \times 1\ \frac{\text{m}}{\text{s}^2} \qquad 1\ \text{lb}_f = 1\ \text{lb}_m \times 32.2\ \frac{\text{ft}}{\text{sec}^2}$$

$$1\ \text{kg}_f = 1\ \text{kg}_m \times 9.81 \frac{\text{m}}{\text{s}^2} \qquad g_c = 32.2 \frac{\text{lbm-ft}}{\text{lbf-sec}^2}$$

The conversion factors for force units are:

1 kg_f = 9.81 N, 1kg_f = 2.205 lb_f, and 1lb_f = 4.4462 N

Pressure:
Pressure is force per unit area and it acts uniformly on the surface.
Units of Pressure: N/m^2 (Pascal, Pa),
lb_f/in^2 (psi), kg_f/cm^2, bar
Atmospheric pressure at sea level is
101 kPa or 14.7 psia
Commonly used conversion factors for pressure are: 1 bar = 10^5 N/m^2 = 100 kPa
1 lb_f/in^2 (psi) = 0.0703 kg_f/cm^2 = 6.896 kPa

Temperature:
Units of Temperature (°F or °C): ° F = 1.8 (°C) + 32, °C = (°F)(5/9) – 32
Absolute temperature: Degree Rankine: °R = 460+ °F, Degree Kelvin: °K = 273 + °C

Mass Flow Rate
Units of mass flow rate (lb_m/hr or kg_m/s): 1 kg_m/s = 132.3 lb_m/hr
The mass flow rate will be the same at compressor/pump inlet and outlet as per the law of conservation of mass.

Volume flow rate or liquid/gas throughput:
Units of volume flow rate
Liquids: gallons per minute (gpm), Liters per second (L/s), cubic meters per hour (m^3/hr), barrels per day (bpd).
Useful conversion factors are:

1 bpd = 0.0066 m^3/hr = 0.0292 gpm

Gases: The volume of gas depends on the absolute pressure (gage pressure + atmospheric pressure), and absolute temperature of the gas. The volume flow rate of gases is usually specified in terms of Standard Cubic Feet Minute (SCFM – measured at 60°F and 1 atm. Pressure) or Normal cubic meters per hour (nm^3/hr – measured at 0°C and 1 atm. Pressure).

1 nm^3 = 32.326 SCF and 1 nm^3/hr = 0.622 SCFM

Work/Energy:
Work is force times distance.
Units of work: ft-lbf, N.m, kg_f.m
Energy has the same units of work.

Units of energy: Btu = 778 ft-lb$_f$, Joule (J = N.m)

Power:
Power is the rate of producing work or consuming energy.
Units of power: HP = 550 ft-lbf/sec, 1 W = 1 J/s,
1 HP = 746 kW

An extensive list of conversion factors for various physical quantities is presented in the Appendix

Unit Prefixes:

kilo (k) = 10^3	Mega (M) = 10^6	Giga (G) = 10^9
milli (m) = 10^{-3}	micro (μ) = 10^{-6}	nano (n) = 10^{-9}

Practical Exercise 1.3
The pressure in a natural gas pipeline is 750 psig and the temperature is 125°F. Calculate:
A. The pressure in kPa and kg$_f$ /cm^2.
B. The temperature in °C, K and °R

(solution)
P = 750 psig + 14.7 psi = 764.7 psia

$$P = 764.7 \text{ psia} \times \frac{6.896 \text{ kPa}}{1 \text{ psia}} = 5273 \text{ psia}$$

$$P = 764.7 \text{ psia} \times \frac{0.0703 \text{ kg}_\text{f} / cm^2}{1 \text{ psia}} = 53.76 \text{ kg}_\text{f} / cm^2$$

$$°C = (125°F)(5/9) - 32 = 37.44°C$$

$$K = 37.44°C + 273 = 310.44 \text{ K}$$

$$°R = 125°F + 460 = 585°R$$

Practical Exercise 1.4
The flow of oil in a pipeline is 650,000 barrels per day. Calculate the flow rate in m^3/hr and gpm.

