



Design, Construction, and Operation of Petroleum Pipelines

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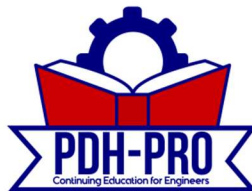
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1 INTRODUCTION

1.1 U.S. PIPELINE NETWORK

The U.S. liquid petroleum pipeline industry is large, diverse, and vital to the nation's economy. Comprised of approximately 200,000 miles of pipe in all fifty states, liquid petroleum pipelines carried more than 40 million barrels per day, or 4 trillion barrel-miles, of crude oil and refined products during 2001. That represents about 17% of all freight transported in the United States, yet the cost of doing so amounted to only 2% of the nation's freight bill. Approximately 66% of domestic petroleum transport (by ton-mile) occurs by pipeline, with marine movements accounting for 28% and rail and truck transport making up the balance. In 2004, the movement of crude petroleum by domestic federally regulated pipelines amounted to 599.6 billion ton- miles, while that of petroleum products amounted to 315.9 billion ton-miles (AOPL 2006). As an illustration of the low cost of pipeline transportation, the cost to move a barrel of gasoline from Houston, Texas, to New York Harbor is only 3¢ per gallon, which is a small fraction of the cost of gasoline to consumers.

Pipelines may be small or large, up to 48 inches in diameter. Nearly all of the 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. U.S. pipelines are located in coastal plains, deserts, Arctic tundra, mountains, and more than a mile beneath the water's surface of the Gulf of Mexico (Rabinow 2004; AOPL 2006).

The network of crude oil pipelines in the United States is extensive. There are approximately 55,000 miles of crude oil trunk lines (usually 8 to 24 inches in diameter) in the United States that connect regional markets. The United States also has an estimated 30,000 to 40,000 miles of small gathering lines (usually 2 to 6 inches in diameter) located primarily in Texas, Oklahoma, Louisiana, and Wyoming, with small systems in a number of other oil producing states. These small lines gather the oil from many wells, both onshore and offshore, and connect to larger trunk lines measuring 8 to 24 inches in diameter.

There are approximately 95,000 miles of refined products pipelines nationwide. Refined products pipelines are found in almost every state in the United States, with the exception of some New England states. These refined product pipelines vary in size from relatively small, 8- to 12-inch-diameter lines, to up to 42 inches in diameter.

The overview of pipeline design, installation, and operation provided in the following sections is only a cursory treatment. Readers interested in more detailed discussions are invited to consult the myriad engineering publications available that provide such details. The two primary publications on which the following discussions are based are: *Oil and Gas Pipeline Fundamentals* (Kennedy 1993) and the *Pipeline Rules of Thumb Handbook* (McAllister 2002).



Both are recommended references for additional reading for those requiring additional details. Websites maintained by various pipeline operators also can provide much useful information, as well as links to other sources of information. In particular, the website maintained by the U.S. Department of Energy's Energy Information Administration (EIA) (<http://www.eia.doe.gov>) is recommended. An excellent bibliography on pipeline standards and practices, including special considerations for pipelines in Arctic climates, has been published jointly by librarians for the Alyeska Pipeline Service Company (operators of the Trans-Alaska Pipeline System [TAPS]) and the Geophysical Institute/International Arctic Research Center, both located in Fairbanks (Barboza and Trebelhorn 2001), available electronically at <http://www.gi.alaska.edu/services/library/pipeline.html#codes>. The Association of Oil Pipe Lines (AOPL) and the American Petroleum Institute (API) jointly provide an overview covering the life cycle of design, construction, operations, maintenance, economic regulation, and deactivation of liquid pipelines (AOPL/API 2007).

1.2 FLUIDS HANDLED

The products carried in liquid pipelines include a wide range of materials. Crude oil systems gather production from onshore and offshore fields, while transmission lines transport crude to terminals, interconnection points, and refineries. The crude oil may be of domestic origin or imported. Refined petroleum product, including gasoline, aviation fuels, kerosene, diesel fuel, heating oil, and various fuel oils, are sizable portions of the pipelines business, whether produced in domestic refineries or imported to coastal terminals. Other materials include petrochemical feedstocks (also known as secondary feedstocks) such as benzene, styrene, propylene, and aromatics such as xylene, toluene, and cumene that are delivered by pipeline from refineries to petrochemical production plants or to other refineries. Also carried by pipeline are liquefied petroleum fuels such as liquefied natural gas (LNG) (albeit over relatively short distances), liquefied petroleum gas (LPG) and propane, all of which are gases at standard temperature and pressure but easily liquefied with the application of pressure.¹ Still other materials transported by pipelines include carbon dioxide and anhydrous ammonia, both transported as liquids under their own pressure.² In recent years, long-distance pipelines have been constructed to carry distillate fractions from the distillation of crude oils from refineries to production facilities for crude feedstocks such as bitumen recovered from tar sands and heavy oils. Such feedstocks are too viscous to be transported by pipeline. However, the distillate fractions are used to dilute these feedstocks, with the resulting mixture being suitable for delivery back to the refinery by pipeline for further processing. Also in recent years, long-distance pipelines have been constructed to carry "produced water"³ from oil and gas fields to refineries and other industrial facilities that use copious amounts of water, but are located in arid areas or areas where water availability is limited. Hydrogen is also delivered by pipeline, albeit over relatively short distances, typically connecting hydrogen production facilities with refineries and other industries that use hydrogen as a starting material in their processes. Table 1.2-1

¹ However, the majority of natural gas transported by pipeline over long distances is transported as a gas.

