Material Handling - An Overview:

material handling means: *providing the right amount and the right material in the condition at the right place at the right time in the right position and for the right cost ,by using the right method.*
it simply picking up, moving, and lying down of material through manufacture.

material handling Definitions: *is the movement and storage of material at the lowest possible cost through the use of proper method and equipment .*

Objectives of Material Handling

1-Reduce Unit Material Handling Cost

- Eliminate Unnecessary Handling
- Handle Material in Batch Lots
- Minimize Required Handling Time
- Replace Handling Equipment as Appropriate

2- Reduce Production Time

- Minimize Delays of Machine Operations
- Maintain Uniform, Appropriate Movement of Material
- Use Automatic Processing When Appropriate
- Coordinate All Material Handling

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5 - Reduce Overhead

- Minimize Non-Productive Labor
- Prevent Damage to Materials

6- Conserve Floor Space

- Avoid Excessive Stock Storage
- Move Materials in a Position to Save Space
- Use Equipment Requiring No Floor Space

7 - Prevent Accidents

- Reduce Physical Load Required
- Insure Handling Equipment is Safe

8 - Improve Employee Morale

- Provide Proper Relationship Between Employee & Work

Principles of Material Handling

There are 10 principles of material handling:

1. Planning Principle
2. Standardization Principle
3. Work Principle
4. Ergonomic Principle
5. Unit Load Principle
6. Space Utilization Principle
7. System Principle
8. Automation Principle
9. Environmental Principle
10. Life Cycle Cost Principle

- **The several factors that must be known when a material handling system is designed include:**
    1. Form of material at point of origin, e.g., liquid, granular, sheets, etc.
    2. Characteristics of the material, e.g., fragile, radioactive, oily, etc.
    3. Original position of the material, e.g., under the earth, in cartons, etc.
    4. Flow demands, e.g., amount needed, continuous or intermittent,timing, etc.
    5. Final position, where material is needed, e.g., distance, elevation differences, etc.
    6. In-transit conditions, e.g., transocean, jungle, city traffic, in plant, etc., and any hazards, perils, special events or situations that could occur during transit.
    7. Handling equipment available, e.g., devices, prices, reliability,maintenance needs, etc.

8. Form and position needed at destination.
9. Integration with other equipment and systems.
10. Degree of control required.

   Other factors to be considered include:
   - Labor skills available
   - Degree of mechanization desired
   - Capital available
   - Return on investment
   - Expected life of installation

Material Handling Equipment's:

These may broadly be divided into the following types:

1. Fixed Path equipment's
2. Semi-Fixed Path equipment's
3. Variable Path equipment's
4. Accessories

- **Fixed Path equipment's:**
  Conveyors , Chutes , Pipelines / Tubes , Elevators , Lifts

  Advantages:

1. More economical if large volume of material moved to same place
2. One power supply to drive entire "belt" – more economical
3. Reduction in need for lot identification tags
4. Can be used to pace the workers

  Disadvantages

1- Less economical if material follows diverse paths

- **Semi Fixed Path Material Handling:**
  Cranes , Tracks

  Advantage

  1- Can cover a wider area

  Disadvantage

  2- Still limited to area covered

- **Wide Area (Variable Path):**

Powered , Manual

Advantage

1- Flexible

Disadvantage

2 - Must have portable power supply with each piece of equipment

- **Accessory Items:**

  1- Carriers

  Skids , Pallets

  2- Containers

  Tote Boxes , Baskets , Pans

  3- Hoist Accessories

  Chains , Clamps , Slings , Chime Hooks , Spreader Bars lectures

The Unit Load Concept:

A unit load is either a single unit of an item, or multiple units so arranged or restricted that they can be handled as a single unit and maintain their integrity.

- **Advantages of unit loads**:
  1- .More items can be handled at the same time, thereby reducing the number of trips required and, potentially, reducing handling costs, loading and unloading times, and product damage.

  2 - Enables the use of standardized material handling equipment.

- **Disadvantages of unit loads:**
  1. Time spent forming and breaking down the unit load.
  2. Cost of containers/pallets and other load restraining materials used in the unit load
  3. Empty containers/pallets may need to be returned to their point of origin.

- **Unit Load Design**

  Unit loads can be used both for in-process handling and for distribution (receiving, storing, and shipping).

