GAS TRANSPORTATION AND STORAGE

(Transportasi dan Penyimpanan Gas)

Teknologi Pemrosesan Gas (TKK 564)

Instructor: Dr. Istadi
(http://tekim.undip.ac.id/staf/istadi)

Email: istadi@undip.ac.id
Instructor’s Background

- Meng. (2000): Institut Teknologi Bandung
- PhD. (2006): Universiti Teknologi Malaysia

Specialization:
- Catalyst Design for Energy Conversion
- Process Design for Energy Conversion
- Combustion Engineering
- Computational Fluid Dynamic (CFD)
Course Syllabus: (Part 2)

1. Hydrocarbons Recovery (*Pengambilan Kembali Hidrokarbon*)
2. Nitrogen Rejection/Removal (*Penghilangan Nitrogen*)
3. Trace Component Removal (*Penghilangan Komponen lainnya*)
4. Natural Gas Liquid Processing and Sulfur Recovery (*Pemrosesan Cairan Gas Alam dan Penghilangan Sulfur*)
5. Gas Transportation and Storage (*Transportasi dan Penyimpanan Gas*)
6. Liquified Natural Gas #1 (*Gas Alam Cair*)
7. Liquified Natural Gas #2 (*Gas Alam Cair*)
8. Second Assignment
9. Ujian Akhir Semester
Important of Gas Transportation

- Raw natural gas is usually located relatively close to gas plants. The processed natural gas and natural gas liquid products must be transported to the end-user, industrial or residential.

- Transportation and storage problems in natural gas are more difficult than with other common forms of energy, such as coal and oil, because the energy density of natural gas is so low at ambient temperatures and pressures.
In equal volume, **oil and coal have quite higher energy than gas**:

- First, a relatively high pressure is required to increase the gas density and raise the energy content per unit volume so that the gas can be transported economically by pipeline (common pressures are approximately 800 to 1,500 psig [60 to 100 barg])

- Second, large quantities of natural gas cannot be stored in relatively simple and inexpensive aboveground facilities similar to those used for liquid-petroleum products. Note that for methane, the primary component of natural gas, the critical temperature is $-118^\circ F \approx -83^\circ C$ and, consequently, no amount of pressure can convert methane into a liquid at $60^\circ F \approx 15^\circ C$. 
Natural Gas Liquid (NGL)?

- Many natural gases contain significant quantities of hydrocarbons that can be removed and liquefied (NGL) to produce the dry natural gas distributed to industrial and residential customers.
- Although more volatile, **NGL is transported and stored in much the same way as crude oil** and refined petroleum products.
- **Natural gas can be liquefied** at cryogenic temperatures as liquefied natural transporting and storing **LNG**.
GAS TRANSPORTATION AND STORAGE: Transportation

- Gas Producers ship **less common gas products** such as hydrogen sulfide, carbon dioxide, nitrogen, and raw helium to customers via dedicated pipelines. ➜ **less efficient economically**
- These lines tend to be short because the customer usually is located near the gas plant.
- Although some plants have a single dedicated customer for the sales gas, most gas goes to an extensive pipeline network dedicated to natural gas service.
- Because **product quality is so uniform** within each country, many different gas processors utilize **the same trunk pipelines**, and many gas plants are connected to multiple pipelines.
- Example: The United States in 2004 had over 212,000 miles of interstate gas pipelines (Energy Information Administration 2005a), serviced by more than 1,200 compressor stations, and capable of transporting over 32 Tcf (910 Bm3) of natural gas per year (Smith et al., 2005).
Pipeline Diameter

- The smaller diameter lines are normally used in the gathering systems which bring the gas from the wellhead to the gas processing plant.
- The larger lines are generally long distance transmission lines designed to bring sales gas to customers.
- The larger and longer lines are normally built with 30-inch or more (75 cm) diameters.

![Pie charts showing U.S. and World pipeline diameters.](image)
Pipeline Compressor Cost

- An approximate cost for **new gas pipeline compressor stations** can be determined from the following equation:

  \[
  \text{Cost (106 US $)} = 2.6 + 1.1 \ (\text{hp/1,000})
  \]

- The cost for a compressor station on gathering systems may be as much as 50% lower
Compressor Power vs Compressor Cost

![Graph showing the relationship between compressor power and cost.](image-url)
Gas can flow through a pipe due to **PRESSURE DROP**

How much pressure drop to determine the total pressure required for transporting gas in a pipeline under various configurations, such as series and parallel pipelines?