(solution)

$$650000 \text{ bpd} \times \frac{0.0066 \text{ m}^3 / hr}{bpd} = 4290 \text{ m}^3 / hr$$

$$650000 \text{ bpd} \times \frac{0.0292 \text{ gpm}}{bpd} = 18980 \text{ gpm}$$

1.9 Case Study: The Trans-Alaska Pipeline

The Trans-Alaska Pipeline System was designed and constructed to move oil from the North Slope of Alaska to the northern most ice- free port, Valdez, Alaska. The following are some basic facts about the Trans – Alaska Pipeline:

- Length: 800 miles.
- Diameter: 48 inches.
- Crosses three mountain ranges and over 800 rivers and streams.
- Cost to build: $8 billion in 1977, largest privately funded construction project at that time.
- Construction began on March 27, 1975 and was completed on May 31, 1977.
- First oil moved through the pipeline on June 20, 1977.
- Over 14 billion barrels have moved through the Trans Alaska Pipeline System.
- First tanker to carry crude oil from Valdez: ARCO Juneau, August 1, 1977.
- Tankers loaded at Valdez: 16,781 through March 2001.
- Storage tanks in Valdez: 18 with total storage capacity of 9.1 million barrels total.
- The mission of Alyeska's Ship Escort Response Vessel System is to safely escort tankers through Prince William Sound.

The Trans – Alaska Pipeline posed several design and engineering challenges, which called for some innovative and creative solutions. A summary of the engineering and design challenges and the methods adopted to overcome them is presented here as an informative and useful case study. The technical details of the Trans – Alaska Pipeline are also presented here along with explanation of basic terminologies associated with pipelines. The reader is strongly urged to review the case study and technical details of the Trans – Alaska Pipeline to obtain a fundamental understanding of pipeline design, engineering, construction, operation and maintenance.

Design and Engineering Challenges: Permafrost

Art Lachenbruch was a geologist at the U.S. Geological Survey (USGS) in Menlo Park, California, when he first heard about the Trans - Alaska Pipeline project. Lachenbruch was an expert in permafrost, the rock-like layer of frozen soil just below the thin, insulated cover of soil and vegetation in Alaska. In December 1970, he released a study in which he explained the damage a hot pipe would inflict upon the permafrost. At a temperature of 158 to 176°F, the oil in the pipe would thaw a cylindrical area 20 to 30 feet in diameter within a decade. The thawing would cause damage not only to the pipe, but also to the landscape. This observation led to the complete redesign of the pipeline.

With 75% of the 800-mile pipeline passing through permafrost terrain, the engineers came up with three principal redesign plans to fit the needs of each particular area. The consortium of oil companies building the pipeline, Alyeska, decided to have 380 miles of buried pipeline. Four hundred and twenty miles would be elevated on supports or pilings.

The soil on every inch of the pipeline would be tested to figure out which design worked best.

Buried Pipeline

The buried pipeline used was under one of three categories: ***Conventional below ground pipe, Special non-refrigerated buried pipe and Special refrigerated buried pipe.***

Conventional below ground pipe: The designers determined that the conventional below ground pipe could be used in three types of ground: permanently thawed soils, bedrock, and some areas of permafrost which, when thawed, were considered unlikely to cause damage to the pipe. This permafrost was usually a mixture of sand, gravel and ice. Although the method was conventional, the pipeline was not buried like other oil pipelines, which are generally buried in a ditch at a uniform depth. Instead, in Alaska, depending on soil conditions, the engineers buried the pipes at depths of 8ft. to 16 ft. at most locations, but up to a depth of 49 ft. at one location. The pipe is laid on top of a layer of fine bedding material and covered with prepared gravel padding and soil fill material. Zinc ribbons, which serve as sacrificial anodes to inhibit corrosion of the pipe, are buried alongside the pipeline. The Atigun pipe replacement section, 8.5 miles in length, has four magnesium ribbon sacrificial anodes installed. Electrical currents in the earth's surface, called "telluric currents" and caused by the same phenomenon that generates the Northern Lights, can be picked up by the pipeline and zinc anodes. The zinc anodes act like grounding rods to safely return these currents back to the earth, reducing the risk of damage to the pipeline.

