"OPTIMAL DESIGN OF GAS PIPELINES"

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OPTIMAL DESIGN OF GAS PIPELINES

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CERTIFICATE

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NOMENCLATURE

ANSI: American National Standards Institute.

API: American Petroleum Institute

ASME: American Society of Mechanical Engineer

CGS: City Gate Station.

CNG: Compressed Natural Gas.

GAIL: Gas Authority of India.

GI: Galvanized Iron.

IPRS: Industrial Pressure Regulating Station.

ISO: Indian Standards Organization.

LNG: Liquefied Natural Gas.

MDPE: Medium Density Polyethylene.

MMSCMD: Million Metric Standard Cubic Meters per Day

MAOP: Maximum Allowable Operating Pressure.

ND: Nominal Diameter.

OISD: Oil Industry Safety Directorate.

PCV: Pressure Control Valve.

PNG: Piped Natural Gas.

PSV: Pressure Safety Valve.

ROW: Right of Way.

ROU: Right of Use

ABSTRACT

Natural Gas transportation requires a continuous pipeline network from well head to burner tip. Because its gaseous in nature, Natural gas must be transported through completely inter connected pipeline system to avoid leakage to the atmosphere. The system which transports this gas is comprised of a number of networks within each other.

This work applies analytical network analysis techniques to the pipeline network design problem.

Optimization of pipeline operations has traditionally been approached from inside the pipe. Understanding flow in pipes, friction reduction, proper placements of pumps and compression, and proper material selection are criteria of this focus.

The issues receives attention is spatially-optimal network design .minimum spanning tree are in an analytical algorithm for generatating near-optimal pipeline networks.

Because flow is continuous minimum storage facilities are required at either end (filled supply end and consumer end), operating cost are very low and flow is guaranteed under all conditions of weather with good control. There are no spillages or other handling losses, unless the line developed a leak, which can be easily located and fixed for surface lines.

Oil and Gas pipelines are made from steel or plastic tubes with inner diameter from 30 to 120 cm (about 12 to 47 inches). Where possible, they are built above the surface. However, in more developed, urban, environmentally sensitive or potentially dangerous areas they are buried underground at a typical depth of about 1.3 - 1.6 meters (about 3 feet). The oil is kept in motion by a system of pump stations built along the pipeline and usually flows at speed of about 1 to 6 m/s. Multi-product pipelines are used to transport two or more different products in sequence in the same pipeline.

Case study of Faridabad City Gas Distribution networks illustrate the network concept presented.

CHAPTER 1

INTRODUCTION

Optimization of pipeline operations has traditionally been approached from inside the pipe. Understanding the flow in pipes, friction reduction, proper placement of pumps and compressor and proper material selection are common example of this project.

Design of pipeline network layout contributes to overall system efficiency.

Pipeline networks are continuous structures which can receive or deliver gas volumes at any point along the route so long as the necessary mechanical components exist at the location. These components include a valve and a metering device with downstream pipeline connections. Continuous transportation systems contrast with discrete systems in which receipts and delivery may only be made at certain drop-off and pick up locations.

Pipelines are most heavily utilized for transportation of petroleum and petroleum products; natural gas relies most heavily on pipelines because of its gaseous nature. Here, in this project focus is placed on natural gas pipelines, however most of the concepts may be applied with little modification to other pipeline system.

The efficient and effective movement of natural gas from producing regions to consumption region requires an extensive and elaborate transportation system.

In many instances, natural gas produced from a particular well will have to travel a great distance to reach its point of use. The transportation system of natural gas from its origin, to areas of high natural gas demand.

Transportation of natural gas is closely linked to its storage as well; should the natural gas being transported not be required at that time. It can be put in to storage facilities for when it is needed. There are essentially three major types of pipelines along the transportation route.

The transmission of gas to the consumer may be divided in to four distinct units.

- Gathering system
- Compression station
- The main trunk line
- The distribution line or service line

Pipeline comprises gathering system, mainline and service line provide and economical method of transporting fluids over great distances.

After the initial capital investment required for their construction they show low operating cost and unit cost that decline with large volume of throughput. Many factors must be considered in the design and construction of long distance or cross country gas pipes.

These include the nature and volume of the gas to be transmitted, the length of pipeline, and the type of terrain to be crossed and maximum elevation of the route.

Construction of pipelines provides an economical means of transportation fluids in large volume over great distances .they are convenient to fabricate and install and provide an almost long life span.

Because flow is continuous minimum storage facilities are required at either end (filled supply end and consumer end), operating cost are very low and flow is guaranteed under all conditions of weather with good control. There are no spillages or other handling losses, unless the line developed a leak, which can be easily located and fixed for surface lines.

So design and construction of pipeline transmission system calls for the services of well trained fully dedicated and experienced engineer .complex engineering studies are needed to decide on the diameter yield strength ,pumping horse power required to give the optimum result for ant particular pipeline transportation.

Pipelines may be small or large, up to 48 inches in diameter. Nearly the entire mainline pipe is buried, but other pipeline components such as pump stations are above ground. Some lines are as short as a mile, while others may extend 1,000 miles or more. Some are very simple, connecting a single source to a single destination, while others are very complex, having many sources, destinations, and interconnections. Many pipelines cross one or more state boundaries (Interstate), while some are located within a single state (intrastate), and still others operate on the Outer Continental Shelf and may or may not extend into one or more states.

TYPES OF LINE PIPE

Steel pipe is used in most pipelines transporting hydrocarbons. It is manufactured according to the specifications of the American Petroleum Institute (API 1994, 2000), the

American Society of Mechanical Engineers (ASME), the American National Standards Institute (ANSI), and the American Society of Testing Materials (ASTM).

Various grades of line pipe are specified, based on yield strength. Grade A line pipe has a minimum yield strength of 30,000 pounds per square inch (psi), with Grade B having a minimum yield strength of 35,000 psi. Other grade categories may indicate special fabrication methods. For example, Grade X42 indicates a pipe made of steel with 42,000 psi minimum yield strength; X60 pipe has minimum yield strength of 60,000 psi, etc. Newer pipe grades X70 and X80 are available, but are typically used in offshore or high-pressure gas pipelines for Large-diameter or high-pressure applications.

Line pipe is manufactured as either seamless or welded. These designations refer to how each length, or joint, of pipe is manufactured, not how the joints are connected in the field to form a continuous pipeline. Seamless steel pipe is made without a longitudinal weld by hot- working lengths of steel to produce pipe of the desired size and properties. Welded pipe is made using several manufacturing processes. The two types of pipe differ both by the number of longitudinal weld seams in the pipe and the type of welding equipment used. Welded pipe is the most common pipe used in petroleum pipeline service. The individual lengths of pipe are normally joined by welding sections of pipe together (20 or more feet in length). Pipe made of materials other than steel, including fiberglass, various plastics, and cement asbestos, has been used for special applications involving corrosive liquids, such as saltwater disposal or the transport of highly corrosive crude oils. Most pipes used are manufactured as seamless, or longitudinally welded, pipe.

CHAPTER 2

SYSTEM COMPONENTS

2.1 Tankage

Most pipeline systems have the ability to temporarily store and/or receive shipped product on each end of the pipeline, to facilitate product movements and, in some cases, to accommodate product blending. The size and nature of the storage depend on the business of the pipeline and the product(s) it carries. API and ASME standards have been promulgated to address the design and construction of these facilities. In addition, each facility needs to have waste handling and environmental control capabilities. Again, the nature and capacity of the storage depend on the business of the pipeline and the product(s) it carries. Since many pipelines originate or terminate at coastal facilities to enable marine movements, dock facilities are also often included in a comprehensive definition of a pipeline system.

Along with meeting all of the tankage requirements mentioned above, most facilities has the ability to handle pipeline waste materials and/or interface materials when the pipeline handles multiple products. Transmix, which is the mixture of two hydrocarbons shipped together, must be segregated and either downgraded to an appropriate specification or reprocessed. Crude oil delivered through pipelines also often contains small amounts of produced water. If the crude is at a storage field, this is collected and trucked to wastewater treatment. As a first step in the refining process, refineries will process crude oils in a "desalter" to remove all water. Waters recovered in the desalter are typically combined with other refinery wastewaters and treated in on-site facilities before being used (recycled) or to meet the requirements and pollutant limitations of discharge permits.

Nearly all pipeline terminal facilities have pumps, pig launching/recovery facilities, and the capability of handling pipeline sludge that can accumulate on pipeline walls and is removed during pigging activities. All pipeline terminals need to handle the drainage of lubricants and pipeline products, sampling dump stations, contaminated condensates, etc. Terminals are also required to develop spill prevention, control, and countermeasure plans for responses to accidental releases of products. Some materials recovered in responses to accidental releases, as well as waste materials generated through routine pipeline and terminal operation, qualify as hazardous waste under federal or state environmental laws, so terminals typically also include facilities to temporarily store such materials before transport to permitted treat. A number of facilities have on-site waste water treatment and disposal facilities, which is more cost effective. Depending on the amount of production water that is allowed to be introduced into the pipeline and the source, pipelines that carry certain crude oils, as well as the terminals and refineries that receive them, may also generate waste from pigging operations or tank and equipment cleaning operations that contain naturally occurring radioactive materials (NORM). Such wastes require segregation and treatment or disposal in specially permitted facilities.

The primary shipping and receiving terminals are adjacent to, but not necessarily within pipeline rights-of-way (ROWs) or designated energy corridors. However, interconnecting pipelines and surge or pressure-relief tanks or breakout tanks are integral to interstate pipeline transport and can be expected to be located close to, if not within, the pipeline's ROW or within the designated energy corridor. Also, at changes in elevation, small tanks that serve as pressure stabilizing elements of overall pipeline operations will also be located close to the pipeline.

In accordance with federal or state environmental regulations and to provide for safe operation, typical design and operational considerations that have been incorporated into industry standards are reflected at facilities where storage is occurring. Adherence to relevant standards results in features such as tank dikes, enclosed drainage systems, double seals on floating roof tanks, leak detection, corrosion monitoring and protection, requirements for periodic inspection and monitoring programs, procedures for purging tank vapor spaces and vapor recovery/treatment, and specification of minimum corrosion allowances. All storage locations with capacities above prescribed volumes are also required to develop and periodically exercise emergency response plans for accidental releases of stored product. Some of the API standards and recommended procedures described above address these requirements. Although storage could occur in both aboveground and underground tanks, aboveground tanks generally predominate. Various tank designs are employed, some specifically suited for particular products or conditions. These include cone roof tanks, open-top floating roof tanks, covered floating roof tanks, spherical tanks (typically used for gases stored at high pressure), or bullet-style tanks (Typically used to store gases at high pressures, often in a liquefied state).

2.2 Piping Types

2.2.1 Flowlines

Flow lines are used as part of a crude gathering system in production areas to move produced oil from individual wells to a central point in the field for treating and storage. Flowlines are generally small-diameter pipelines operating at relatively low pressure. Typical flowlines are between 2 and 4 inches in diameters. The size required varies according to the capacity of the well being served, the length of the line, and the pressure available at the producing well to force the oil through the line. Some wells are not pressurized and require pumping to collection systems. Flowlines typically operate at pressures below100 psi.

Flowlines are normally made of steel, although various types of plastic have been used in a limited number of applications. Pipelines used for oil flowlines typically operate at low pressures, and therefore could be made of materials other than steel. Flowline pipe wall thicknesses of 0.216 inch for a 3-inch-diameter pipe are not uncommon, corresponding to a weight of 7.58 lb/lineal foot for a 3-inch-diameter pipe (Kennedy 1993).

2.2.2 Crude Trunk Lines

Crude is moved from central storage facilities over long-distance trunk lines to refineries or other storage facilities. Crude trunk lines operate at higher pressures than flowlines and could vary in size from 6 inches in diameter to as large as 4 feet, as in the TAPS in Alaska.

2.2.3 Product Pipelines

Pipelines carrying products that are liquid at ambient temperatures and pressures do not have to operate at excessive pressures in order to maintain the product in a liquid state. However, liquids that vaporize at ambient temperatures must be shipped at higher pressures. For instance, ethane pipelines can operate at pressures up to 1,440 psi. Product pipelines usually are 12 to 24 inches in diameter, but can be as large as 40 inches in the case of the Colonial Pipeline, which carries gasoline and distillate from the Gulf Coast to northeast markets.