In the flow of incompressible fluids such as water, the pressure required to transport a specified volume of fluid from point A to point B will consist of the following components:

1. Frictional component
2. Elevation component
3. Pipe delivery pressure

When **pumping gases**, which are compressible fluids, the three components listed in the preceding section also contribute to the total pressure required
Pipeline .... FRICTIONAL EFFECT

- The frictional effect results from the **fluid viscosity** and **pipe roughness**. It is similar in liquid and gas flow.
- The magnitude of the pressure drop due to friction in a gas pipeline is generally held to smaller values in comparison with liquid pipelines.
- This is because efficient gas pipeline transportation requires keeping the average gas pressure as high as possible.
- The lower the pressure at the downstream end, the higher will be the compression ratio required (hence, the higher the HP) to boost the pressure for shipment downstream to the next compressor station in a long-distance gas pipeline.
Effect of Pipeline Elevation

- The elevation component is due to the difference in elevation along the pipeline that necessitates additional pressure for raising the fluid in the pipeline from one point to another.
- Of course, a drop in elevation will have the opposite effect of a rise in elevation.
- READ EXAMPLE 1 PAGE 87 (*E.S. Menon, (2005), Gas Pipeline Hydraulics, Taylor & Francis Group.*)
EFFECT OF CHANGING PIPE DELIVERY PRESSURE

- The higher the pressure desired at the delivery end or terminus of the pipeline, the higher will be the total pressure required at the upstream end of the pipeline.
- The impact of changing the delivery pressure is not linear in the case of a compressible fluid such as natural gas.
A pipeline in which gas enters at the beginning of the pipeline and the same volume exits at the end of the pipeline is a pipeline with no intermediate injection or deliveries.

When portions of the inlet volume are delivered at various points along the pipeline and the remaining volume is delivered at the end of the pipeline, we call this system a pipeline with intermediate delivery points.
Pipeline with injection and deliveries......
Pipeline with branches.....
READ EXAMPLES 2 – 6 PAGES 94-111 (E.S. Menon, (2005), Gas Pipeline Hydraulics, Taylor & Francis Group.)
# Summary of Pressure Drop Equations

<table>
<thead>
<tr>
<th>Equation</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Flow</td>
<td>Fundamental flow equation using friction or transmission factor; used with Colebrook-White friction factor or AGA transmission factor</td>
</tr>
<tr>
<td>Colebrook-White</td>
<td>Friction factor calculated for pipe roughness and Reynolds number; most popular equation for general gas transmission pipelines</td>
</tr>
<tr>
<td>Modified Colebrook-White</td>
<td>Modified equation based on U.S. Bureau of Mines experiments; gives higher pressure drop compared to original Colebrook equation</td>
</tr>
<tr>
<td>AGA</td>
<td>Transmission factor calculated for partially turbulent and fully turbulent flow considering roughness, bend index, and Reynolds number</td>
</tr>
<tr>
<td>Panhandle A</td>
<td>Panhandle equations do not consider pipe roughness; instead, an efficiency factor is used; less conservative than Colebrook or AGA</td>
</tr>
<tr>
<td>Panhandle B</td>
<td></td>
</tr>
<tr>
<td>Weymouth</td>
<td>Does not consider pipe roughness; uses an efficiency factor used for high-pressure gas gathering systems; most conservative equation that gives highest pressure drop for given flow rate</td>
</tr>
<tr>
<td>IGT</td>
<td>Does not consider pipe roughness; uses an efficiency factor used on gas distribution piping</td>
</tr>
</tbody>
</table>
The capital cost of a pipeline project consists of the following major components:

- Pipeline
- Compressor stations
- Mainline valve stations
- Meter stations
- Pressure regulator stations
- SCADA (supervisory control and data acquisition) and telecommunication
- Environmental and permitting
- Right of way acquisitions
- Engineering and construction management
Gas Market Center

- **Market centers**, or hubs, are usually located near the **intersection of several major pipelines**
- The defining **characteristics of a natural gas market center** are that it provides customers (shippers and gas marketers primarily) with **receipt/delivery access** to two or more pipelines systems, provides transportation between these points, and offers **administrative services** that facilitate that movement and/or transfer of gas ownership.
- Market center services vary widely between facilities, and no two hubs are identical.
Services Arranged and Coordinated in Market Hub Centers

- **Transportation/wheeling**—Transfer of gas from one interconnected pipeline to another through header (hub), by displacement (including exchanges), or by physical transfer over the transmission of a market-center pipeline.

- **Parking**—A short-term transaction in which the market center holds the shippers gas for redelivery at a later date. Often uses storage facilities, but may also use displacement or variations in linepack.

- **Linepack**—Refers to the gas volume contained in a pipeline segment. Linepack can be increased beyond the pipeline’s certificated capacity temporarily and, within tolerances, by increased compression.
- **Loaning** — A short-term advance of gas to a shipper by a market center that is repaid in kind by the shipper a short time later. Also referred to as advancing, drafting, reverse parking, and imbalance resolution.

- **Storage** — Storage that is longer than parking, such as seasonal storage. Injection and withdrawal operations may be separately charged.

- **Peaking** — Short-term (usually less than a day and perhaps hourly) sales of gas to meet unanticipated increases in demand or shortages of gas experienced by the buyer.

- **Balancing** — A short-term interruptible arrangement to cover a temporary imbalance situation. The service is often provided in conjunction with parking and loaning.

- **Title transfer** — A service in which changes in ownership of a specific gas package are recorded by the market center. Title may transfer several times for some gas before it leaves the center.
- **Electronic trading** — Trading systems that either electronically match buyers with sellers or facilitate direct negotiation for legally binding transactions.