  Unit load design involves determining the:

  1. Type, size, weight, and configuration of the load
  2. Equipment and method used to handle the load
  3. Methods of forming (or building) and breaking down the load.

  Selecting unit load size for in-process handling:

  •Unit loads should not be larger than the production batch size of parts in process—if the unit load size is larger, then a delay would occur if the load is forced to wait until the next batch of the part is scheduled to start production (which might be days or weeks) before it can be transported.

  •Large production batches (used to increase the utilization of bottleneck operations) can be split into smaller transfer batches for handling purposes, where each transfer batches contains one or more unit loads, and small unit loads can be combined into a larger transfer batch to allow more efficient transport (e.g., several cartons at a time can be transported on a hand truck, although each carton is itself a unit load and could be transported separately); thus:

Single part ≤ Unit load size ≤ Transfer batch size ≤ Production batch size

• When parts are transferred between adjacent operations, the unit load may be a single part.

•When operations are not adjacent, short distance moves ⇒ smaller unit load sizes, and long distance moves ⇒ larger unit load sizes.

•The practical size of a unit load (cf. the Unit Load Principle) may be limited by the equipment and aisle space available and the need for safe material handling (in accord with the Safety Principle).

Selecting unit load size for distribution .

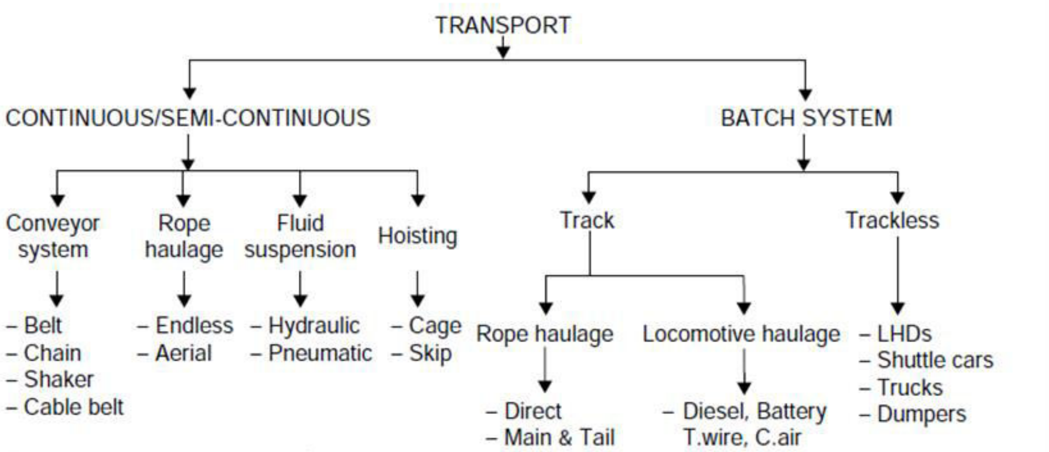
•Containers/pallets are usually available only in standard sizes and configurations.

•Truck trailers, rail boxcars, and airplane cargo bays are limited in width, length, and height.

•The existing warehouse layout and storage rack configuration may limit the number of feasible container/pallet sizes for a load.

• Customer package/carton sizes and retail store shelf restrictions can limit the number of feasible container/pallet sizes for a load.

- **classification of mine transportation system**



Batch & continuous systems of mine transportation

Figure 7.2 Batch and continuous system of transportation.