Special buried pipe (non-refrigerated): In areas of thaw-unstable soils calling for elevated pipeline construction, but where the pipeline had to be buried for highway, animal crossings, or avoidance of rockslides and avalanches, the line was insulated, to protect the permafrost from the heat of the pipeline, and buried.

The conventional buried section of the pipeline, including the special insulated sections, account for 376 miles of the pipelines total length of 800 miles.

Special buried pipe (refrigerated): For four miles of the route, neither the conventional buried method nor the elevated one was possible. At these locations, pipe had to be buried in the permafrost to avoid getting in the way of the highway or animal migration as well as a precaution against rockslides and avalanches. These stretches of pipe have their own refrigeration system. The pipe sits on two six-inch coolant pipes. Refrigerated brine is circulated through these lines, powered by electric motors that are housed in a nearby building, which also contains a heat exchanger that removes the heat from the coolant to the outside air. The brine goes into the ground at 8 to 10 degrees Fahrenheit and comes out at 18 to 21 degrees Fahrenheit, absorbing a significant amount of heat from the oil in the pipeline.

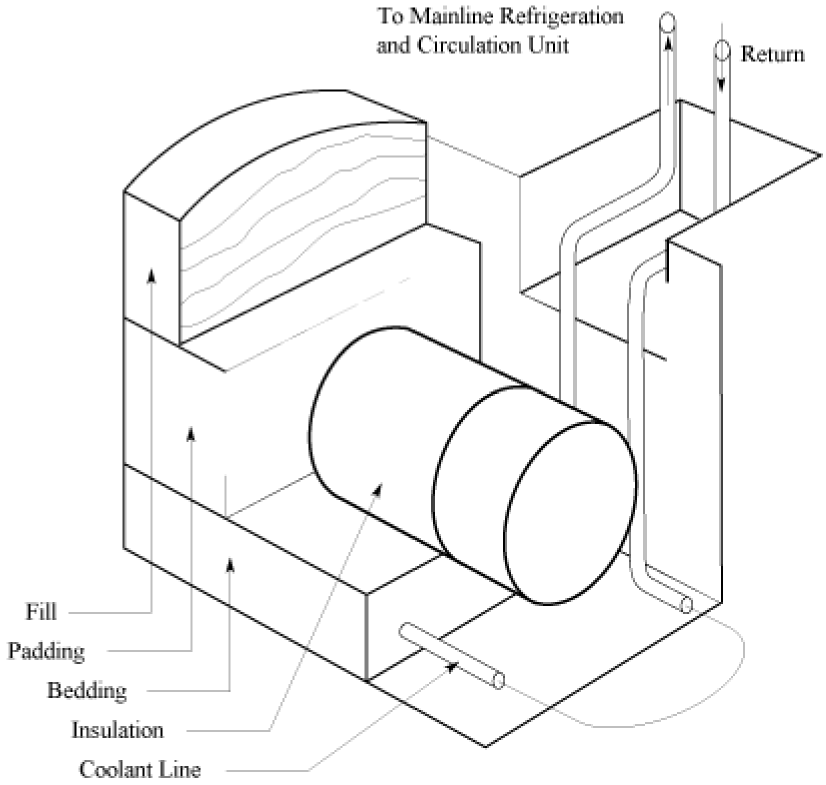

Figure 1.2
Buried, Refrigerated Section of the Trans-Alaska Pipeline

Elevated Pipe
Across 420 miles of the pipeline's route, where the permafrost was unstable and the pipe could not be buried, the engineers designed Vertical Support Members (VSM). These H-shaped pilings elevate the pipe several feet above the ground. The pipe is placed in a Teflon-coated steel shoe that sits on top of the crossbeam. This allows the pipe to slide sideways as it expands (when it's hot) and contracts (when it's cold).
In particularly sensitive areas where the permafrost hovers just above the freezing temperature, the engineers added a passive refrigeration system. At those sites, each VSM was equipped with a pair of tubes that sit inside the VSM and descend into the ground. The tubes are filled with anhydrous ammonia, which absorbs the heat, releases it in to the air and then circulates back into the ground. These 2-inch pipes are called "heat pipes." Heat is transferred through the walls of the heat pipes to aluminum radiators atop the pipes.