Product pipelines are unique, since they are typically used to transport a variety of petroleum distillate products concurrently in a batch-wise manner. The petroleum products jointly carried in the same pipeline are always chemically compatible with each other, but may differ in physical properties such as density. Some intermixing occurs at the interface of two products sequentially introduced into the pipeline. Operating methods allow for minimizing the interface between products. Regardless of how the commodities are separated while in the pipeline, any mixtures of two commodities are segregated from the rest of the flow at terminals and handled by downgrading (i.e., marketing them as product mixtures of lower quality than the original individual products) or by recovering and refractionating each mixture into the two original petroleum products. In some instances, a sphere or a specially designed pig can be inserted between batches to reduce the amount of mixing.

2.3 Pumping Stations

As with storage tanks, pump stations require an infrastructure of their own. They require waste handling, such as nearby sewer facilities or holding facilities for transfer in batches to an off-site waste-handling facility. Also, the handling and injection of additives, such as for viscosity reduction, often occurs at pump stations. Pumps are typically driven by electric motors; however, engines operating on a variety of fuels (but typically obtained from sources other than the pipeline itself) can also be used to drive the pumps. Depending on location, power may be an issue. In the event of power failures or other significant upset conditions, pump stations are typically equipped with sufficient emergency power generation to support monitoring and control systems to accomplish an immediate safe shutdown.

2.4 Metering Stations

Although primarily utilized to measure the volume, quality, and consistency of product for billing purposes and delivery receipts, storage tank monitoring and product metering can be used with line pressure monitors to verify that pipeline integrity has not been compromised. Any discrepancy could indicate some sort of system leak. Typically there is some "shrinkage" in volume when products are transferred from pipeline to tanks to pipeline. Systems and processes are in place to determine when the shrinkage observed is outside expected values.

2.5 Valve Manifolds

Valves are installed at strategic locations along the mainline pipe to control flows and pressures within the pipe and to isolate pipe segments in the event of upset or emergency conditions. Regardless of design, all valves require regular monitoring and maintenance. Along with pump seals that require continuous leak detection and repair, valve manifolds must be closely monitored and periodically overhauled based on schedules established by the manufacturer (preventative maintenance), reduced performance, and/or observed deterioration and wear.

2.6 Piping Manifolds

Depending on the facility, the presence of piping manifolds can result in a very significant and complex operation at either the origin or destination of a pipeline. Since many interstate pipelines have blending facilities on one end or the other, the manifolds in which such Blending is accomplished can be elaborate and have much more piping than what would normally be required for simple movements from one location to another. Such blending facilities may also be present within a pipeline ROW in a centralized corridor.

2.7 Pigging Stations

Pipeline operators may incorporate the use of pigs, depending on the nature and quality (Purity) of the materials being transported. Pigs can be designed to clean accumulated sludge and debris off the inside walls of a pipe, or to monitor the pipe for conditions such as corrosion (known as "smart pigs"). Pigs are introduced at launching facilities located along the mainline pipe ROW, often in conjunction with a pump station. The pig's outer diameter is the same as, or slightly larger than the internal diameter of the pipe, so that a portion of the pig is compressed when placed inside. In most instances, the pig itself has no power source to propel it along the pipe, but instead is carried along the pipe by the flow of the liquid in the pipe. Obviously, pigs must be removed before reaching the next pump station. Such pig recovery stations are typically immediately upstream of the next downstream pump station. Depending on the product and the age of the pipeline, cleaning and monitoring pigs are routinely introduced into and recovered from the pipeline without any interruption of pipeline operations. Data recorded by smart pigs are typically integrated with the data from the pipeline's supervisory control and data acquisition.

2.8 Supervisory Control and Data Acquisition (SCADA) Systems

Pipelines are monitored and operated using sophisticated SCADA systems. SCADA systems regulate pressure and flow by monitoring and controlling pump operation and the positions of valves. SCADA systems also perform a variety of additional functions including alarm processing, leak detection, hydraulic analysis, pump station monitoring, throughput analysis, and other functions deemed critical to the safe operation of the pipeline.

2.9 Telecommunication Towers

SCADA systems, regardless of their degree of sophistication, are only as good as the communication system that transmits data and commands throughout the pipeline system. A communication system includes equipment, such as telecommunication towers, and cabling to provide voice and/or data communications to the various facilities along the pipeline as well as to the SCADA system components. Real-time data communications are necessary between the control center, the various pump stations, storage/distribution terminals, delivery facilities, and mainline block valve sites.

Real-time operational data communications can be supported through a combination of the following approaches: telephone company circuits, satellite terminals, microwave, point-to-point radio pairs, and fiber optic cable. Often, pipeline systems employ redundant communication links to ensure that critical data are communicated in the event of a failure in one of the systems.

2.10 Mass Flow Meters

There are two types of flow meters used in liquid pipeline systems. The first type is referred to as a volumetric flow meter. In the oil industry, the majority of transfers and sales are measured in volumetric units such as barrels or gallons, so this type of meter is usually applied. In other instances such as for petrochemicals, flow rates are measured in units of pounds by a mass meter. With both types of flow meters, the accuracy of the measurements is periodically checked by a "meter prover." This process is conducted to insure the accuracy of the measured flow quantities. Flow meters are commonly used where custody transfers or sales are involved. Flow meters also offer the pipeline operator the opportunity to monitor for any leaks by performing volume or mass balance checks around specified sections of the pipeline network. These balance checks would typically be performed via the SCADA computer system.

2.11 Valves

Valve types and locations comprise an important facet of liquid pipeline design and operation. Valves located in the mainline must be compatible with pigging equipment. Valve location is a critical design issue to insure that discrete portions of the line can be isolated in the event of a line leak or when maintenance is required. Check valves that would prevent backflows of product down grades in the event of loss of power to pipeline pumps are also essential to prevent over pressurization of pipe segments at the base of grade changes.

2.12 Corrosion Control Systems

Corrosion control of pipeline systems primarily composed of steel and other metals is critical to system integrity. Buried metallic objects will corrode (chemically oxidize) through participation in electrochemical reactions if not adequately protected. Corrosion control is accomplished through a variety of means. In most instances, paints and protective coatings are applied followed by wrapping and taping sections of mainline pipe prior to burial to isolate the metallic pipe and prevent its participation in electrochemical reactions. In addition, cathodic protection is provided through the use of an impressed current or sacrificial anodes to counteract those electrochemical reactions. Various polyethylene- or epoxy-based paints, some also including asphalt and/or coal tar, are used for buried pipe and valves.

Cathodic protection involves either the use of an impressed current or sacrificial (Or galvanic) anode. For impressed-current systems, anodes are buried in the soil proximate to the section of buried pipe being protected. A current is applied to the anodes equivalent to the current that would result from the electrochemical oxidation of the pipe. This current is allowed to flow through the soil to the pipe which then completes the circuit. This impressed current counterbalances the flow of electrons from the pipe to the soil that would otherwise have resulted from the pipe's oxidation, thereby canceling that reaction.. Impressed-current systems can be monitored from the ground as a demonstration of their continued proper performance. Unless malfunctions occur, impressed-current system components that are buried with the pipe will typically not need replacement for 20 to 25 years, and many last over the lifetime of the pipe. SCADA systems can be configured to monitor the performance of impressed-current systems. Alternatively, individuals using monitoring devices can check their performance (i.e., measure the voltage being applied to the pipe) at ground-level monitoring points installed along the length of the pipeline.

An alternative to impressed-current systems is the use of galvanic electrodes. Electrodes composed of magnesium or zinc, both of which corrode more easily than the iron in the pipe, are electrically bonded to and buried along side of the pipe. Current is allowed to naturally flow from the pipe to the ground; however, it is the zinc or magnesium in the electrodes that looses electrons in the process. Thus, the electrodes are "sacrificed" to protect the iron pipe. Galvanic electrodes must be replaced periodically. Site-specific conditions of soil moisture and electrical conductivity determine the proper anode replacement intervals. Typically, such site-specific conditions are determined using a test electrode placed in virtually the identical electrochemical environment, but not connected in any way to the pipeline and easily recoverable, so that the extent of its degradation can be observed and replacement intervals established for the electrodes attached to the pipe, and excavations to expose those electrodes for replacement can be done only as necessary.

CHAPTER 3

PIPELINE DESIGN

3.1 FACTORS INFLUENCING PIPELINE DESIGN

3.1 General Pipeline Design Considerations

The major steps in pipeline system design involve establishment of critical pipeline performance objectives and critical engineering design parameters such as:

- Required throughput (volume per unit time for most petroleum products;
Pounds per unit time for petrochemical feedstocks);

- Origin and destination points;
- Product properties such as viscosity and specific gravity;
- Topography of pipeline route;
- Maximum allowable operating pressure (MAOP); and
- Hydraulic calculations to determine:
- Pipeline diameter, wall thickness, and required yield strengths;
- Number of, and distance between, pump stations; and
- Pump station horsepower required.

3.2 Safety

Safety in pipeline design and construction is achieved by the proper design and application of the appropriate codes and system hardware components, as detailed above. Design codes as set forth in U.S. Department of Transportation's (DOT's) Office of Pipeline Safety (OPS) regulations provide appropriate safety factors and quality control issues during construction. Metering stations and SCADA systems provide continuous monitoring oversight of pipeline operations. Training of pipeline operating and maintenance personnel is also a key ingredient in the ongoing efforts to insure system integrity and safety. Safe operations result from developing and strictly adhering to standard procedures and providing the workforce with adequate training, safety devices, and appropriate personal protective equipment. Standard operating procedures typically are developed with reference to government and standard industry practices, as well as corporate safety policies, experience, philosophy, and business practices. Regulations promulgated by the Occupational Safety and Health Administration (OSHA) and by counterpart agencies at the state level specify the procedures and controls required to ensure workplace safety, including, in some instances, the performance of process safety analyses and the development of very specific procedures for activities thought to represent potentially significant hazards to workers and the public.

3.3 Industry Codes and Standards

The ASME has a long history of developing standards for use in the oil and gas pipeline industry. The scope of the first draft of the ASME Code for Pressure Piping, which was approved by the American Standards Association in 1935, included the design, manufacture, installation, and testing of oil and gas pipelines (ASME B31.4). As the needs of the industry evolved over the years, rules for new construction have been enhanced, and rules for operation, inspection, corrosion control, and maintenance have been added. In addition to ASME, several other organizations, including the API and the National Association of Corrosion Engineers (now known as NACE International), also develop standards used by the pipeline industry.

The industry adheres to the following summary of standards:

- Tank operation and construction (15 standards maintained by a committee operated by API)
- Underground storage caverns (2 API standards)
- Manufacture of line pipe (4 API standards)
- Cathodic protection against corrosion (8 NACE standards and guides)
- Welding (15 American Welding Society [AWS] and 1 API standards)
- Pipeline awareness (2 API standards)
- Pipeline integrity (API Recommended Practice 1129, "Assurance of Hazardous Liquid Pipeline System Integrity")
- Pipeline wall thickness (API Standard B31.G)

The following is a list of some of the primary standards governing pipeline design, manufacturing, construction, and operation:

- API standards (including standards issued jointly by ANSI):

- "Pipeline Maintenance Welding Practices," 3rd edition, API Recommended Practice (RP) 1107
- "Specification for Pipeline Valves (Gate, Plug, and Check Valves)," 21st edition, API 6D1, June 1998 Supplement 2
- "Welding of Pipelines and Related Facilities," ANSI/API Std. 1104, September 1999
- "Specification for Line Pipe," API 5L, March 2004
- "Specification for Line Pipe," API 5L Errata 1, January 2005
- "Steel Pipelines Crossing Railroads and Highways," API 1102 (1993)
- "Marking Liquid Petroleum Pipeline Facilities," 3rd edition, API 1109, July 2003
- "Developing a Pipeline Supervisory Control Center," API 1113, February 2000
- "Movement of In-Service Pipelines," ANSI/API 1117, August 1996
- "Computational Pipeline Monitoring for Liquids Pipelines," API 1130, November 2002
- "Pipeline Variable Uncertainties and Their Effects on Leak Detectability," API 1149, November 1993
- "Evaluation Methodology for Software-Based Leak Detection Systems," API 1155, February 1996
- "Hydrostatic Test Water Treatment and Disposal," API 1157, October 1998
- "Managing System Integrity for Hazardous Liquid Pipelines," API 1160, November 2001
- "In-Line Inspection Systems Qualification Standard," 1st edition, API 1163, August 2005
- "Pressure Testing of Liquid Petroleum Pipelines," ANSI/API RP 1110, March 1997
- "Repairing Crude Oil, Liquid Petroleum Gas, and Product Pipelines," 3rd edition, API RP 2200, May 1994
- "Steel Pipelines Crossing Railroads and Highways," API RP 1102, January 1993

- ASTM standards
- ASME standards

- "Boiler and Pressure Vessel Code," 2004 (triennial updates)
- "Gas Transmission and Distribution Piping Systems," ASME B31.8, 1999
- "Refrigeration Piping," ASME B31.5 and Addenda B31.5A, 1994
- "Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids," ASME B31.4, 1998
- "Power Piping," ASME B31.1, 1998; Addenda B31.1A, 1999; Addenda B31.1B, 2000
- "Process Piping," ASME B31.1, 1999; Addenda B31.3A, 1999
- "Slurry Transportation Piping Systems," ASME B31.11, 1989; Addenda B31.11A, 1991
- "Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids," ASME B3 1.4, 2002
- "Gas Transmission and Distribution Systems," ASME 31.8, 2003

3.4 INDIAN STANDARDS FOR NATURAL GAS PIPELINE SYSTEM

1. IS 15663(Part 1):2006 This code covers requirements and recommendations for the design, materials, construction and testing of pipelines made of steel and used in the transportation of natural gas and re-gasified liquid natural gas (RLING).