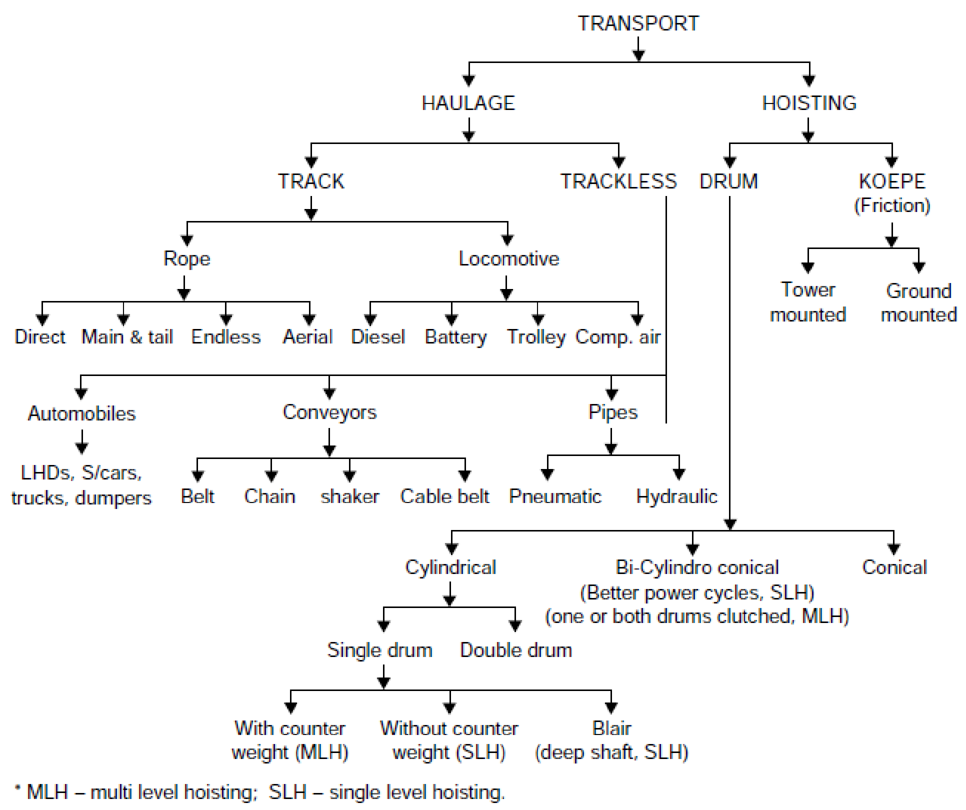
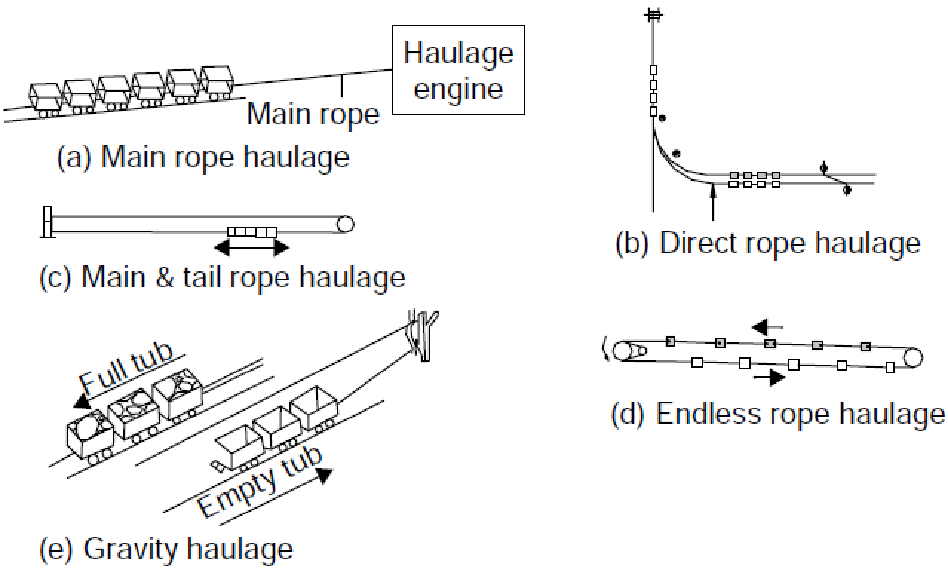


Figure 7.1 General classification of mine transportation system.

- RAIL OR TRACK MOUNTED – ROPE HAULAGE:



Scope and applications of rope haulage

This system is simple in construction and maintenance. It can suit any gradient and curvature of roadways. Even gravity can assist it to the extent that in hilly terrain it could be installed as shown in above figure (e). This type of arrangement, when installed in an incline, it is known as self-acting-incline. Main drawbacks of rope haulage are large amount of manual work required at the terminals; absence of complete mechanization and automation of all operations, less reliability and complicated work involved in negotiating branches and junctions. This makes the system inadequate for modern mines and tunnels. This system could be used for low capacity mines having low degree of mechanization. It finds its application as a auxiliary haulage for material transport in some mines. However, on steep gradients, where belt conveyors cannot be deployed, its use is almost mandatory; and it is used in conjunction with cage and skip hoisting operations in shafts and inclines.