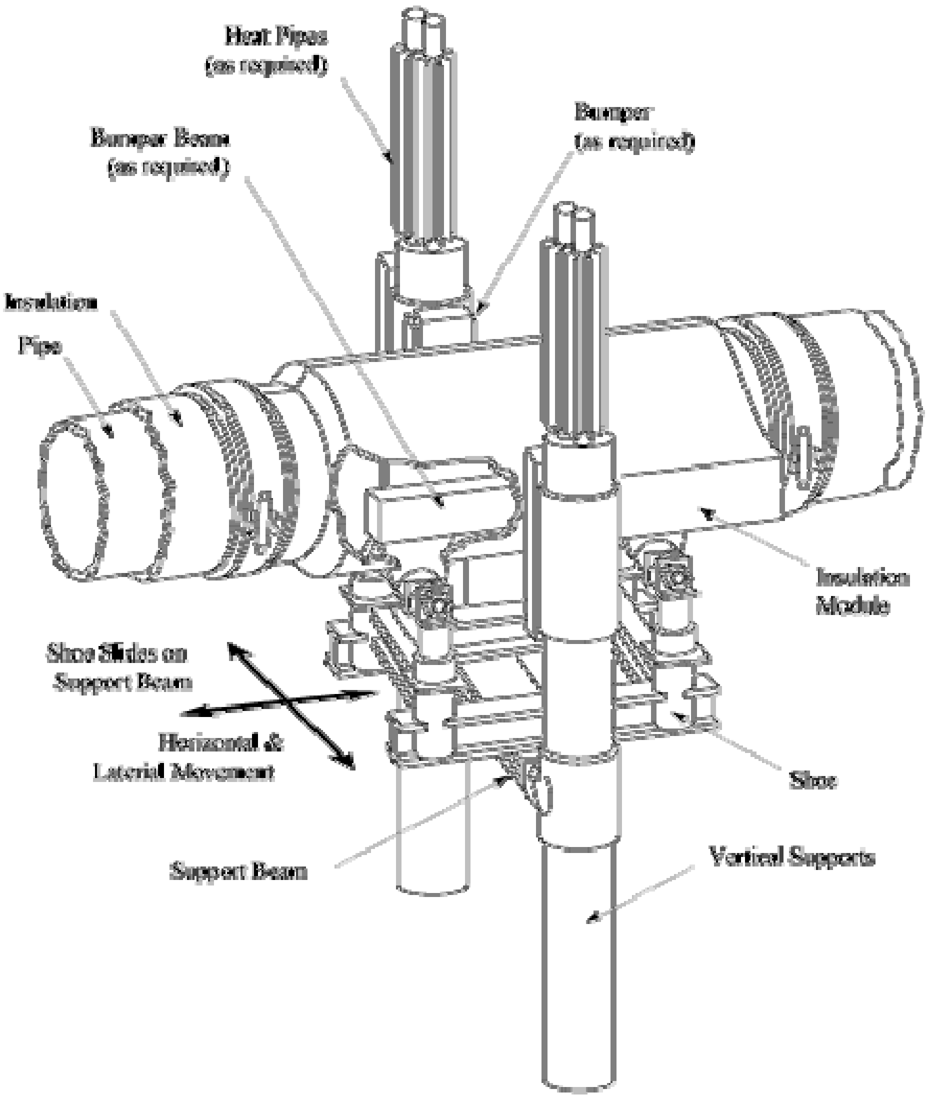

Figure 1.3
Elevated Sections of the Trans-Alaska Pipeline with Vertical Support Members (VSMs)

Technical Details on the Trans Alaska Pipeline

Pipe Dimensions:
Outside diameter: 48 in. (122 cm)
Standard Lengths: 40 ft. and 60 ft.
Wall Thickness: 0.462 in. and 0.562 in.
Pieces required for pipeline: Over 100,000

Steel Grades Used for Pipes:
The steel grades used in the pipeline are given along with the Specified Minimum Yield Strength (SMYS) in parenthesis. Mechanical properties are discussed in greater detail in Chapter 7.

X60 (60,000 psi SMYS)
X65 (65,000 psi SMYS)
X70 (70,000 psi SMYS)

Miles, by Specification, Used in Pipeline Construction:
X60: 44 mi.
X65: 732 mi.
X70: 24 mi.