2. IS 15663(Part 2):2006 The code covers the minimum requirements for design, installation and testing of pipelines of steel, crossing roads, railways, water courses and other buried services.

3. IS 15663(Part 3):2006 This code covers requirements for pre-commissioning and commissioning of pipelines.

4. IS 15654:2006 The standard provides guidelines for the definition, specification, performance analysis, and application of systems used for supervisory control and data acquisition for oil and gas pipe lines.

5. IS 15655:2006 This standard enlists various types of telecommunication facilities required for smooth and efficient operation and maintenance of oil and gas pipelines.

3.4 Pipeline Coating

Corrosion-resistant coatings are applied to the exteriors of most pipes to inhibit corrosion. These may be applied at the manufacturing plant or a pipe coating plant located separately. However, coatings are also sometimes applied at the construction site. Even for precoated pipe, field dressings of joints and connections are also performed at the construction site just prior to burial. For particularly corrosive products (including some crude oils with high total acid numbers), pipes are also sometimes coated on the inside for corrosion resistance. In addition to the resistance to corrosion they provide, some interior coatings are also designed to reduce Frictional losses between the product and the interior walls of the pipe, thereby reducing the total amount of energy required to move the materials along the pipeline. Protective wrappings, followed by the application of tape to the edges of the spirally applied overlapping wrapping, are often installed on the exterior of the pipe to further assist in corrosion control, but also to primarily protect the pipe from mechanical damage at installation. Wraps and tape often are impregnated with tar or other asphalt-based materials and heated in place once applied, to ensure uniform coverage. Once cured, the exterior coatings are chemically stable and environmentally inert, resisting degradation by soil moisture and bacteria, yet remaining sufficiently flexible that they continue to provide a protective coating on the pipe throughout a wide temperature range. Likewise, wrapping materials and tape are stable and inert (including toward the material being transported in the pipeline) and do not pose a potential for adverse environmental impacts. Figure 1 illustrates installation of an exterior pipe tape wrap prior to the pipe's installation in its trench. Other coatings, such as thin-film epoxy and extruded polymers are also used as alternative to wraps and asphaltic coatings.

Depending on local soil conditions, material of uniform size is sometimes imported to the construction site to form a bed on which the pipe is placed. The same material may also be installed around the sides and top of the pipe before the trench is filled with indigenous soils. Such bedding

FIGURE 1 Coatings Newly Installed Pipe for Corrosion Control (Source: Photo courtesy of Corrosion Control Products Co. Reproduced with permission.)

Material serves two principal functions: protection of the pipe from mechanical damage during installation and trench filling, and stabilization of the pipe in the event of seismic shifts or frost heaves. Sands and gravels are typical bedding materials and are tamped in lifts of 12 to 18 inches per lift to ensure adequate compaction and avoid future subsidence. Bedding materials also assist in draining accumulated water from the vicinity of the pipe.

All newly coated pipe used to transport hazardous liquids must be electrically inspected prior to backfilling to check for faults not observable by visual examination. Material faults such as micro cracks demonstrate a characteristic response to applied current when the detector is operated in accordance with the manufacturer's instructions and at the voltage level appropriate for the electrical characteristics of the coating system being tested.

3.5 Sizing

The dimensions of a pipeline — both the sizes and capacities of the various components — as well as the conditions under which the pipeline system operates dictate the system's capacity. Larger diameter pipes allow for higher mass flows of materials provided other components of the pipeline system, primarily pumps and pressure management devices, are properly sized and positioned. In general, the longer the segment of mainline pipes between pump stations, the greater the drop in line pressure. However, grade changes and the viscosity of the materials being transported can also have major influences on line pressures. API Standard 5L provides dimensions, weights, and test pressures for plain-end line pipe in sizes up to 80 inches in diameter.

Several weights are available in each line pipe diameter. The weight of the pipe in lb/ft, in turn, varies as the wall thickness for a given outside diameter. For instance, API Spec 5L lists 24 different weights in the 16-inch-diameter size (five weights are special weights), ranging from 31.75 lb/foot to 196.91 lb/foot. The corresponding wall thickness ranges from 0.188 inch to 1.250 inches. As the wall thickness increases for a given outside diameter, the inside diameter of the pipe decreases from 15.624 inches for the lightest weight pipe to 13.500 inches for line pipe weighing 196.91 lb/foot. Greater wall thicknesses are selected for high-pressure applications or when the pipe segment might be subjected to unusual external forces such as seismic activities and landslides.

Also, in hard-to-reach places, such as beneath transportation routes and at river crossings or difficult-to-access environmentally sensitive areas, overbuilding in size or quality is sometimes chosen to accommodate future expansion requirements.

3.6 Pressure

Operating pressure of a pipeline is determined by the design flow rate vapor pressure of the liquid, the distance the material has to be transferred, and the size of line that carries the liquid. Pipe operating pressure and pump capabilities and cost typically drive decisions on line size, the number of pump stations, and the like. Grades notwithstanding, line pressure follows a sawtooth curve between pump stations. The maximum and minimum line pressure that can be tolerated, together with the physical properties of the materials noted earlier, dictate the spacing of the pump stations and the motive horsepower of the pumps.

3.7 Product specifications

As noted earlier, critical physical properties of the materials being transported dictate the design and operating parameters of the pipeline. Specific gravity, compressibility, temperature, viscosity, pour point, and vapor pressure of the material are the primary considerations. These and other engineering design parameters are discussed in the following sections in terms of their influence on pipeline design.

3.7.1 Specific Gravity/Density

The density of a liquid is its weight per unit volume. Density is usually denoted as pounds of material per cubic foot. The specific gravity of a liquid is typically denoted as the density of a liquid divided by the density of water at a standard temperature (commonly 60 degree F). By definition, the specific gravity of water is 1.00. Typical specific gravities for the distilled petroleum products gasoline, turbine fuel, and diesel fuel are 0.73, 0.81, and 0.84, respectively.

3.7.2 Compressibility

Many gases that are routinely transported by pipeline are highly compressible, some turning into liquids as applied pressure is increased. The compressibility of such materials is obviously critical to pipeline design and throughput capacity. On the other hand, crude oils and most petroleum distillate products that are transported by pipeline are only slightly compressible. Thus, application of pressure has little effect on the material's density or the volume it occupies at a given temperature; consequently, compressibility is of only minor importance in liquid product pipeline design. Liquids at a given temperature occupy the same volume regardless of pressure as long as the pressure being applied is always above the liquid's vapor pressure at that temperature.

3.7.3 Temperature

Pipeline capacity is affected by temperature both directly and indirectly. In general, as liquids are compressed — for example, as they pass through a pump — they will experience slight temperature increases. Most liquids will increase in volume as the temperature increases, provided the pressure remains constant. Thus, the operating temperature of a pipeline will affect its throughput capacity. Lowering temperatures can also affect throughput capacity, as well as overall system efficiency. In general, as the temperature of a liquid is lowered, its viscosity increases, creating more frictional drag along the inner pipe walls, requiring greater amounts of energy to be expended for a given throughput volume. Very viscous materials such as crude oils exhibit the greatest sensitivity to the operating temperatures of their pipelines. However, in the case of crude oils, the impacts are not only from increases to viscosity, but also due to the solidification of some chemical fractions present in the oils. For example, crude oils with high amounts of paraffin will begin to solidify as their temperature is lowered, and they will become impossible to efficiently transport via a pipeline at some point.

3.7.4 Viscosity

From the perspective of the pipeline design engineer, viscosity is best understood as the material's resistance to flow. It is measured in centistokes. One centistoke (cSt) is equivalent to $1.08 * 10^{-5}$ square feet per second. Resistance to flow increases as the centistokes value (and viscosity) increases. Overcoming viscosity requires energy that must be accounted for in pump design, since the viscosity determines the total amount of energy the pump must provide to put, or keep, the liquid in motion at the desired flow rate. Viscosity affects not only pump selection, but also pump station spacing. Typical viscosities for gasoline, turbine, and diesel fuels are 0.64,7.9, and 5 to 6 cst, respectively.

As the material's viscosity increases, so does its frictional drag against the inner walls of the pipe. To overcome this, drag-reducing agents are added to some materials (especially some crude oils). Such drag-reducing agents are large molecular weight (mostly synthetic) polymers that will not react with the commodity or interfere with its ultimate function. They are typically introduced at pump stations in very small concentrations and easily recovered once the commodity reaches it final destination. However, often, no efforts are made to separate and remove these agents. Drag reduction can also be accomplished by mixing the viscous commodity with diluents. Common diluents include materials recovered from crude oil fractionation such as raw naphtha. Diluents are used to mix with viscous crude feedstocks such as bitumen recovered from tar sands and other very heavy crude fractions to allow their transport by pipeline from production areas to refineries.

3.7.5 Pour Point

The pour point of a liquid is the temperature at which it ceases to pour. The pour point for oil can be determined under protocols set forth in the ASTM Standard D-97. In general, crude oils have high pour points. As with viscosity, pour points are very much a function of chemical composition for complex mixtures such as crude oils and some distillate products, with pour point temperatures being influenced by the precipitation (or solidification) of certain components, such as paraffin.

Once temperatures of materials fall below their respective pour points, conventional pipeline design and operation will no longer be effective; however, some options still exist for keeping the pipeline functional.

These include:

- Heating the materials and/or insulating the pipe to keep the materials above their pour point temperature until they reach their destination.

- Introduce lightweight hydrocarbons that are miscible with the material, thereby diluting the material and lowering both its effective viscosity and pour point temperature.

- Introduce water that will preferentially move to the inner walls of the pipe, serving to reduce the effective coefficient of drag exhibited by the viscous petroleum product.

- Mix water with the petroleum material to form an emulsion that will exhibit an effective lower viscosity and pour point temperature.

- Modify the chemical composition before introducing the material into the pipeline, removing those components that will be first to precipitate as the temperature is lowered. (This tactic is effective for crude oils, but is virtually unavailable when moving distillate products that must conform to a specific chemical composition.)

Waxy crude can be pumped below its pour point; more pumping energy is required, but there is no sudden change in fluid characteristics at the pour point as far as pumping requirements are concerned. However, if pumping is stopped, more energy will be required to put the crude in motion again than was required to keep it flowing. When flow is stopped, wax crystals form, causing the crude to gel in the pipeline. If gelling occurs, the crude behaves as if it had a much higher effective viscosity; consequently it may take as much as five to ten times the energy to reestablish design flows in the pipeline than it did to support stable continuous operation when the crude's temperature was above its pour point.