- **Administration** — Assistance to shippers with the administrative aspects of gas transfers, such as nominations and confirmations.

- **Compression** — Provision of compression as a separate service. If compression is bundled with transportation, it is not a separate service.

- **Risk Management** — Services that relate to reducing the risk of price changes to gas buyers and sellers, for example, exchanges of futures for physicals.

- **Hub-to-hub transfers** — Simultaneous receipt of a customer’s gas into a connection associated with one center and an instantaneous delivery at a distant connection associated with another center.
Gas Facilities

- Basically, **two types of storage facilities** exists for natural gas:
  - (1) **relatively small capacity** (to 15 MMscf [400,000 Sm³]) aboveground, floating-roof gas holders that operate near ambient pressure and
  - (2) **much larger underground facilities** (depleted oil and gas fields, salt caverns, and aquifers) that operate at elevated pressures.

- Overall, **underground storage is more important** and the discussion here is limited to this topic.

- Underground storage is prevalent throughout the world, with two exceptions, Japan and Korea. In these two countries, gas storage is primarily in the form of LNG.
Aquifers are underground natural water reservoirs that can, under the right circumstances, be used for gas storage.

However, aquifer storage is usually the most expensive and, thus, the least desirable underground storage method for six reasons (NaturalGas.org, 2004):

- Geologic characteristics of a specific aquifer are generally not well known, which is usually not the case with a depleted gas or oil field, and, consequently, considerable resources must be expended to determine the suitability of the aquifer for gas storage.
- Infrastructure (wells, pipelines, dehydration facilities, compression equipment, etc.) is unavailable at the aquifer site, whereas a depleted gas reservoir would have most of this infrastructure in place.
- Considerable injection pressure may be required to displace the water with gas.
- Withdrawn gas requires dehydration.
- Aquifer formations generally require a much higher level of cushion or base gas (up to 80% of the total gas volume) than do depleted fields or salt caverns, and, thus, less of the reservoir volume is usable.
- Environmental regulations govern the use of aquifers for gas storage.
Underground Salt Bed

- A common and relatively **inexpensive technique for creating large storage facilities** is solution mining of underground salt beds.
- After the salt bed has been located and the appropriate well or wells drilled, a coaxial pipe is inserted in the well bore.
- Water is then pumped down the annulus of the pipe, and the dissolved brine is withdrawn through the inner pipe.
- The cavern formed tends to be free from fractures that would permit gas leaks and is well suited for pressurized gas storage.
underground storage salt caverns by leaching with fresh water
Important Terminology for Underground Storage

- **Total gas storage capacity** - Maximum volume of gas that can be stored in an underground storage facility
- **Total gas in storage** - Volume of storage in the reservoir at a particular time
- Cushion gas (or base gas) - Volume of gas intended as a permanent inventory in a storage reservoir to maintain adequate pressure and deliverability rates throughout the withdrawal season
- **Working gas capacity** - Total gas storage capacity minus cushion gas
- **Deliverability** - Most often expressed as measure of the amount of gas that can be delivered (withdrawn) from a storage facility on a daily basis; deliverability is variable and depends on such factors as the amount of gas in the reservoir at any time, the reservoir pressure, and compression capability available to the reservoir
- **Injection capacity (or rate)** - Amount of gas that can be injected into a storage facility on a daily basis; injection rate is also variable; depends on the same factors as deliverability.
In common with other petroleum products, **liquids are transported by dedicated pipeline**, by batching with other liquids in a petroleum pipeline, and by **rail, truck, and marine transport**

The **most feasible and economical means of transport** depends upon **many factors**, including:

- **Product specifications**, especially with respect to water and sulfur requirements ➔ limitations of pipeline or storage container usage
- **Existing infrastructure**
- **Volatility**
- **Rate of product** produced
- **Distance** between plant and customer
- **Geographic location**
Natural Gas Liquids (NGL)

- Natural gas liquids (NGL) are the major liquid product from gas plants that do not further fractionate demethanizer bottoms.
- Usually, the quantity is large enough to dedicate a pipeline to the customers, who typically are operators of central NGL fractionation and storage hubs.
- Specifications exist on methane content, water content, and sulfur content, but the need for continuous flow is the major reason for the dedicated line.
Ethane-Propane Mixtures

- The high vapor pressure of ethane–propane mixtures (E-P mix) and water-content specification make dedicated pipelines the common transport means for this liquid.
- Common carriers in Texas provide dedicated pipelines to transport E-P mixes to the major customers, refineries, and chemical plants.
- This also applies to high purity ethane.
Liquefied Petroleum Gas

- Because it is a widely used fuel with strict specifications on water and sulfur, liquefied petroleum gas, or LPG, (more specifically HD-5 propane) must use dedicated transport.
- During the early years of the evolving LPG transportation system, the principal method was the railroad tank car, with pipelines playing a minor role, but by 1962, more than 40% of LPG was transported by pipeline and today it is the preferred method.
Light gas-plant producer liquids can be stored aboveground in pressurized vessels or below ground in large caverns

- Cylindrical
- Spherical