² Carbon dioxide is also transported by pipeline as a gas.

³ As used here, produced water includes water recovered at the well head or crude oil and/or natural gas production wells.

TABLE 1.2-1 Characteristics of Liquid Hydrocarbons

Type 1(a): liquefied gases (liquefied petroleum gas, ethylene, propylene)

- Highly volatile
- Gas at ambient conditions; maintained at high pressures

Type 1(b): very light grade oils (gasoline)

- Highly volatile
- Evaporates quickly, often completely within 1 to 2 days

Type 2: light grade oils (jet fuels, diesel, No. 2 fuel oil, light crude)

- Moderately volatile
- Will leave residue (up to one-third of spill amount) after a few days
- Moderately soluble, especially distilled products

Type 3: medium grade oils (most crude oils)

- About one-third will evaporate within 24 hours
- Typical water-soluble fraction 10–100 ppm
- May penetrate substrate and persist
- May pose significant cleanup-related impacts

Type 4: heavy grade oil (heavy crudes, No. 6 fuel oil, bunker C)

- Heavy oils with little or no evaporation
- Water-soluble fraction typically less than 10 ppm
- Heavy surface contamination likely
- Highly persistent; long-term contamination possible
- Weathers very slowly; may form tar balls
- May sink in water, depending on product density
- May pose significant cleanup-related impacts
- Low acute toxicity relative to other oil types

Type 5 low API fuel grade oils (heavy industrial fuel oils)

- Neutrally buoyant or may sink
 - Weathers slowly; sunken oil has little potential for evaporation
 - May accumulate on bottom under calm conditions and smother subtidal resources
 - Sunken oil may be resuspended during storms, providing a chronic source of shoreline oiling
 - Highly variable and often blended with oils
 - Blends may be unstable, and the oil may separate when spilled
 - Low acute toxicity relative to other oil types
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provides an overview of the physical characteristics of the more common liquid hydrocarbons transported via pipeline. Typically, more than one product is transported through the same interstate pipeline. In those instances, the line pipe meets the most rigorous product-specific standards among all of the materials being transported. Increased numbers of products carried on a pipeline increase the support facilities, such as tankage, required to receive and segregate the different products.

1.3 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.⁴ 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 a 42,000-psi minimum yield strength; X60 pipe has a minimum yield strength of 60,000 psi, etc. Newer pipe grades X70 and X80⁵ are available, but are typically used in offshore or high-pressure gas pipelines for large-diameter or high-pressure applications.⁶ Additional information on line pipe grades can be obtained from the EUROPIPE and U.S. Steel Tubular Products websites http://www.europipe.de/www/download/EP_TP47_02en.pdf and <http://www.usstubular.com/products/seamslp.htm>, respectively. A more detailed discussion of pipe fabrication can be found in Kennedy (1993).

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 pipes 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 pipe used in the United States is manufactured as seamless, or longitudinally welded, pipe. However, other parts of the world use spiral-welded pipe, which has a spiral weld along its length.

⁴ Yield strength is the amount of tensile force that must be applied to cause a permanent deformation (elongation) in a test sample. The force is typically expressed in units of pounds per square inch.

⁵ X80 line pipe is for large-diameter high-strength pipelines. See http://www.europipe.de/www/download/EP_TP47_02en.pdf. (Accessed July 12, 2006.)

⁶ See “General Description of Seamless Standard and Line Pipe Grades” at <http://www.usstubular.com/products/seamslp.htm>. (Accessed July 14, 2006.)

1.4 SYSTEM COMPONENTS

1.4.1 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.⁷ 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 have 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.⁸ 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 (see Section 2.1.13), 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

⁷ Over 51 API standards have been promulgated relating to storage tanks, dealing with such topics as design criteria, cathodic protection, and operational procedures. A catalogue of all storage tank-related API standards, as well as all other API publications, is available at the API website: <http://www.api.org/Publications>. (Accessed January 11, 2007.) API standards can be purchased electronically from a number of vendors. See, for example: http://global.ihc.com/search_res.cfm?currency_code=USD&customer_id=2125452C2E0A&shopping_cart_id=2825285B244A403C415B5D58250A&rid=Z56&mid=Z56&country_code=US&lang_code=ENGL&input_doc_title=storage%20tanks&org_code=API. (Accessed January 11, 2007.)

⁸ However, when the produced water recovered at the production well contains naturally occurring radioactive material (NORM), additional controls are typically employed to exclude this water from the pipeline to the greatest extent possible so as to prevent NORM contamination of the pipeline and its associated components. Produced water containing NORM is typically reintroduced into the oil-bearing formation through injection wells.



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