- **LOCOMOTIVE HAULAGE**

The rail transport finds its application as gathering and main haulage in the underground mines and tunnels. The rope haulage system works on track and so is the locomotive haulage. The locomotive haulage is best suited as a long distance haulage with a gradient in the range of 1 in 200 to 300. However, gradient up to 1 in 30 for a short distance can also be negotiated by this system. The system is flexible comparing to rope and belt conveyor systems. Good roads, efficient maintenance, large output and adequate ventilation are the basic requirements for the success of this system. Well-drained, properly graded and minimum turning with smooth curves constitutes a good road. Laying the rails of suitable size (i.e. weight per meter or yard) with proper fittings and alignment is the key to the success of this system. The weight of rails varies depending upon the weight of locomotive and the number of wheels it has got (which could be either four or six). The range is 15–50 kg/m (30–100 lb./yard) for locomotives 'weight that varies from 5 to 100 tons.

Basically locomotives for their underground use are either diesel or electric power driven. Under the electric system – battery, trolley wire, combine trolley-battery and compressed air driven locomotives can be listed. The last one is almost outdated now a days. Elaborate ventilation requirement in underground gassy coalmines restricts the use of diesel locomotives. Similarly use of trolley wires locomotives is also restricted in such mines due to the risk of fire and explosion that can be caused by the bare trolley wire and electric spark. The battery locomotive is, therefore, a better choice for all types of mines and tunnels, particularly when it is used as a gathering haulage. The trolley wire and diesel locomotives find their applications in the main roads and civil tunnels.

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Hoisting equipment

•Cranes:

General characteristics of cranes:

1. Used to move loads over variable (horizontal and vertical) paths within a restricted area
2. Used when there is insufficient (or intermittent) flow volume such that the use of a conveyor cannot be justified
3. Provide more flexibility in movement than conveyors
4. Provide less flexibility in movement than industrial trucks
5. Loads handled are more varied with respect to their shape and weight than those handled by a conveyor
6. Most cranes utilize hoists for vertical movement, although manipulators can be used if precise positioning of the load is required

Type of Cranes

1. Jib crane
2. Bridge crane
3. Gantry crane
4. Stacker crane

•Conveyor system :

•Belt Conveyor

•Apron Feeder

•Screw Conveyor

•Deep Pan Conveyor

•Drag Chain Conveyor

•Flexowell Conveyor

•Rope way Trolley

•Skip Charging System

Belt conveyors

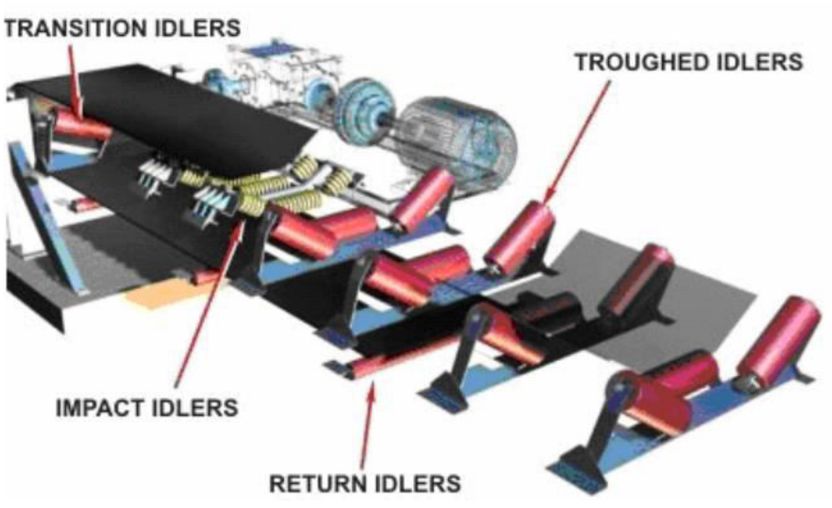
A belt conveyor consists of an endless belt of a resilient material connected between two pulleys and moved by rotating one of the pulleys through a drive unit gearbox, which is connected to an electric motor. The driving pulley end is called as head end, and the pulley is called as head pulley. Conversely, the other pulley is at the tail end and is referred to as the tail pulley as shown in figure bellow.

