A Discussion of Natural Gas Pipeline System Efficiency

Gas/Electric Partnership
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Pipeline System Efficiency
Discussion Points

• Pipeline Goals
• Efficiency Metrics
• Compressor Efficiency Example
• Challenges – what can we change
• Opportunities

• Appendix
  – State-of-the-Art Efficiency Goals for discussion
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19% of total U.S. interstate pipeline mileage
23 Bcf/d capacity (16% of total U.S.)
16 Bcf/d throughput (28% of gas delivered to U.S. consumers)
3.1 million horsepower
Pipeline Goals

Deliver Gas:

1. Safely
2. Reliably
3. Affordably
   • Capital Efficiency
   • Operational Efficiency

The first two points are easily understood but what does “Efficiency” mean?
Pipeline Efficiency

a) Measure of fuel consumed over transported volumes?

b) Measure of engine fuel versus net output power?

c) Measure of compressor input power to useful gas compression?

d) All of the above and more?
Pipeline System Efficiency

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d) All of the above and more!
Pipeline System Efficiency

- **Pipeline** *(<X%) consumed/transported XX¢/Mcf-mile*
- **Engine** *(Btu/hp*hr) lowest heat rate (kJ/kW*hr)*
- **Compressor** *(80+%) highest percentage possible Widest operating range*
Pipeline System Efficiency

• Existing Facilities
  – Maintaining Efficiency/Operating Efficiently
    • Real-time analysis of equipment performance
    • Compressor Valve replacements
    • Pipeline cleaning
    • Station/Unit Dispatch
      – Hydraulic optimization
      – Gas vs Electric
      – Compression efficiency
  – Improving Efficiency
    • Upgrading engines
    • Upgrading compressors
    • Replacing restrictions
    • New technologies: waste heat recovery, magnetic bearings
Operating Efficiently

Snapshot of TGP’s Gas Control Center

TGP Schematic
Serenity Prayer

“...Grant me the serenity to accept the things I cannot change;
Courage to change the things I can;
and wisdom to know the difference...”

Reinhold Niebuhr (1892 – 1971)
New Pipelines are designed to be efficient

- Highest operating pressure justifiable above what is needed; new pipelines operate at 1440 psig
- Largest diameter pipe affordable 42”
- Internally coated to reduce friction
- Highest efficiency drivers and compressors available that provide the market area flexibility demanded by customers
Example Segment Fuel Curve

For this pipeline segment doubling the flow more than quadrupled the fuel requirement – this isn’t indicative of inefficiency, it is a fact of physics, the frictional losses increase exponentially with the increase in gas velocity.
Existing Pipelines apply technology to improve efficiency

• Drivers Upgrades and replacements
  – Repowering
  – Turbocharger replacements
  – High pressure fuel injection
  – Waste heat recovery

• Compressor Upgrades
  – Re-wheels, valve replacements
Compressor Driver Improvements

- Replace high heat rate turbines with high speed motors*
- Replace high heat rate reciprocating engines with slow speed motors*
- Exchange engine cores
- Install new turbine/compressor packages
- Install new reciprocating compressor packages

* where power infrastructure exists, HR > 10,000 Btu/hp*hr
Compressor Efficiency 1980’s

71% 80% 71%

Isentropic Head (FT-LB/LBM)

Surge line
10% Surge margin

Full Load

Inlet Flow (ACFM)

Historical Data
Modern Compressor Efficiency
Challenges

• Environmental
  – BACT

• Economics
  – No payback because of low load factors
  – Paybacks in excess of 20 years, high capital costs
  – Obstacles for waste heat such as utilities paying the lowest avoided purchase power costs
  – Fuel savings may benefit shippers, not the pipeline who made the investment “Fuel Tracker”
Challenges continued

• Funding

• Staffing
  – Training

• Product Support
  – Vendors cannot afford “One-Offs”
  – Pipelines do not want science experiments...
  – No spare equipment for peak days
Challenges - Variable Operations

• Pipelines are traditionally designed to meet full contractual load
  – Lowest capital cost project typically wins
  – Cost recovery for long term efficiency

• Actual conditions can vary from contractual
  – Mainline throughputs
This historic view of mainline operating throughput data is intended for informational purposes only and may not be indicative of future operations.
Monthly Average Throughput

This historic view of mainline operating throughput data is intended for informational purposes only and may not be indicative of future operations.
Horsepower utilization is highly dependent on customer demand. Customer demand is highly price and weather sensitive.
Opportunities

• Identify high load factor locations
• Seek limited rate recovery for “ideal” replacements
• R&D authorization with cost recovery
• Develop an understanding of efficiency at the component and system level
• Questions?