For some products such as diesel fuels that still contain some waxy components (i.e., saturated, long-chain hydrocarbons), "gelling" may also occur as temperatures are lowered; however, such gelling problems are commonplace in storage tanks and vehicle fuel tanks where the fuel sits motionless for long period of time, but rarely materialize in pipelines where the materials are virtually in constant motion and where their passage through pumps typically imparts some amount of heat. Nevertheless, precipitation or gelling of products contained in pipelines can cause significant operational difficulties and may also result in environmentalImpacts if pipeline ruptures occur during attempts to restart the flow, when a pressure well above design limits could result.

3.7.6 Vapor Pressure

The vapor pressure of a liquid represents the liquid's tendency to evaporate into its gaseous phase with temperature. Virtually all liquids exhibit a vapor pressure, which typically increases with temperature. The vapor pressure of water increases steadily with temperature increases, reaching its maximum of one atmosphere pressure (760 mm Hg, or 14.7 psi absolute [psia]) at the boiling point (212 degree F).

Vapor pressures of petroleum liquids are determined using a standardized testing procedure and are represented as the Reid vapor pressure. Reid vapor pressures are critical to liquid petroleum pipeline design, since the pipeline must maintain pressures greater than the Reid vapor pressure of the material in order to keep the material in a liquid state. Blended (or"boutique") vehicle fuels, required over some periods of the year for air pollution control purposes in some parts of the country, have unique chemical compositions and unique Reid vapor pressures (as mixtures). Consequently, pipelines handling such fuels must constantly monitor their vapor pressure and adjust operating conditions accordingly. Pipelines carrying liquids with high vapor pressures can be designed to operate under a variety of flow regimes. Single-phase flow regimes intend for the entire amount of the material in the pipeline to be in the liquid state. Operators of single-phase liquid pipelines attempt to control pressure and flow to maintain a "full face" of liquids in the pipeline, minimizing the amount of volatilization that is allowed to occur. This maximizes system efficiency and also the longevity of system components. Failure to maintain a full face of liquids in a single-phase liquid pipeline can result in increased risks of fires and explosions. Single-phase liquid pipelines are the most common designs for petroleum liquids. However, pipelines can also be designed as two-phase systems in which both vapor and liquid phases of the material are expected to be present. The variation of flow regimes in such two-phase systems can range from bubbles of vapor distributed in liquid to droplets of liquid suspended in vapor. Typical vapor pressures for gasoline, turbine fuel, and diesel fuel are 15, 2, and 2 psia, respectively.

3.7.7 Reynolds Number

The Reynolds number, named after Osborne Reynolds, the scientist who first proposed its usefulness in studying fluid dynamics, is a dimensionless number that represents the ratio of the inertial force to the viscous force — that is, the ratio of the force moving a fluid to the force that attempts to resist that movement. In a pipeline, the inertial force is related to the fluid's velocity, which is a function of the force applied to it by the pumps. The viscous force is a product of the inherent viscosity of the fluid as well as the frictional drag created by interaction of the fluid with the interior surface of the pipeline. A low value for a Reynolds number (<2100) suggests that the fluid will be moved evenly, so-called laminar flow. Higher Reynolds numbers indicate that forces applied to a fluid are much greater than the forces resisting its movement; consequently its movement will be violent and turbulent. The Reynolds number representing the transition zone

Between laminar and turbulent flows is called the critical Reynolds number (Rcrit), which is typically assigned a value of 2320. The Reynolds number depends on the force applied by pumps, the material's viscosity at operating temperature, and the physical size and cross-sectional shape of the pipe through which the material is moving. Most pipeline designers select these components to establish operating conditions near Rcrit while still delivering the desired throughput.

3.7.8 Darcy Friction Factor

Named after the French engineer Henry Darcy, the Darcy friction factor is a dimensionless number that represents the linear relationship between the mean velocity of a moving fluid and the pressure gradient. The Darcy friction factor is critical in determining the necessary force capabilities of pumps as well as the spacing between pump stations to create the desired flow (and thus throughput) of a liquids pipeline.

3.8 Other Design Considerations

3.8.1 Thermal Stresses

Except where local conditions prevent it, petroleum pipelines are typically buried. Burial depths vary with geographic location, but are typically designed to ensure that the entirety of the pipe is below the local frost line. At such depths, the ambient soil temperatures are relative constant with season, although some minor variations can occur. Despite predictably stable temperature environments, pipeline design also accounts for thermal stresses, both expansions and contractions for the pipe and other components. Expansion joints are employed, and, in some instances, trenches are made extra-wide to allow for lateral movements of the pipe with temperature. Thermal expansion joints, or loops, are also critical in locations where conditions require the pipe to be above ground, for example, at some river crossings.

Thermal stress on pipeline components can also come from internal forces. The vapors of certain volatile hydrocarbon fuels will cause super cooling of the remaining liquids, if allowed to escape from the pipeline system at significant rates. Such super cooling can result in thermal cracking of pipes and pump housings.

3.8.2 Soil and Load Design Considerations

During the design and site preparation phases, soil samples are taken at many points throughout to determine mechanical and thermal stability, corrosivity, and electrical conductance. Soils and subsurface materials are also evaluated for their ability to support the weight of the pipeline support facilities at sensitive areas, such as river crossings. Soil properties such as seepage, slope stability, tensile strength, and soil structure are determined. Industry standards published by the American Society of Civil Engineers (ASCE) outline the necessary site characterization studies (ASCE 2001). In addition to engineering considerations, site characterizations regarding the presence of threatened or endangered plant species and soil organisms may also need to be conducted.

3.8.3 Vertical External Load

Under most conditions, the internal pressures imposed on the pipe by moving fluids far exceed the static pressures on the pipe from the weight of backfill and soil material above it. Consequently, vertical external loading is not typically a matter of serious concern to pipeline designers.

However, there are some circumstances where vertical loading becomes critical, including when pipelines pass beneath rivers, railroads, or highways (also see the discussion below on dynamic vertical loads) or in areas with high snowfall or landslide potential.

3.8.4 Surface Live Loads

In addition to supporting dead loads imposed by earth cover, buried pipes may also be exposed to superimposed concentrated or distributed live loads. Large concentrated loads, such as those caused by truck-wheel loads, railway cars, and locomotive loads, are of most practical interest.

Depending on the requirements of the design specification, the live-load effect may be based on American Association of State Highway and Transportation Officials (AASHTO) HS-20 (AASHTO 1998) truck loads or American Railway Engineering Association (AREA) Cooper E-80 railroad loads (AREMA 2006), as indicated in Table 2.1-1. The values of the live- load pressure, Pp, are given in psi and include an impact factor F = 1.5 to account for bumps and irregularities in the travel surface. Other important impact factors are listed in Table 2.1-2. Note that live loads depend on the depth of cover over the pipe and become negligible for HS-20 loads when the earth cover exceeds 8 feet and for E-80 loads when the cover exceeds 30 feet. Casings can also be used to enhance the protection of the pipe.

Other impacts of loads on pipelines can be deforming the pipe (ovalizing), through-wall bending, crushing side walls, and ring buckling. Because ovalizing the pipe will affect the Reynolds number, the pipeline throughput capacity would also be impacted by such deformations, and the deformed pipeline itself would be subject to accelerated wear and an increased potential for failure. Where buried pipe is subjected to large variations in cyclical surface loads, as in the case of pipe crossing under railroad tracks or highways, federal, state, or local regulations usually specify a minimum burial depth. These typically vary from 3 to6 feet, depending on the type of crossing, the type of excavation (rock or normal excavation), the pipe diameter, and the consequence of failure. For example, API RP 1102, "Steel Pipeline Crossing Railroads and Highways," specifies a minimum depth of cover of 6 feet under railroad tracks and 4 feet under highway surfaces.

If the pipe is buried with less than 2 feet of cover, the continual flexing of the pipe may cause a breakup of the road surface. If the pipe is mortar-lined or coated, the deflection limit due to the cyclic live load should be limited to amplitude of 1%.

3.8.5 Buoyancy

Burying pipelines beneath the natural water table creates unique problems and challenges. During periods of saturation of the aquifer, pipeline segments may become buoyant, even when filled with product. This results in a net upward force on the pipeline segment that could be sufficient to compromise the pipe's integrity. When such conditions are anticipated, special construction techniques need to be employed. Anchoring devices or concrete coatings over the corrosion coatings are installed to help the pipe resist the buoyant force. Mechanisms to reduce the hydraulic pressure of the groundwater in the local area of the pipeline can also be successfully applied.

3.8.6 Movements at Pipe Bends

When unusual internal or external forces are applied to the pipe, it is most likely to respond to such forces by moving at the apex of sidebends, sagbends, and overbends. Forces that can cause pipe movement can include a net outward force generated by internal pressure, thermal expansions or contractions of the pipe due to temperature extremes, hydraulic pressures from groundwater, or seismic activity in the vicinity of the pipe. Natural resistances to such forces include the axial stiffness of the pipe itself, the bearing and shear resistance of backfill and overburden materials, and the extent to which those materials were compacted during construction.

3.8.7 Mine Subsidence

Areas where extensive longwall mining of coal or other resources has occurred represent an increased potential for surface subsidence if mine reclamation activities were inadequate or not performed. Although such mining can occur to depths greater than 1,000 feet, collapse of a mined cavity can affect all overlying strata, causing bending and sagging of each and ultimately forming a subsidence basin at the surface. Typically, the area covered by such subsidence basins is substantially larger than the collapsed mine cavity that caused it. The vertical displacement is greatest at the center of a subsidence basin, but is typically less than the original height of the collapsed cavity. Vertical displacement as well as tilting and shearing forces throughout the basin are of greatest concern for surface structures that lie within the basin's footprint. Forces on buried linear features within the basin's footprint are unique. The bending moments of the sagging overburden strata result in horizontal forces that behave as tensile forces on the outer portions of the basin and compressive forces closer to the center of the basin. Depending on its exact location within the basin, a buried pipeline can be subjected to both forces. The strengths of these forces may be sufficient to buckle pipe or tear pipe connections apart.

3.8.8 Effects of Nearby Blasting

Blasting in the vicinity of a pipeline typically occurs as a result of mining or nearby construction activities. While normally an issue for existing pipelines, blasting effects may be considered for new designs if future land-use plans are known to include the construction of an adjacent pipeline or the development of mined areas. Pipeline stresses generated by nearby blasting can vary greatly, depending on local variations in site conditions, the degree to which the blast is confined, delays between multi-shot blasts, and the type of explosive used. Expressions for peak radial ground velocity (of the resulting pressure wave) and peak pipe stress are based on characterizing the blasting configuration as corresponding to either point or Parallel-line sources.

3.8.9 Fluid Transients

Rapid changes in the flow rates of liquid or two-phase piping systems can cause pressure transients that generate pressure pulses and transient forces in the piping system. The magnitudes of these pressure pulses and force transients are often difficult to predict and quantify. As a result of water hammer, an unbalanced impulsive force called a "thrust" load is applied successively along each straight segment of a buried pipe. This causes a pressure imbalance between consecutive bends. Such hammering actions, if sufficiently strong and continued over long periods of time, can compromise the pipe's integrity or introduce fatigue stress cracks.

3.8.10 In-Service Relocation

It is commonplace to relocate short pipeline segments without taking the pipeline out of service. The process involves careful excavation of the pipe, raising it out of its original trench, and placing it into a prepared parallel trench. Obviously, the new path for the pipeline must be located generally adjacent and proximate to the original path for this relocation to occur without the need of adding new pipe segments. Causes for such relocations include accommodating a new highway or rail crossing, performing over-the-ditch coating renovation, inspecting or repairing pipe submerged in shallow water, or avoiding encroachment. Even though the physical displacements of the pipe are minimal, the newly positioned pipe will be subjected to new longitudinal stresses during its move and thereafter.

3.8.11 Earthquakes and Landslides

Landslides involve the mass movement of native surface and subsurface materials in the uppermost portions of the soil mantle at a moderate to rapid rate (generally greater than1 feet/year). Landslides that are characterized as catastrophic in their impacts typically involve mass movements that are many orders of magnitude more rapid. However, landslides can also involve slow creep of materials over a relatively long period of time to a point where adverse impacts result. In most instances, the movement is downslope as a result of gravitational forces, often aided by water. Landslides are initiated by a variety of forces and events, both natural (e.g., earthquakes, seismic activity, excessive saturation of surface and subsurface soils, and volcanism) and anthropogenic (e.g., nearby use of explosives, surface disturbances on steep slopes brought about by construction activities without appropriate mitigation, clear-cutting of vegetative cover, improper use of herbicides, improper management and release of precipitation). Potential earthquake and landslide impacts to buried pipelines include transitory strains caused by differential ground displacement and permanent ground displacement from surface faulting, lateral spread displacement, soil mass displacement, and settlement from compaction or liquefaction.