Material is conveyed by placing it on the belt, through a feeder. As the belt

rotates, the material is carried with it on the other end, where it is then dropped in the discharge chute. It should be noted that discharge can be arranged at any point along the run by means of special discharge devices.

As the belt rotates, due to the weight of the belt and the conveyed material,

the belt will sag. To support this sag, rollers called as idlers or idler pulleys are placed on both sides (carrying side and the return side). Closely spaced idlers are placed at the loading point, as there is some impact due to the falling material and overcrowding of the material in this region. The belt is subjected to tension and it being from a resilient material is prone to elongation. This reduces the tension in the belts. Reduction in tension causes slackness of the belt on the pulleys resulting in slippage and loss in power. To compensate for this, a tensioning device called as take-up arrangement is used.



- Types of belt conveyors
    1- Channel Stringer Belt Conveyors
    2- Truss Frame Conveyors
    3- Slider Bed Belt Conveyors
    4- U-Trough Belt Conveyors
    5- Flat Slide Belt Conveyors

6- Totally Enclosed Belt Conveyors
7- Custom engineering conveyors

- Advantages of belt conveyor over other system

1. Can be operated over long distances over any kind of terrain.
2. Having high load carrying capacity and carry all kinds of loads.
3. Noiseless as compared to chain conveyors.
4. Much simpler to maintain and don’t require any major lubrication system like chain conveyors.
5. Their reliability has been proved over a long period by its use in the industry.
6. Environmentally more acceptable.
7. Low labor and low energy requirements.
8. Unlike screw conveyors, belt conveyors can be easily used for performing processes functions in a production line.

- Types of conveyor layout
  1. Horizontal
  2. Inclined upwards
  3. Inclined upwards – Horizontal
  4. Horizontal- Inclined upwards
  5. Horizontal Inclined Horizontal
  6. Inclined Horizontal Inclined

Major equipment's of belt conveyor

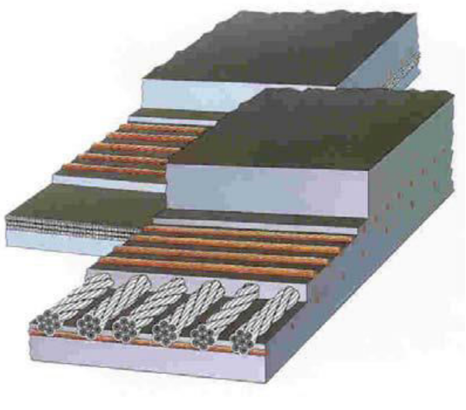
- Conveyor Belt
- Pulleys
- Idlers
- Coupling
- Bearing
- Drive unit
- Electric motor
- Cleaning device

- **Requirement of belt which is to be used in belt conveyor**
  1. High strength: The belt is subjected to tensile loads. It is also subjected to other loads due to scrapers, plows. The material fed also creates an impact load on the belt. All these conditions require the belt to have high strength.
  2. Low self weight: The belt is continuously driven on the pulleys. The power requirement to drive this belt is dependent on its weight.
  3. High wear resistance: The belts are subjected to rough working conditions over a long period of time. Besides this, scrapers, plows, and other cleaners further create wear as they rub over the belt surface. The belt should thus have a high wear resistance to survive in tough conditions.

4. Low elastic and permanent elongation: Any elongation in the belt reduces the tension created in the belt. This would reduce the power transmitting capacity of the belt should have a low elastic and permanent elongation.
5. Flexibility: They should have a good flexibility in the longitudinal and lateral planes. In many cases, belts are made to run over many pulleys. The belt material should have the necessary flexibility to mould over the idlers.
6. High resistance to ply separation: Belts are made from plies, which are bonded with a rubber element. The bonding of the plies should be such that it doesn't separate out due to the repeated bending of the belt over the pulleys.
7. Low water absorption capability: Water if it gets absorbed by the belt increases the weight of the belt. This would result in increased power consumption and reduced conveying capability. It also gives more dimensional stability of the belt.
8. Suitable working environmental conditions: Humidity, extreme heat or cold. The belt material should be good enough to ensure that it works with optimum results under such working environmental conditions.