• Comments?

• Do you have a case study to share?
Pipeline Efficiency Discussion

Thank you

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Interested in further discussion?
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Appendix
Economic State-of-the-Art

- Transmission Pipeline (transport): ~95-98%\(^2\)
- Compressor station with waste heat: ~40-49%\(^3\)
- Large Gas fired Compressor Station: ~30-40%\(^3\)
- Motor Efficiency: ~95-98%
- Reciprocating Engine Thermal: ~30-42%
- Large Turbine Thermal: ~25-40%
- Centrifugal Compressor: ~78-89%
- Reciprocating Compressor: ~78-92%

Efficiency varies significantly with size and load. Larger compressor stations 30,000\(^*\) hp can achieve economies of scale that are not economically possible with smaller units installed 20\(^*\) years ago.

\(^{1}\) Part load conditions greatly improve efficiency and are dictated by the marketplace.

\(^{2}\) Newer pipelines with minimal compression and/or high pressure and large diameter relative to flow

\(^{3}\) Includes station piping losses
Engine / Compressor Efficiency

Thermal Eff = \frac{2544}{\text{HeatRate, } \frac{Btu}{hp \times hr}} \times 100

Engine efficiencies in the range of 25% - 42%

Compressor Eff % ≈ \frac{(T_s + 460)}{(T_d - T_s)} \times \left[ \left( \frac{P_d + P_a}{P_s + P_a} \right)^{(k-1)} - 1 \right] \times 100

Compressor efficiency in the range of 75% - 92%

English units
Temperature in Rankine
‘s’ Suction conditions
‘d’ Discharge conditions
‘a’ Atmospheric conditions
Example Fundamental Flow Equation

\[
Q = 77.54 \frac{T_b}{P_b} D^{2.5} e \left[ \frac{P_s^2 - P_d^2 - \frac{0.0375G(h_2 - h_1)}{P_{avg}}}{G * T_{avg} * L * Z * f} \right]^{0.5}
\]

where

- \( Q \) = Gas flow in CF/d
- \( P_b \) = Pressure base, p.s.i.a.
- \( T_b \) = Base temperature, °R
- \( D \) = Internal pipe diameter, inches
- \( e \) = Efficiency factor (dimensionless \( \approx 1 \))
- \( P_s \) = Inlet pressure, p.s.i.a.
- \( P_d \) = Outlet pressure, p.s.i.a.
- \( G \) = Specific gravity
- \( Z \) = Gas compressibility factor
- \( h_2 - h_1 \) = Change in elevation, feet
- \( L \) = Length of pipeline, miles
- \( P_{avg} \) = Average pressure, p.s.i.a. \((2/3 [P_1 + P_2 - (P_1P_2 / (P_1 + P_2))]\)
- \( T_{avg} \) = Average design gas-flowing temperature
- \( f \) = Friction factor

Pipeline efficiency factor typically in the range of 98% - 100%
Fans Laws

- Flow \( (Q) \) is a function of speed \( (N) \)
- Head \( (H) \) “~Pressure” is a function of speed\(^2\)
- Power \( (P) \) is a function of speed\(^3\)

\[
\frac{Q_1}{Q_2} \approx \left( \frac{N_1}{N_2} \right)
\]

\[
\frac{H_1}{H_2} \approx \left( \frac{N_1}{N_2} \right)^2
\]

\[
\frac{P_1}{P_2} \approx \left( \frac{N_1}{N_2} \right)^3
\]

http://en.wikipedia.org/wiki/Affinity_laws