Wall Thickness Used:
0.462 in.: 466 mi.
0.562 in.: 334 mi.

Thickness/Grade Used:
X60/0.462 in.: 20 mi.
X60/0.562 in.: 24 mi.
X65/0.462 in.: 446 mi.
X65/0.562 in.: 286 mi.
X70/0.462 in.: 0 mi.
X70/0.562 in.: 24 mi.
Atigun Floodplain Pipe Replacement Project (1991)
Thickness/Grade: X70/0.562 in.: 8.47 mi.

Weight Per linear ft.: 235 lbs. (0.462"); 285 lbs. (0.562")
Total weight shipped: 550,000 tons (approx.)

Insulation
Thickness on elevated pipeline: 3.75 in.
Thickness on refrigerated below ground pipeline: 3.2 in.
Thickness on under gravel work pad or road: 2 in. to 4 in. (limited areas only)

Line Fill
Definition: The amount of oil in pipeline from PS 1 to Marine terminal.
The line fill is 9,059,057 bbl.

Number of pipe shoes: 39,000 (approx.)

Types and number pipeline valves
Check: 81
Gate: 71
Block: 24
Ball: 1
Total: 177

Thermal expansion

Thermal expansion: Change in pipe length due to change in crude oil temperature

Tie-in temperature: Actual pipe temperatures at the time when final welds were made, which joined strings of pipe into a continuous line

Hot position: Pipe at maximum oil temperature (145° F)

Cold position: Pipe at minimum steel temperature (-60° F) (pre-startup)

Each 40 ft. length of pipe expands 0.031 inches with each 10° F rise in temperature and contracts the same distance with each 10°F drop in temperature.

Longitudinal expansion of typical 720 ft., straight, above ground segment from minimum tie-in temperature to maximum operating temperature will be 9 inches.

Due to anchoring, the pipeline does not expand lengthwise but shifts laterally on the above ground supports.

Maximum above ground lateral movement:

Tie-in to hot position: 8 ft.

Tie-in to cold position: 4 ft.

Maximum thermal stress: 25,000 psi - where below ground pipeline is fully restrained by the soil, the maximum longitudinal stress due to change in temperature from pipe temperature at tie-in to maximum oil temperature

Above ground sections of the pipeline are built in a zig-zag configuration to allow for expansion or contraction of the pipe because of temperature changes. The design also allows for pipeline movement caused by an earthquake.

Pipeline Operations

Maximum daily throughput: 2.136 million bbl., with 11 pump stations operating.

Rates exceeding 1,440,000 bbl./day use Drag Reduction Agent (DRA) injection.

Fuel required for all operations (fuel oil equivalent): 210,000 gal/day.

Maximum operating Pressure: 1,180 psi

Temperature:

At Pump Station 1: 114 ° F at injection into pipeline

At Terminal: 65 ° F approx.

Total travel time: PS 1 to Valdez: 9 days

Velocity: 3.7 mph.

Weight: 310.9 lb./bbl.

Average Throughput (2002 figures):

1 million bbl./day or 41,705 bbl./hr. or 29,194 gal./min.

Recoverable reserves, at discovery (estimated): 13.7 billion bbl.

Pump Stations (PS)

Number of stations in original design: 12

Number of stations operating as of June 2004 was 6, that is, PS 1, 3, 4, 7and 9;

PS 5 is a relief station

PS 11 is a security site.

There were 8 stations operating at start up (PS 1, 3, 4, 6, 8, 9, 10 and 12).

Number of stations at maximum throughput: 11

Crude oil holding capacity

PS 1: 420,000 bbl.

PS 5: 150,000 bbl.
All others: 55,000 bbl.