Conveyor belt

Conveyor belt is made up of compounds comprised of natural rubbers, styrene-butadiene rubber blends of natural and other synthetics, nitriles, butyl, ethylene propylene-based polymer, poly chloroprene , poly butadiene, polyvinyl chloride, urethanes and silicones, etc., Each of those elastomers has specific usefulness for various ranges of properties and operating conditions from which manufacturers and end-users can choose.



Constructional details

Conveyor belts generally are composed of three main components:

1) Carcass
2) Skims
3) Covers

Carcass:

The reinforcement usually found on the inside of a conveyor belt is referred to as the carcass. The functions of a carcass include the following:

•Provide the tensile strength necessary to move the loaded belt.

•Absorbs the impact of the impinging material being loaded on to the conveyor belt.

•Provide the bulk and lateral stiffness required for the load support.

•Belts are connected at the ends by splicing them with belt fasteners. The carcass

should provide the necessary strength to hold fasteners.

The carcass is normally rated by the manufacturer in terms of maximum permissible operating tension. The carcass can of two major types:

1. Fabric ply type
2. Steel cord type

Skims:
The rubber, PVC or urethane between the plies is called as skim. Skims are important contributors to internal belt adhesions, impact resistance and play a significant role in determining the belt load support and trough ability. Improper skims can give reverse effect too. It can lead to ply separation failure.

Covers:
They are used in conveyor belt construction to protect the conveyor belt carcass and also to extend its service life. Its desirable properties such as:

1) Textures.
2) Clean ability.
3) A specific co-efficient of friction.
4) A specific color.
5) Cut resistance.
6) Enhanced impact resistance.
7) Hardness.
8) Fire, oil and chemical resistance

Type of pulley based on Function

1. Driving pulleys (Head and Tail pulleys
2. Snub pulleys
3- Idlers

a) Carrying idlers.

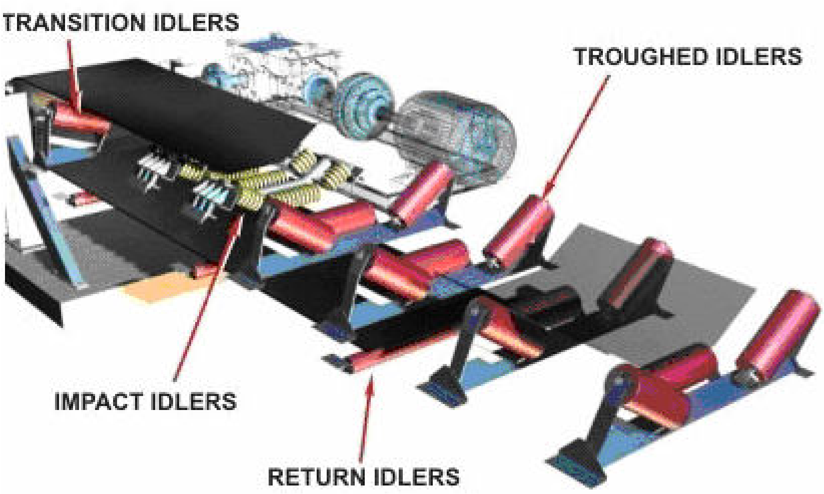
b) Return idlers.

Snub pulley

Snub pulleys are incorporated into the design of a conveyor in order to increase the angle of wrap of the belt on the drive pulley. The greater wrap angle on the pulley allows more power to be introduced into the belt as is passes around the drive pulley without slip occurring. In this way, fewer drives are needed on longer conveyors or conveyors with high conveying loads.

Idlers

The needs for Idlers are to give proper support to conveyor and also to the Material to conveyor. An endless conveyor belt in a conveyor structure is dragged from the tail pulley where material is loaded onto the conveyor, to the head pulley or drive pulley where the material is discharged. Between a conveyors' tail and head pulleys, whether the distance is a number of kilometers or merely a few meters, the carrying and return strand belting is supported on idler sets. The rolls are fitted with antifriction bearings with seals and with adequate lubrication packed into it. The friction between the roller surface and the belt makes the rollers to rotate and thus material is transferred from one point to another through belt conveyor.