3.8.12 Scour at Stream Crossings and Suspended Rock Crossings

Pipelines buried beneath or adjacent to rivers can be compromised over time by the erosive force of the moving water. Scouring can occur that would displace the cover materials and expose the pipe, subjecting it to additional lateral forces and possibly even causing sufficient displacement to break the pipe.

High velocities of water in rocky areas or watercourses with steep banks have the highest scouring potential. Areas prone to flooding can also experience excessive water flow velocities during those periods that can also result in scouring action. The typical response to traversing rivers or drainage ways with high scouring potential is to bury the pipe at greater depths or to suspend the pipe above these areas. In addition, major river crossings are required to be inspected every 5 years for indications of scour and/or exposed pipe.

3.9 Leak Detection

Methods used to detect product leaks along a pipeline can be divided into two categories, externally based (direct) or internally based (inferential). Externally based methods detect leaking product outside the pipeline, and include traditional procedures such as ROW inspection by line patrols, as well as technologies like hydrocarbon sensing via fiber optic or dielectric cables. Internally based methods, also known as computational pipeline monitoring, use instruments to monitor internal pipeline parameters (i.e., pressure, flow, temperature, etc.), which are inputs for inferring a product release by manual or electronic computation (API 1995a).

The method of leak detection selected for a pipeline depends on a variety of factors including pipeline characteristics, product characteristics, instrumentation and communications capabilities, and economics (Muhlbauer 1996). Pipeline systems vary widely in their physical characteristics and operational functions, and no one external or internal method is universally applicable or possesses all of the features and functionality required for perfect leak detection performance. Small leaks on large pipelines are very difficult to detect through these automated and measurement methods.

However, the chosen system should include as many of the following desirable leak detection utilities as possible (API 1995a):

- Possesses accurate product-release alarming,
- Possesses high sensitivity to product release,
- Allows for timely detection of product release,
- Offers efficient field and control center support,
- Requires minimum software configuration and tuning,
- Requires minimum impact from communication outages,
- Accommodates complex operating conditions,
- Is available during transients,
- Is configurable to a complex pipeline network,
- Performs accurate imbalance calculations on flow meters,
- Is redundant,
- Possesses dynamic alarm thresholds,
- Possesses dynamic line pack constant,
- Accommodates product blending,
- Accounts for heat transfer,
- Provides the pipeline system's real-time pressure profile,
- Accommodates slack-line and multiphase flow conditions,
- Accommodates all types of liquids,
- Identifies leak location,

- Identifies leak rate,
- Accommodates product measurement and inventory compensation for various corrections (i.e., temperature, pressure, and density), and
- Accounts for effects of drag-reducing agent.

3.10 Overpressure Protection

A pipeline operator typically conducts a surge analysis to ensure that the surge pressure does not exceed 110% of the maximum operating pressure (MOP). The pressure-relief system must be designed and operated at or below the MOP except under surge conditions. In a blocked line, thermal expansion is a concern, especially if the line is above ground.

3.11 Valve Spacing and Rapid Shutdown

The spacing of valves and other devices capable of isolating any given segment of a pipeline are driven by two principal concerns: (1) maintaining the design operating conditions of the pipeline with respect to throughput and flexibility and (2) facilitate maintenance or repairs without undue disruption to pipeline operation and rapid shutdown of pipeline operations during upset or abnormal conditions. Valve spacing and placement along the mainline are often selected with the intention of limiting the maximum amount of material in jeopardy of release during upset conditions or to isolate areas of critical environmental concern to the greatest extent possible. Valves designed to prevent the backward flow of product in the event of a pump failure check valves) will also be installed in critical locations. Valves may also be required on either side of an exceptionally sensitive environmental area traversed by the pipeline. Finally, valves will be installed to facilitate the introduction and recovery of pigs for pipeline cleaning and monitoring. They also are required to be installed at river crossings over 100 feet wide. The design of these must comply with regulations and industry best practices.

3.12 Pumps and Pumping Stations

Desired material throughput values as well as circumstantial factors along the pipeline route are considered in designing and locating pump stations. Desired operating pressures and grade changes dictate individual pump sizes and acceptable pressure drops (i.e., the minimum line pressure that can be tolerated) along the mainline; grade changes also dictate the placements of the pump stations. Pump stations are often fully automated, but can also be designed to be manned and to include ancillary functions such as serving as pig launching or recovery facilities or serving as the base from which inspections of mainline pipe are conducted. Because there are multitudes of ways in which the desired operating conditions can be obtained and sustained, the outfitting and location of pump stations are also often influenced by economics, typically representing a compromise between few large-capacity pump stations and a greater number of smaller-capacity stations. The overall length of the pipeline (to its terminal destination) and the flexibility needed to add or remove materials along the course of the pipeline also dictate pump station placement.

At a minimum, pump stations include pumps (components that actually contact the fluids in the pipeline and provide kinetic energy) and prime movers (power sources that provide power, typically some form of mechanical energy) to the pumps. To facilitate maintenance and to prevent disruptions of pipeline operation as a result of equipment failure, most pump stations use several pumps arranged in parallel fashion. Typically, all but one of the pumps is capable of producing the desired operating pressures and throughputs, so some pump is constantly off-line and in standby. Pump stations also represent locations where ownership or custody of the material is transferred. For the sake of accountability, such pump stations are also equipped with flow monitoring devices. Pump stations typically also have colocated facilities that support pipeline operation or facilitate shutdowns or maintenance on pipeline segments. Thus, breakout tanks for temporary storage of materials or for use in managing line pressures and controlling product surges are also present at pump stations. Finally, pump stations are, in some instances, colocated with terminal or breakout tankage facilities.

Although certain pump designs are preferred for certain applications, all pumps require regular maintenance and are subject to failure from a variety of factors. Pump maintenance, therefore, is critical to continued safe performance of pipeline systems.

3.12.1 Pump Designs

Pumps of various designs are used in crude oil and petroleum product pipelines. Selection of pump design is based on desired efficiency as well as the physical properties of the materials being moved, especially viscosity and specific gravity. The pump's head pressure, or the pressure differential it can attain, is critical for selecting pumps that are capable of moving fluids over elevation changes.

Two fundamental pump designs are in common use: centrifugal pumps and positive displacement pumps. Centrifugal pumps are preferred for moving large volumes of material at moderate pressure, while positive displacement pumps are selected for moving small volumes of material at higher line pressures. Centrifugal pumps consist of two main components: the impeller and the volute. The impeller, the only rotating component of the pump, converts the energy it receives from the force that causes its rotation into kinetic energy in the fluid being pumped, while the volute converts the kinetic energy of the fluid into pressure. Positive displacement pumps can be of various designs; however, two designs predominate in pipeline applications: reciprocating and rotating pumps. Rotating pumps are often the pump design of choice for viscous fluids such as crude oils. Unlike a centrifugal pump where power demands rise sharply with increasing fluid viscosity, the performance of rotating pumps is generally unaffected by variations in either fluid viscosity or line pressure.

3.12.2 Driver Selection

The component that actually provides power to the pump is referred to as the prime mover. A wide variety of primer movers are in use, including electric motors, gas turbines, and diesel internal combustion engines. In recent years, most long-distance transmission pipelines have begun using electric motors or gas turbines. Virtually any prime-mover pump design combination is possible, with decisions resting primarily on the physical properties of the fluids being pumped, the desired throughputs, operating pressures, and transport speeds for the pipeline and for logistical needs such as meeting operating parameters, availability of power or fuel for the prime mover, and compatibility with SCADA systems in use and the sensors they rely on. Initial costs and maintenance demands can also influence selection. In terms of initial costs, electric motors are far less expensive than any other option. Operating costs (measured as $/brake horsepower/year) are generally uniform across all options; however, overall efficiencies of electric motors are substantially better than other options. When maintenance costs are considered, times between major overhauls of prime movers vary, with electric motors and industrial turbines expected to require the fewest overhauls over time (Kennedy 1993).

3.13 Pigging Devices and Pig Launching/Receiving Facilities

Pipeline pigs come in a wide variety of sizes and designs. Pigs are inserted into the pipeline while it is operational and are carried along by the fluid being pumped. Because they are solid devices constructed of various materials including metal, plastics, and rubber derivatives, pigs must be removed before reaching the next pump. Typically, pig traps, launchers, and recovery facilities are colocated with pump stations. Pigs are designed to perform a wide array of functions. Their basic purpose is threefold: (1) provide a way to clean debris and scale from the inside of the pipe, (2) inspect or monitor the condition of the pipe, (3) or act as a plug or seal to separate products in multi-product commercial pipelines or to isolate a segment for repair without depressurizing the remainder of the pipeline. Pigs designed to clean the pipe can use mechanical means (often called scraper pigs) or chemicals. Pigs that monitor the condition of the pipe are categorized as in-line inspection tools. Monitoring pigs, also sometimes called "instrument pigs" or "smart pigs," can perform a wide variety of functions. Geometry pigs check for deformation of the pipe (which can greatly influence throughput efficiencies, but can also be an early indicator of significant problems that could compromise pipeline integrity). Pipeline curvature, temperature and pressure profiles, bend measurements, corrosion detection, crack detection, leak detection, and product sampling represent some of the other major functions performed by smart pigs. Magnetic flux leakage and ultrasonic technologies are employed for some of these inspections. Another type of pig recently developed is the gel pig. As the name implies, gel pigs consist of a series of gelled liquids that are introduced for a variety of purposes, including serving as a separator between products in a multi-product pipeline, collecting debris (especially after initial construction or repairs that involved opening the pipeline, and dewatering the pipeline. Figure 2.1-2 provides examples of the various types of pigs in use today, while Figure 2.1-3 depicts the typical configuration of a pig launching/recovery facility.

CHAPTER 4

PIPELINE SIZE OPTIMIZATION

Based on projected throughput, different lines sizes are selected for detailed analysis.

Line size: - Diameter, thickness, grade (API), Specific minimum yield strength (SMYS).

4.1DIAMETER:-

Determination of pipeline internal diameter

1. From historical data

2. By calculating erosional velocity and opting 40% of it as actual flowing velocity in the pipeline.

$U_{MAX} = C/p^{0.5}$

Where U_{MAX} = Erosional velocity (m/sec)

p = density of liquid (kg/m^3)

3. By using the following formula for optimum diameter for an oil pipeline.

$D = (q/500)^{0.5}$

Where q = flow rate (bbl/day)

D = Diameter in inches

4. For industrial practices velocity of fluid is considered 3 to 5 ft/second.

For range of velocity we can get different diameter range and thickness of pipe & grade.

4.2 NUMBER OF STATIONS REQUIRED.

$P_{DP} = (P_T + S + (N-1) PS + P_R)/N$

Where

P_{DP} = station discharge pressure or maximum operating pressure (MAOP).

MAOP = (2s*t*S.F.)/D

P_T = Total friction loss = $(0.561264*f*L*p*Q^2)/D_I^{5.}$

S = System static pressure = (Δelevation *p)/144, psi.

N = Number of booster station.

P_S = Station suction pressure, psi.

P_R = Residual or back pressure at the end of line.

s = yield strength (psi).

t = wall thickness (inches).

S.F. = Safety Factor.

D_I = Inside diameter (inches).

D = Outer diameter (inches).

Gas pipeline are like a storage system for city gas distribution system. The pipe should have maximum quantity inside so the pressure drop should be minimum. If we have more pressure drop then we have to build-up more pressure and so compression ratio increases and volumetric efficiency decreases.

FOR CALCULATING THE INTERNAL DIAMETER

EROSIONAL VELOCITY (E_v):- E_v=100/ (29GP/ZRT)

Here G = Gas gravity

P = minimum pipeline pressure (psi)

Z = compressibility factor at the specified pressure and temperature

T = Temperature of flowing gas (^{0}R)

R = Gas Constant (10.73 psia/lb mole.^{0}R)

For actual practice we take 40% of actual erosional velocity

Then, we know that

FLOW RATE =CROSSSECTIONAL AREA * VELOCITY =0.4*(3.14/4) $D^2 * E_V$

4.3 GAS VELOCITY (U)

$U = 0.002122(Q_B/D^2)(P_B/T_B)(ZT/P)$

U = Velocity, ft/sec

Q_B = Flow Rate Measured at Standard Condition (Ft^3/day)

D = DIAMETER OF PIPELINE (INCH)

P_B = Base pressure (psi)

T_B = Base Temperature (^0R)

DESIGNING AS PER INDUSTRY PRACTICE: - for industry practice gas velocity 12-15 meter per second is considered.