Pumps
Number of pumps operating at a throughput of 0.999 million bbl./day: 2 operating at PS 1, 3 and 9. PS 4, 7 and 12 have 1 unit operating.
Definitions:
Full head pump: It is a two-stage pump with both impellers in series. It has one inlet and one outlet.
Half head pump: It is a two-stage pump with both impellers in parallel. It has two inlets and two outlets. It can handle twice the flow of the full head but only produces half the head (pressure rise).
Capacity of mainline pumps:
Half head configuration: 60,000 gpm each
Full head configuration: 20,000 gpm each
Configuration of Pumps:
Half head configuration: PS 2 and 7
Full head configuration: All other pump stations
PS 12 is configured to operate with either 2 full head or 1 half head pump.
Booster pumps: All pump stations have booster pumps to move oil from the storage tanks to the mainline. (PS 1 has three mainline booster pumps to boost oil pressure.) PS 5 also has injection pumps

Power Generation
Size of Power Plants: Ranges from 1.3 MW at PS 12 to 4.7 MW at PS 6, depending on availability of commercial power, presence of topping unit and/or vapor recovery system.
Stations generating electrical power: All stations.
Stations also purchasing commercial power: PS 8, 9 and 12.
Definition of Topping Unit: A mini-refinery that produces turbine fuel.
Location of Topping Units: PS 6, 8 and 10.
Production capacity of Topping Units: 2,400 avg. bbl./day of low sulphur turbine fuel.

Turbines
Fuel requirements:
Gas fired units: 4.3 mcf/unit/day (avg.)
Liquid fired units: 30,000 gal./unit/day (average, for half head configuration) and 24,000 gal./unit/day (average, for full head configuration)
Reaction Turbine Power Output: 18,700 brake horsepower (half head configuration) and 15,300 brake horsepower (full head configuration)

Pig launching/receiving facilities
Three (at PS 1, 4, and Marine Terminal).

Control system
Basic function: Provides instantaneous monitoring, control of all significant aspects of operation, and pipeline leak detection. Operators in the Operations Control Center (OCC) at the Marine Terminal monitor the system 24 hours a day and control oil movement through the pipeline and loading of tankers.
Location: Computer hardware and controllers' consoles are located in the Operations Control Center (OCC) at the Marine Terminal.

Points monitored:

- Pipeline: 3,047 input points and 352 control points.
- Marine Terminal: 1,074 input points and 461 control points.

Remote data acquisition units:

- Pipeline: 14 (each Pump Station, plus the North Pole Metering facility and Petro Star Refinery)
- Marine Terminal: 24
- Metering: 14

Software programming functions:

- Data acquisition and control
- Alarm and data processing and display
- Hydraulic modeling
- Leak detection
- Historical archiving and reporting
- Seismic evaluation

Earthquake Protection

Earthquake magnitude pipeline system designed to withstand:

- 8.5 Richter Scale (maximum).
- Range from 5.5 to 8.5, depending on area.

The instrumentation at field locations consists of accelerometers mounted on concrete pads, which measure strong ground motions in three directions (tri-axial) which are connected to a Digital Strong Motion Accelerograph (DSMA). The DSMA, generally located in the Pump Station control room, processes the signals from the accelerometers in real time and reports alarms and selected data to the central processor at the OCC.

Alyeska's Earthquake Monitoring System (EMS) consists of sensing and processing instruments at all pump stations south of Atigun Pass and at the Valdez Terminal. A central processing unit at the Operations Control Center (OCC) is linked to the Pipeline and Terminal operator consoles. The EMS is specifically designed to process strong ground motions, to interpolate or extrapolate estimates of earth quake accelerations between the sensing instruments and to prepare a mile-by-mile report comparing the estimated accelerations along the pipeline with the pipeline seismic design criteria.

On November 3, 2002, the pipeline withstood a 7.9 earthquake that was centered along the Denali Fault, in the interior of Alaska, approximately 50 miles west of the pipeline. Estimates indicate that the ground along the fault moved 7 feet horizontally and nearly 2.5 feet vertically. The 7.9 quake was the largest on the Denali Fault since at least 1912 and among the strongest earthquakes recorded in North America in the last 100 years.

Glossary of Terms Used in Pipeline Design, Operations and Maintenance

Crude Oil: A fluid made up of various hydrocarbon components, natural gas liquids and fixed gases.
Basic conversions: 1 bbl. = 42 gallons, bbl. per ton = 7.07
Gravity: 29.4° API at 60° F (SG = 0.88)

Block Valve: When closed, the valve can block oil flow in both directions. Block valves include manual gate valves, remote gate valves and station block valves (suction valves and discharge valves).