Idlers serve following functions

1- Support the belt and the conveyed material on the upper run and the belt in the lower run with minimum frictional resistance.

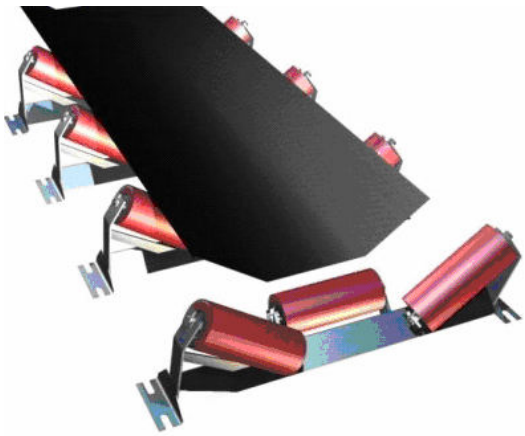
2- Spacing of the idlers is reduced near the loading point, so as to support the belt due to impact of material in that region. This would prevent the belt from wearing quickly
3- Idlers help in centering the belt and guiding it to the drive and snub pulleys.

- **Type of Idlers**

Carrying idler sets

These idler sets support the carrying-side (top) conveyor belt onto which the material is loaded and transported. In the loaded zone we have Impact carrying Idler which is covered by rubber material to absorb the loads as the loading or transferring points. Also we have Self-aligning carrying idlers to avoid the belt off tracking.

Carrying or troughing idler sets usually comprise between two and five individual idler rolls mounted into a common base, which is attached to the conveyor structure. Each idler roll in a 'set' comprises its own set of bearings, seals, shaft and outer shell.



Return idler sets

These idler sets support the return-side (bottom) conveyor belt which returns to the tail pulley after having discharged product over the head pulley. The diagram shown above is flat return type of Idler where only one flat roller is used. The return idler may also have more than one idler arrangement which is called as Garland type idlers.

Once the material has been discharged from the carrying belt, the return belt is guided back to the tail pulley on return idlers. The impact, carrying and return idlers are spaced at different intervals. On the carrying-side, the mass of the belt plus the load conveyed is greater than the mass to be supported on the return-side and thus, for the tension in the conveyor belt (by the take-up and induced by the drive unit), the idler spacing is selected accordingly. This 'sag' in the belt between the carrying and return idler sets must therefore be designed on the basis of the heaviest load that the conveyor is to transport.

PIPELINE HANDLING SYESTEM

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).

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 feeds tocks (also known as secondary feed stocks) 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.

Still other materials transported by pipelines include carbon dioxide and anhydrous ammonia, both transported as liquids under their own pressure.

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 feed stocks such as bitumen recovered from tar sands and heavy oils. Such feed stocks are too viscous to be transported by pipeline. However, the distillate fractions are used to dilute these feed stocks, 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" 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

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 sub tidal 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.

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.

SYSTEM COMPONENTS

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, 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,9 so terminals typically also include facilities to temporarily store such materials before transport to permitted treatment and disposal facilities. A number of facilities have on-site waste water treatment 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.

.2 Piping Types
.2.1 Flow lines
.2.2 Crude Trunk Lines
.2.3 Product Pipelines

.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.

.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.

.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.

.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.

.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 (SCADA) system (see below) and are used to control inspection, maintenance, and repair activities.

.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.

.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.

.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.

.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 overpressurization of pipe segments at the base of grade changes.

.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) anodes. 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 alongside 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.

2 PIPELINE DESIGN

1 FACTORS INFLUENCING PIPELINE DESIGN

1.1 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 feeds tocks);
• 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.

1.2 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 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.
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

1.3 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)

1.4 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.

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 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 microcracks 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.

1.5 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 pipe 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.25 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.

1.6 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 Saw tooth 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.

1.7 Product Qualities

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.

1.7.1 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°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.

1.7.2 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.

1.7.3 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.

1.7.4 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 centistoke 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 feed stocks such as bitumen recovered from tar sands and other very heavy crude fractions to allow their transport by pipeline from production areas to refineries.

1.7.5 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 paraffins. 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 environmental impacts if pipeline ruptures occur during attempts to restart the flow, when a pressure well above design limits could result.