FLOW RATE:--

WEYMOUTH EQUATION

$Q = 433.5E\ (T_B/P_B)\ ((P_1^2 - e^s P_2^2)/\ (GT_F LZf))^{0.5}\ D^{2.667}$

Where , E = Pipeline efficiency

e=2.53

L = Equivalent length

$S = 0.0375G\ (H_2 - H_1)/T_F\ Z$

Q = Flow Rate (Ft3/day)

f=friction factor

P_B = Base pressure (psi)

T_B = Base Temperature (^0R)

P_1, P_2= Upstream and Downstream pressure

G = Gas gravity

T_F = Average gas flowing temperature (^0R)

CHAPTER 5

CASE STUDY : SYSTEM DESIGN FOR OF FARIDABAD CITY GAS DISTRIBUTION SYSTEM

5.1 Faridabad Project Planning.

Adani Energy Limited has received the NOC for the development of city gas distribution in cities of Faridabad. By the development of city gas distribution project in these cities, Adani Group wants to supply natural gas to domestic, commercial, industrial consumers and CNG to transport sectors.

City	Planning		
Faridabad	Steel pipeline (Kms.)	MDPE pipeline (Kms.)	CNG stations (Nos.)
	49	50	10

Table 1

PROJECT BREAKUP

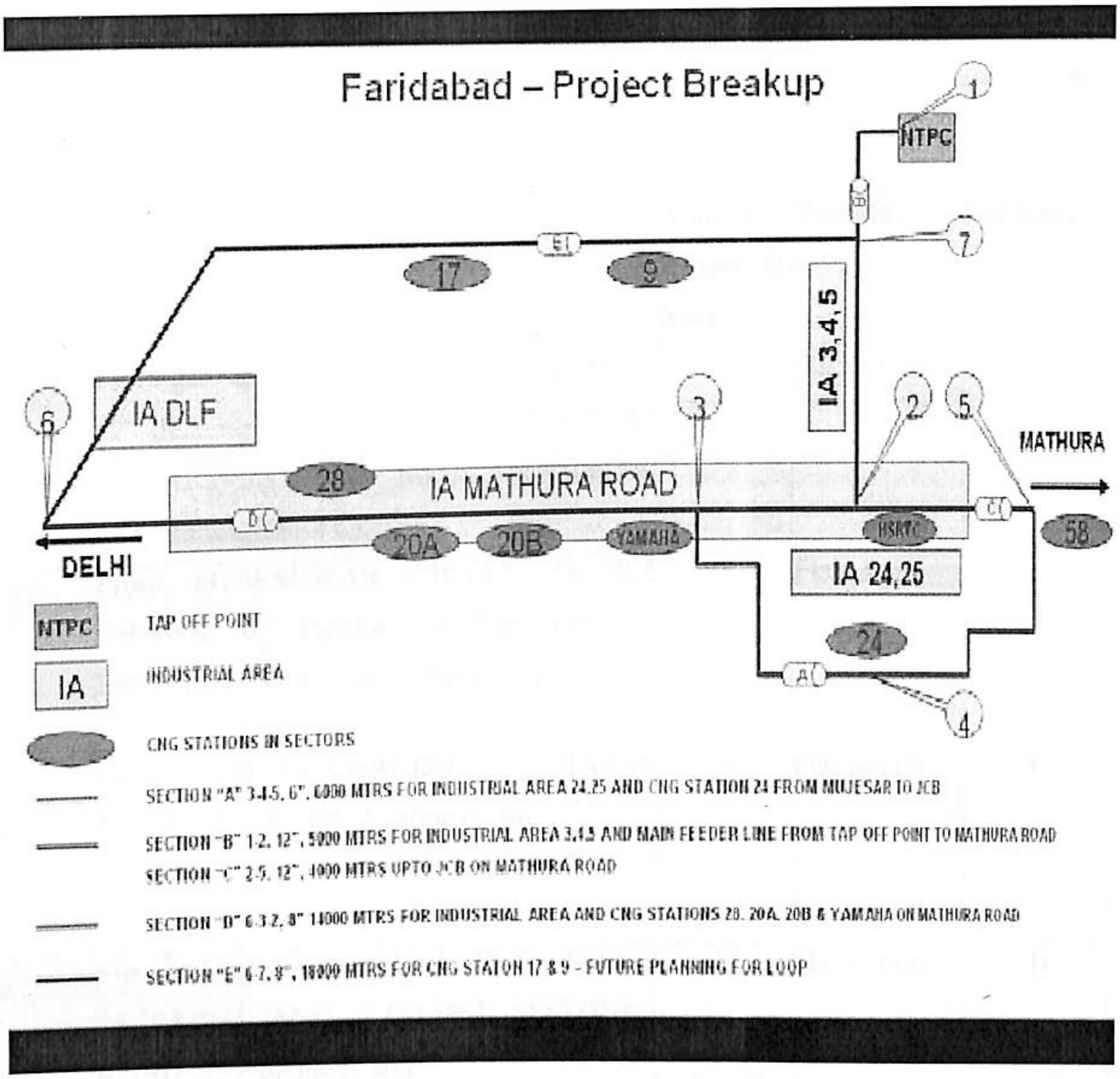


Figure 2 project break up

SECTION WISE DETAILS OF THE MAINLINE ROUTE IN FARIDABAD CITY:

For distribution of natural gas in entire Faridabad, the pipeline will start from the gas source available near NTPC.

Section	Location Details	Approx. Length (In Km)	Terrain	Location
I	From gas tap off point at GAIL's SV station 12" diameter pipeline shall be laid on NTPC To Harayana State Road Transportation Corporation(HSRTC).	5	Flat terrain	B
II	From MUJESHWAR CHOWK To JCB CHOWK 6" Pipeline is laid including Industrial area 24,25and CNG station.	6	Flat terrain	A
III	From JCB To CHAUDHARY CHARAN SINGH MARG 12" Pipeline is laid.	4	Flat terrain	C
IV	For Industrial Area and CNG Stations 28,20A,20B AND YAMAHA MATHURA ROAD 8" Pipeline is laid.	14	Flat terrain	D
V	For CNG stations 17 and 9 & for future planning loop 8" Pipeline is laid.	18		E

Table 2

5.2 Design Philosophy:

The design philosophy shall be to:

- Optimize the use of each component of the overall system (i.e. do not make uneconomical decision on one component to compensate for another).
- Conserve available energy to distribute the gas (i.e. fewer pressure regulating stations).
- Generally minimize the use of mechanical components in the system (i.e. stations, regulators, meters, and valves which are high capital cost, high maintenance and generally reduce pressure availability for distributing natural gas).

The design philosophy will be achieved by:

- Operating the system at the appropriate rated pressure for each component. Failure to do so leaves latent capacity unused and generally results in expenditures on other system components to compensate.
- Minimizing the number of different system pressures
- Carefully evaluating the use of mechanical components and generally minimize usage.

The PE Pipeline Network will provide service mainly to residential customers with some mix of commercial customers.

5.3 SYSTEM PLANNING ASSUMPTIONS

The high gas pressure which is available for city gas distribution network is generally above 30 bar (g). This high pressure will be regulated to a medium pressure of 26-19 bar (g) at facility called City Gate Station (CGS). This CGS will also serve the purpose of custody transfer of gas from gas Transmission Company to gas Distribution Company. The network pressure downstream of the CGS will be in the range of 19-26 bar (g).

Major industrial customers are supplied directly from this steel system, as the pressure above 4 bar makes it an unsafe pressure for direct reticulation to domestic consumers. For the purpose of Piped Natural gas distribution to Domestic, Commercial & Industrial customers, the medium pressure is further regulated to low pressure of 4 bar (g) though the facilities called District Regulating stations (DRS). The distribution network downstream of DRS comprises of Medium Density Polyethylene (MDPE) pipelines network which is laid right up till the customer premises. It is at this point that the 4 bar distribution pressure is further reduced to service pressure of 2 bar-21 mbar based on the customer's requirement of natural gas making it safe to use inside customer premises. MDPE material, apart from having commercial benefits over steel pipeline network also has the advantage in laying in city like conditions. MDPE is also recommended to standardize the distribution system as much as possible. Further, it is proposed to have only three principal distribution pipe sizes of nominal outside diameters of 63 mm, 90 mm and 110 mm. This material is recommended for distribution pressure of up to 4 bar (g); and for the distribution pressure above 4 bar (g) steel pipes of 4" size will be used.

To connect customers, service network is required. These will be installed by fusing a tapping saddle at the top of the distribution main for supply of gas to consumer's premises. At the end of each service, a metal up stand will be installed upon which an isolation valve, regulator and meters will be connected. 21 mbar pressures is recommended for domestic customers, however, pressure for commercial and industrial customers is regulated as per the pressure requirement for that unit. Services are also proposed to be MDPE, with the standard diameters of 20 mm and 32 mm for domestic consumers.

During the detailed design phase of the project, these routes will be refined and selected in detail, to ensure safety, ease of construction and minimal obstruction of other buried services. In addition, during the detailed design the exact location of the CGS and DRS will be nominated, as well as issues such as "Risk Factors with respect to third party system" and "Interruption management".

The principal international standards proposed for the distribution project is ANSI / ASME B 31.8, 'Gas Transmission and Distribution Piping Systems'. In addition, guidelines specified in the American Gas Association (AGA) publication, Volume III Distribution, Book D-1 'System Design' are adopted.

Four principal design variables are nominated for the safety and reliability of a gas distribution system; these are:

➢ **Use of a looped or radial system:** It is proposed to have, as far as practical, a looped distribution design such that back-feed can be supplied during interruptions. As the distribution system expands, it is proposed to expand the transmission system, effectively completing the loop around city.

- **Placement of Valves:** It is proposed to have approximately one valve buried every 2.5 kilometers of distribution main and at every branch off. These valves will be normally open, but will be made accessible from the surface, such that they can be utilized as emergency isolation valves.

- **Layout of services (single and branched):** To save on infrastructure cost, it is proposed, where ever practical, to have one gas service to supply up to three domestic customers. This will, however, have a minor negative impact on the reliability of the system, in that should the service be interrupted, three customers will be affected.

Levels of pressure in the system.

Pressure levels

The concept is based on the pressure levels given in the following sections.

High-Pressure

This applies to the pipelines connecting the Gas transmission System to the "City Gates".

Design data for HP system are sparse

The maximum inlet pressure for the City Gate was taken as 49 bar(g) being known as the supply pressure at off-take points.

Medium pressure

This applies to the pipelines connecting City Gate Station to DRS

Design data for MP system

- Maximum Operation Pressure (MOP) = 26 barg (compatible with ASA Class 300 flanges and fittings);
- Operating Pressure fluctuating between 26 barg to inlet pressure of CNG Compressor and DRS depending on actual operating pressure and pressure drops.

Low pressure

This applies to the pipelines connecting DRS to customers

Design data for LP system

- MOP = 4 barg
- Operating pressure fluctuating between said MOP and the minimum pressure (Pmin) necessary at the inlet to End-Users SC to guarantee MGP to End- users.

City gates are interfacing the High-Pressure system by lowering the pressure to medium pressure level. Pressure reducing stations (DRS) are interfacing MP to LP.

Application to present Projects

The project development considers both Medium Pressure and Low Pressure networks. Major industrial consumers will be directly fed through connection in MP network. CNG On-line/ mother stations will be connected to MP network. Small scale industrial customers in industrial estates will be provided through connections in LP network. Network analysis shall consider that Pmin at the farthest end (end of LP network) shall not be lower than 1.0 bar under normal operation.

5.4 TYPE OF PIPELINE NETWORK

Steel mains

Notwithstanding the major advantages of polyethylene (PE), steel pipelines remain necessary as follows:

High-Pressure Mains

Mandatory for all high-pressure design systems.