Station Block Valve: A gate valve installed at the inlet (suction) side and the outlet (discharge) side of the pump station to isolate the pump station from the pipeline in the event of an emergency.

Manual Gate Valve: Block valves that are operated manually. Usually placed in check valve segments periodically to provide more positive isolation than can be provided by check valves.

Remote Gate Valve*:* A remotely controlled block valve for the primary purpose of protecting segments of the line in the event of a catastrophic pipeline break.

Check Valve: Operates one-way and prevents the reverse flow of oil. Check valves are designed to be held open by flowing oil and to drop closed automatically when oil flow stops or is reversed.

Pressure Relief Valve: A valve designed to open automatically to relieve pressure and keep it below a designated level.

Maximum Allowable Operating Pressure: A rating indicating the maximum pressure at which a pipeline or segment of a pipeline may be operated under regulations in normal conditions. Also called pressure rating.

Suction Pressure: Pressure of the oil as it enters a pump station.

Discharge Pressure: Pressure of the oil as it exits a pump station.

Pressure Spike: A sudden, brief rise in pressure.

Pressure Surge: A pressure spike/excursion moving through the pipeline at sonic velocity, produced by a sudden change in velocity of the moving stream that results from shutting down a pump station or pumping unit, closure of a valve or any other blockage of the moving stream.

DRA (Drag Reduction Agent): A long chain hydrocarbon polymer injected into the oil to reduce the energy loss due to turbulence in the oil.

Linefill: The amount of oil in the pipeline from PS 1 to the Marine Terminal.

Slackline: Oil flow that does not completely fill a pipeline.

Packline: Oil flow that completely fills a pipeline.

Breakout Tank: A tank used to relieve surges in a hazardous liquid pipeline system, or to receive and store hazardous liquid transported by a pipeline for re-injection and continued transportation by pipeline.

Permafrost: Any rock or soil material that has remained below 32°F continuously for two or more years.

Pig: A pig is a mechanical device, which is pushed through the pipeline by the oil. Several types of pigs are used to improve flow characteristics, inspect for dents and wrinkles, inspect for pipeline corrosion, and measure pipeline curvature.

Types of Pigs

Scraper: A pig used for cleaning and flow enhancement. Consists of cone-shaped, polyurethane cups on a central body, which matches the shape of the interior pipe wall. Bumper nose, urethane construction and lightweight prevent damage to check valve clappers.

Deformation: A pig, which measures the diameter of the pipe. Defines changes in pipe diameter caused by dents, ovalities, or pipe bending. Changes are recorded and analyzed by engineers.

Corrosion: A pig, which detects corrosion or pitting in the pipe wall. These pigs may use different technologies to collect and record corrosion data.

Ultrasonic Corrosion Pig: Measures and records wall thickness of pipeline using ultra sonic transducers.
Magnetic Corrosion Pig: Detects metal loss in pipe wall by measuring disturbances in a magnetic field.
Curvature: A pig using an inertial navigation system to determine pipeline location, curvature and pipe wall deformation.
Telluric Currents: Electrical currents in the earth's surface which are caused by the same phenomenon that generates the Northern Lights.
Thermal Expansion: Change in pipe length due to a change in crude oil temperature.
Topping Unit: A mini-refinery that draws crude off the line and produces turbine fuel to power the station.
VLCC: Very Large Crude Carrier, tanker 150,000 to 300,000 dwt.
ULCC: Ultra-Large Crude Carrier, tanker more than 300,000 dwt.
VSM: Vertical Support Member
Ultimate Strength: The stress level at which the pipe will fail/rupture or "break." The ultimate strength of the steel is determined by testing during the manufacture of the pipe.
Yield Strength: The stress level above which the pipe will yield/bend/stretch.

1.10 Summary

The fundamental aspects of pipeline design, engineering, construction, operation and maintenance have been explained in this chapter. In addition, the following topics have been covered:

- Physical Quantities and Units typically used in pipeline design.
- Pipeline Economics.
- Codes and Standards Affecting Pipeline Design and Operations.

Finally, a comprehensive case study of the Trans – Alaska Pipeline has been presented to illustrate the different aspects of pipeline design. A “Glossary of Terms Used in Pipeline Design, Operations and Maintenance” is also included.