Peculiar conditions:

- Location class: the design of High pressure mains shall consider requirements as for Location Class 4 (ASME 31.8) to allow timelessness should the environment change in the future.

➢ Wall thickness: according to ASME B31.8 – Section 841.11 with Design factor of 0.4. In addition, wall thickness shall, in no way, be lower than the values below in function of Nominal Diameter (ND)

4 in. and below	3.9 mm;
6 in.	4.5 mm;
8 in.	5.0 mm;
10 in.	5.6 mm;
20 in.	6.3 mm.

➢ Steel Grade: The Design Concept considers API Grade B Steel quality to offer maximum flexibility for line pipes procurement.

➢ Bend Radius: to allow pigging under special circumstances.

Medium Pressure network

Medium pressure MP network shall be realized in Grade B steel.

Above Ground Mains

Polyethylene being forbidden for above ground crossings, if any, steel mains sections are needed at the crossing with PE/steel transition fitting to be buried with the adjacent PE mains.

Polyethylene

1. Base resin

The PE resins shall be of "Third Generation" (PE 100 or MRS 10) in full compliance with detailed specification.

2. Wall thickness

The study considers a LM network designed and qualified for a MOP of 4 bar. The "Network analysis" and resulting structure and behaviors are based on such design. PE line pipes wall thickness shall be in accordance with the following SDR

➢ Gas mains (ND ≥ 90 mm): SDR 17.6

➢ Gas mains and Service lines (ND ≤ 90 mm): SDR 11.

The corresponding wall thicknesses are given in the table hereunder:

Nominal Diameter	SDR 11		SDR 17.6	
D_e	e_{min} (mm)	e_{max} (mm)	e_{min} (mm)	e_{max} (mm)
32	3	3.5		
63	5.8	6.6		
90			6.3	7.2
160			11.4	12.8

Table 3

5.5 Other equipment

All in-line valves, fitting and equipment shall be PE in full compliance with specifications. With exception to transition fitting to steel piping, Steel equipment is not considered suitable due to sensitivity to corrosion.

Cover - Clearance – Protection

Notwithstanding OISD remains the basis for minimum requirements, such requirements are to be considered as not sufficient. More stringent measures shall be applied.

Sectionalizing

Mains are subdivided into sections by means of valves adequately located in order to Isolate a section for works or in case of up-set. All sectionalizing valves are manually and locally operated.

Network design and analysis defines the number and basic location of sectionalizing valves having in mind the following principles:

- Reduce reasonably the number of End-users that may be directly affected by a section of Mains that need to be put out of services
- Assure best continuity of gas service to other End-users that are not directly supplied from the isolated section by using as much as feasible other sections of the meshed network available to divert the gas flow.

However, considering the cost of valves and difficulty to find suitable location in the city premises, the Sectionalisation Study results from a reasonable compromise.

5.6 PIPELINE NETWORK

The primary network of steel pipelines will provide the core backbone connecting CGS to various DRS. The pressure levels for primary network are between 26 bar(g) to 19 bar(g). While most of the industrial customers are not required to be supplied at this pressure level, only a select few units have specific requirement for medium pressure delivery would be connected to through this network. The design of the primary network is based on the demand forecast to be catered. Pipe sizing is carried on basis of Weymouth formula with efficiency and roughness of pipeline set at 0.9 and 20.4 microns respectively. The primary network is designed to meet 20% higher load than the expected peak flow and is designed to have a 40 meters per second maximum limiting velocity.

Secondary network system consisting of MDPE pipelines operates at pressure level between 4 bar(g) to 1 bar(g). MDPE pipeline network is planned for cluster of industrial units at low pressure. The secondary network would be developed with MDPE 100 grade pipes. The design of the MDPE pipelines is based on the demand forecast to be catered.

Pipe sizing is carried on basis of Weymouth formula and is designed to meet 20% higher load than the expected peak flow. This network is designed to have a maximum limiting velocity of 40 m / sec.

Method of Supply:

Supply Method

Using the domestic / small commercial quantity and large commercial quantity values, and additional information, including location of customers, pressure requirements at major customers, availability of existing supply, and geographic features, optimum method of supply was determined.

Supply Facilities

The supply facilities, existing and new, were considered and include the following:-

- High pressure Steel pipeline main
- Medium pressure Steel pipelines
- Low pressure MDPE mains
- Low pressure MDPE/GI services
- CGS/ DRS / Hot Taps
- Service Connections
- Odorisation Facilities

ANALYSIS OF FARIDABAD CITY GAS DISTRIBUTION NETWORK

Steady state analysis Newton nodal method (multidimensional case)

Here we are analyzing the flow in loop. We are taking the loop 3-4-5-2.

Here, we are considering the point 2 as source node. Because from point 2 gas delivered to load node 3,5 & 4. for simplification, we are considering 3,4 &5 as load node, where gas is distributed to industry. We are considering that gas from tap off point through

City gate stationis coming to point 2 at 25 bars. We are taking 3 cases. here at different flow rate we are calculating the pressure drop in the system.

For solving high pressure network operating above 7.0 bar, we use panhandle A equation.

$Qn = 7.57*10^{-4}Tn/Pn((P-P)D/f.s.L\ T\ z)$

Where,

P= bar

Qn=m/hr

Tn=temperature = 288 k

Pn= 0.1 MPa

D= Internal Diameter (mm)

f = friction factor

L=length of pipe(meter) the friction factor is given by

(1/f) = 6.672(Re) E

E= efficiency factor(varies between 0.8 to 1)

Re= reynold number=Dwp/u

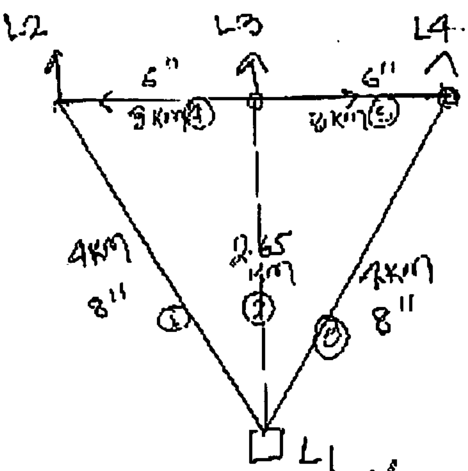
K= 18.43 L/E2 D4.814

Where k = pipe constant

(F)

$L_2 = 200\ m^3/hr$
$L_3 = 100\ m^3/hr$
$L_4 = 150\ m^3/hr$

Source Node = 25 bar (g)



Pipe	Sending Node	Receiving Node	Diameter	Length
1.	1.	2	208 mm	4000 meter
2.	1.	3	208 mm	2650 meter
3.	1.	4	208 mm	4000 meter
4.	3.	2	152 mm	3000 meter
5.	3.	4	152 mm	3000 meter

Branch	1.	2.	3.
Q.	200	100	150

Using common pipe flow equation can be expressed in general form. For any pipe K, the pipe flow equation from node i to node j can be expressed as

$$\phi[(Q_n)_K] = K_K (Q_n^{m_1})_K$$

where $\phi[(Q_n)_K]$ = The flow function for pipe K
K_K = The pipe constant for K
Q_n = The flow in pipe.

m_1 = The flow exponent = 2 for low-pressure networks.
= 1.848 for medium pressure networks
= 1.854 for high pressure network

For medium & high pressure version of the flow equation.

$$\phi\,[(Q_n)_k] = K_k\,(Q_n^{m_1})_k = P_i - P_j = \Delta P_k$$

where $P_i = P_i^2$, $P_j = P_j^2$

ΔP_k = The pressure drop for pipe K

P_i = The absolute pressure at node i

P_j = The absolute pressure at node j

i = The sending node of pipe K

j = The recieving node of pipe K.

The equation for low pressure, and for medium and high pressure can be arranged

$$\phi'(\Delta P_k) = (Q_n)_k = (\Delta P_k / K_k)^{1/2} \quad \text{---(A)}$$
$$\phi'(\Delta P_k) = (Q_n)_k = (\Delta P_k / K_k)^{1/m_1} \quad \text{---(B)}$$

Taking account of the fact that a change of the flow direction of the gas stream may take place in the network, above equation (A) & (B) can be rearranged to the form.

11

$$(Q_n)_K = S_{ij}\left(\frac{S_{ij}(P_i - P_j)}{K_K}\right)^{1/2} \quad \text{— (i)}$$

$$(Q_n)_K = S_{ij}\left(\frac{S_{ij}(P_i - P_j)}{K_K}\right)^{1/m_1} \quad \text{— (ii)}$$

where, $S_{ij} = 1$ if $P_i > P_j$ $(P_i > P_j)$

$S_{ij} = -1$ if $P_i < P_j$ $(P_i < P_j)$

Using $\Delta P_K = K_K\, Q_K^{1.854}$ (for high pressure i.e above 7 bar).

$$K_K = 18.43 \frac{L}{E^2 D^{4.854}}$$

where E = Efficiency factor (0.8 to 1)

D = Diameter (mm)

L = Length (meter)

Taking Efficiency factor $E = 0.90$

$$K_1 = 18.43 \frac{4000}{(0.90)^2 \times (203)^{4.854}}$$

$$= \frac{73720}{1.285496 \times 10^{11}} = 5.735 \times 10^{-7}$$

$$K_2 = 18.43 \frac{2650}{(0.90)^2 \times (203)^{4.854}}$$

$$= \frac{48839.5}{1.285496 \times 10^{11}} = 3.7992 \times 10^{-7}$$

$$K_3 = 18.43 \frac{4000}{(0.90)^2 \times (203)^{4.854}} = 5.735 \times 10^{-7}$$

$$K_4 = 18.43 \times \frac{3000}{(0.90)^2 \times (152)^{4.854}}$$

$$= \frac{55290}{3.156 \times 10^{10}} = 1.752 \times 10^{-6}$$

$$K_5 = 18.43 \times \frac{3000}{(0.90)^2 \times (152)^{4.854}}$$

$$= \frac{55290}{3.156 \times 10^{10}} = 1.752 \times 10^{-6}$$

Pipe	K
1	5.735×10^{-7}
2	3.7992×10^{-7}
3	5.735×10^{-7}
4	1.752×10^{-6}
5	1.752×10^{-6}

The Source Node pressure is fixed at 25 bar. Therefore the pressure at 2, 3 & 4 can be calculated.

$P_i = P_1 - \Delta P_K$

i = Load node

K = Tree branch connecting that node.

$\Delta P_1 = K_1 Q_1^{1.854} = 5.785 \times 10^{-7} \times (200)^{1.854}$

$= 1.05888 \times 10^{-7} \times 10^{5} = 1.058 \times 10^{-2}$

$= 0.01058$ bar

$\Delta P_2 = K_2 . Q_2^{1.854}$

$= 3.7992 \times 10^{-7} \times (100)^{1.854}$

$= 1.9895 \times 10^{-3}$

$= 0.0019895$ bar

$\Delta P_3 = K_3 Q_3^{1.854}$

$= 5.785 \times 10^{-7} \times (150)^{1.854}$

$= 6.2 \times 10^{-9} \times 10^{-7}$

$= 0.0062$ bar

Node	2	3	4
P(bar)	24.48992	24.998	24.9998

CALCULATION OF NODAL ERRORS $F(P_i)$

$$Q_K = S_{ij}\left[S_{ij} \frac{(P_i - P_j)}{K_K} \right]^{1/2}$$

Chord	4	5
$Q\ (m^3/hr^{-1})$	-69.92	-48.96

The Negative sign indicates that the direction of flow is opposite of our assumption.

Nodal error for node 3

$$f_3 = Q_2 - Q_4 - Q_5 - L_3$$

$$= 100 - (-69.92) - (48.96) - 100$$

$$= 118.88$$

Nodal Errors

$$F(P_i)^0 = \begin{bmatrix} -69.92 \\ 118.88 \\ -48.96 \end{bmatrix}$$

Nodal Jacobi matrix, J

$$\Delta P_K = P_i - P_j$$

i = Sending Node for pipe K

j = Recieving node of Pipe K.

Branch	1	2	3	4	5
Q (m³/h)	200	100	150	-69.42	48.96
ΔP (bar)	0.01058	0.0019390	0.0062	-0.004607	-0.002379
Q/ΔP	18903.59	51559.6	24193.5	11518.95	20580.08

Applying Newton-Nodal method
(multi-Dimensional case)

$$J^K (\delta P)^K = -[F(P_i)]^K \quad \text{---(E)}$$

where K: The number of iterations.

J = Jacobi matrix.

$$J = -\frac{1}{m_1}\begin{bmatrix} (Q_1/\Delta P_1 + Q_4/\Delta P_4) & -Q_4/\Delta P_4 & 0 \\ -Q_4/\Delta P_4 & \left(\frac{Q_2}{\Delta P_2}+\frac{Q_4}{\Delta P_4}+\frac{Q_5}{\Delta P_5}\right) & -\frac{Q_5}{\Delta P_5} \\ 0 & -\frac{Q_5}{\Delta P_5} & \left(\frac{Q_3}{\Delta P_3}+\frac{Q_5}{\Delta P_5}\right) \end{bmatrix}$$

$$= -\frac{1}{1.854}\begin{bmatrix} (18903.59 + 11518.95) & -11518.95 & 0 \\ -11518.95 & (51559.6 + 11518.95 + 20580.08) & -20580.08 \\ 0 & -20580.08 & 24193.5 + 20580.08 \end{bmatrix}$$

$$= \frac{1}{1.854}\begin{bmatrix} 30422.54 & -11518.95 & 0 \\ -11518.95 & 83658.63 & -20580.08 \\ 0 & -20580.08 & 44778.58 \end{bmatrix}$$

$$= \begin{bmatrix} -16409.137 & 6213.0258 & 0 \\ 6213.0258 & -45123.32 & 11100.36 \\ 0 & 11100.36 & -24149.72 \end{bmatrix}$$

So, from equation (E).

$$\begin{bmatrix} -16409.137 & 6213.0258 & 0 \\ 6213.0258 & -45123.32 & 11100.36 \\ 0 & 11100.36 & -24149.72 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} -69.92 \\ 118.88 \\ -48.96 \end{bmatrix}$$

$-16409.137x + 6213.0258y = -69.92$ — (i)

$6213.0258x - 45123.32y + 11100z = 118.88$ — (ii)

$11100.36y - 24149.72z = -48.96$ — (iii)

Rearranging the above equation.

$234.68x - 88.86y = 1$ — (iv)

$52.26x - 379.57y + 93.37z = 1$ — (v)

$-226.72y + 493.23z = 1$ — (vi)

From equation (IV)

$$y = \frac{234.68x - 1}{88.86} \quad \text{--- (VII)}$$

Putting equation (VII) in (V)

$$52.26x - 371.57\frac{(234.68x-1)}{88.56} + 479.312 = 1$$

$$295.80x - 150.88z = 1 \quad \text{--- (VIII)}$$

& Putting y in equation (VI), we get

$$886.30x - 318.22z = 1 \quad \text{--- (IX)}$$

Solving equation (VIII) & (IX),

multiplying (VIII) with 318.222 & 150.88 in (IX) & substract

$$94129.478x - 48013.03z = 318.22$$
$$58284.944x - 48018.03z = 150.88$$

$$35844.53x = 167.34$$

$$x = \frac{167.34}{35844.53} = 0.004668$$

Putting the value of x in (VII)

$$y = \frac{234.68 \times 0.004668 - 1}{88.86} = \frac{1.0956 - 1}{88.86}$$

$$= 1.07588 \times 10^{-3}$$

Putting the value of x in equation (viii)

$$z = \frac{295.80 \times 0.004668 - 1}{150.88}$$

$$= \frac{0.38079}{150.88} = 2.58 \times 10^{-3}$$

$$= 0.002528$$

$x = 0.001668$

$y = 0.00107588$

$z = 0.002528$

So, $\delta P_i^0 = \begin{bmatrix} 0.004688 \\ 0.00107588 \\ 0.002528 \end{bmatrix}$

Therefore, New Nodal pressure

$P_1' = P_1^0 + \delta P_1^0$

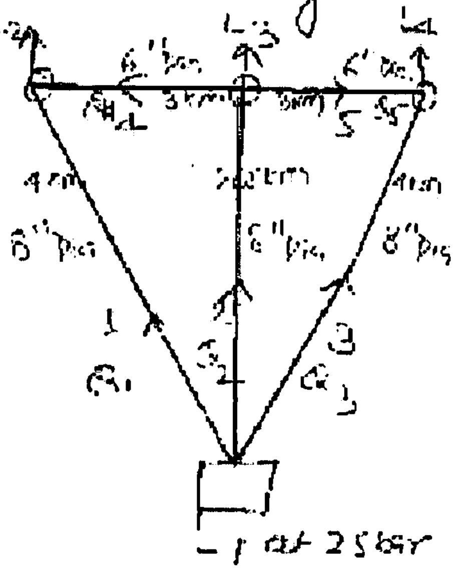
$= 24.98992 + 0.004688 = 24.9941$ bar

$P_2' = 24.998 + 0.00107588 = 24.9990758$ bar

$P_3' = 24.99938 + 0.002528 = 24.996828$ bar

CASE - II

In this case, we are considering the load



$L_2 = 1600\ m^3/hr$

$L_3 = 1000\ m^3/hr$

$L_4 = 1200\ m^3/hr$

Considering initially

$Q_1 = L_1 = 1600\ m^3/hr$

$Q_2 = L_2 = 1000\ m^3/hr$

$Q_3 = L_3 = 1200\ m^3/hr$

Calculating the pressure at Node & Like(?)

we get,

$P_1 = 24.659$ bar

$P_2 = 24.915$ bar

$P_3 = 24.98$ bar.

Case III

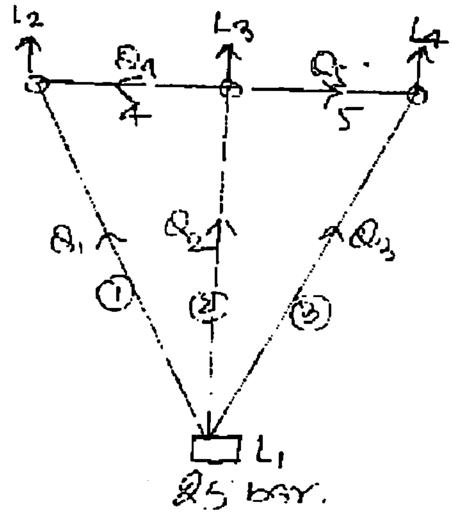
Taking

$L_2 = 6000\ m^3/hr$

$L_3 = 4000\ m^3/hr$

$L_4 = 5000\ m^3/hr$

Keeping the source node inlet pressure 25 bar



we also assume that, initially

$Q_1 = L_2 = 6000\ m^3/hr$

$Q_2 = L_3 = 4000\ m^3/hr$

$Q_3 = L_4 = 5000\ m^3/hr$

Using the same equation & the value of K.

we find,

$\Delta P_1 = K_1 Q_1^{1.854} = 5.735 \times 10^{-7} \times (6000)^{1.854}$

$= 10108632.74 \times 5.735 \times 10^{-7}$

$= 5.799$ bar

$\Delta P_2 = K_2 Q_2^{1.854} = 3.7492 \times 10^{-7} \times (4000)^{1.854}$

$= 3.7492 \times 10^{-7} \times 4766715.412$

$= 1.8109$ bar.

$$\Delta P_3 = K_3 Q_3^{1.854} = 5.735 \times 10^{-7} \times (5000)^{1.852}$$
$$= 4.135 \times 10^{7-7} = 4.135 \text{ bar}$$

We know,

$$P_i = P_1 - \Delta P_k$$

So,

Node	2	3	4
P (bar)	19.201	23.1891	20.65

<u>CALCULATION OF NODAL ERROR</u>

$$Q_K = S_{IJ} \left[\frac{S_{IJ}(P_i - P_J)}{K_K} \right]^{1/2}$$

$$Q_4 = -1 \left[-1 \times \frac{19.201 - 23.1891}{1.752 \times 10^{-6}} \right]^{1/2}$$

$$= -1508.75 \ m^3/hr$$

$$Q_5 = -1 \left[-1 \times \frac{20.65 - 23.1891}{1.752 \times 10^{-6}} \right]^{1/2}$$

$$= -1203.60 \ m^3/hr.$$

<u>For Node 3</u>, Nodal Error (f_3)

$$f_3 = Q_2 - Q_4 - Q_5 - L_3$$
$$= 6000 - (-1508.75) - (-1203.6) - 6000$$
$$= 9712.35$$

Calculating pressure drop in section 4 & 5

$$\Delta P_4 = K_4 \, Q_4^{1.854}$$

$$= 1.752 \times 10^6 \times (-1508.75)^{1.854}$$

$$= -1.37 \text{ bar}$$

$$\Delta P_5 = K_5 \, Q_5^{1.85}$$

$$= 1.752 \times 10^6 \times (-1203.6)^{1.854}$$

$$= -0.9 \text{ bar}$$

So, Nodal error $F(P_1^0) = \begin{bmatrix} -1508.75 \\ 9712.95 \\ -1203.60 \end{bmatrix}$

Branch	1	2	3	4	5
Q (m³/hr)	6000	4000	5000	-1508.75	-1203.60
ΔP (bar)	5.8	1.81	4.19	-1.37	-0.9
Q/ΔP	1034.5	220.9	1201.7	1101.3	1337.3

Applying Newton Nodal method (Multi dimensional case)

$$J^K (\delta P^K) = -[F(P_1)]^K \quad \text{——— Equation (4)}$$

where, K = The number of iterations

J = Jacobi Matrix

After solving these three equations.

we get.

$x = 0.48$

$y = -0.16$

$z = 0.77$

So, $\delta P_1^0 = 0.48$ bar

$\delta P_2^0 = -0.16$ bar

$\delta P_3^0 = 0.77$ bar

Therefore New Nodal pressure

$P_1' = P_1^0 + \delta P_1^0$

$P_1' = 19.201 + 0.48 = 19.681$ bar

$P_2' = 23.1691 + (-0.16) = 23.009$ bar

$P_3' = 20.65 + 0.77 = 21.42$ bar

After solving these three equations.

we get.

$x = 0.48$

$y = -0.16$

$z = 0.77$

So, $\delta P_1^0 = 0.48$ bar

$\delta P_2^0 = -0.16$ bar

$\delta P_3^0 = 0.77$ bar

Therefore New Nodal pressure

$P_1' = P_1^0 + \delta P_1^0$

$P_1' = 19.201 + 0.48 = 19.681$ bar

$P_2' = 23.1691 + (-0.16) = 23.009$ bar

$P_3' = 20.65 + 0.77 = 21.42$ bar

CHAPTER 6

RESULTS AND DISCUSSION

We have analyzed three cases at different load (flow rate) drop in pressure with Newton nodal study (multi dimensional) method. Pressure is very important in pipeline system. We know the pressure at source node which is 25 bars.

Case: 1 at load 1= 200 m3/hr

Load 2= 100 m3/hr

Load 3= 150 m3/hr

After the analysis, we found the pressure at load node

P1= 24.9941 bar

P2= 24.9997 bar

P3= 24.9962 bar

Case: 2 at load 1= 1600 m3/hr

Load 2= 1000 m3/hr

Load 3= 1200 m3/hr

Pressure at load node is found to be

P1= 24.6590 bar

P2= 24.9150 bar

P3= 24.9812 bar

Case: 3 at load 1= 6000 m3/hr

Load 2= 4000 m3/hr

load 3= 5000 m3/hr

Pressure at load node is found to be

P1= 19.681 bar

P2= 23.001 bar

P3= 21.420 bar

So, by doing above analysis we find that pressure drop increases as we keep on increasing load.

CHAPTER 7

CONCLUSIONS

- This work applies established flow analysis techniques to the pipeline network design problem in an effort to develop straight forward analytical design for pipeline industry.
- Several networks with various flow rates are considered and by using flow analysis at different flow rates and calculating pressure drop between two nodes optimization has been done.
- Each subsequent chapter highlights parameters and other design factors which specifically relates to pipeline network design.
- Case studies are used to exemplify the proposed network techniques.
- Perhaps, most significant finding of this work was one of the first, for the apparent shortage of published research work in field of network optimization for pipelines.
- Pipeline network designers in industry tend to rely on trial and error method rather then optimization technique analytical or computational in nature to plan pipeline development.
- The existence of external influences such as environment, existing corridors and production consideration make exact optimization inappropriate in every case, so that near optimal alternative solution provides equal value to the design process.

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