Data Analysis and Model Validation of Natural Gas Transmission Pipeline with Compressor Station

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Introduction

- Growth of net income relies on reducing the delivery cost and maintaining the pipeline transport efficiency

Introduction

- Pipeline design and operation targeting higher efficiency and lower cost
  - New Pipeline: Design efficiency and minimum delivery cost at design flow rate
  - Brown Field Pipeline: Optimized flow rate and efficiency change after years into service
- Maintenance needs:
  - improve transport performance
  - reduce fuel consumption
  - increase flow capacity
Introduction

• Model plays major role in decision making
  • Provide data as basis for economic evaluation and forecasting
  • As the foundation of the Jcurve Analysis
    • Minimize the delivery cost of the pipeline ($/MMSCF of gas or $/MBbl of oil)
    • Maximize the ROI (Market forecast as input)
Introduction

• Model accuracy is very important
  • New pipeline: impact the design of the system, CAPEX, and OPEX estimate
  • Brown Field Pipeline: Impact the reliable understanding of the efficiency of the system and estimate on delivery cost
  • Fuel consumption evaluation and optimization
Introduction

• Benchmarking pipeline hydraulics performance under the agreed testing procedure
• Analyzing data collected through the DCS or SCADA system
• Problems:
  • Pipeline falls short on supply and demand in early phase of operation. Flow capacity of the pipeline needs to be projected through models
  • Uncertainty in gas quality and data measurements
  • Pipeline supplies and demands are transient and random in nature
Model Validation Approach

• Five steps of modeling and hydraulics performance assessment:
  • data collection,
  • model parameter tuning,
  • model validation,
  • flow condition prediction,
  • performance assessment.
Model Validation Approach

- DCS data
  - Hourly pressure, flow rate, and temperature from transmitters at compressor stations, mainline block valves, and metering stations
  - The specific gravity of the gas and the ambient soil temperature information are also collected from the DCS system.
Model Validation Approach

- Data in relatively stable operating periods used in parameter tuning and model benchmarking
- Tuned model is validated using more hourly and daily data
- Pressure profile from model are compared with measurements
- Square root error of the pressure distribution is reported
- Model that passes the error threshold can be used in the assessment and prediction of the performance
- Validated pipeline hydraulics model, with tuned parameters, is then used to predict delivery flow, pressure, and temperature at all stations at planned operation conditions.
Procedure

• To validate a model, the gas pipeline model must be sufficient and accurate in the following aspects:

  1) Accurate pipeline as built information
      • The model must be based on accurate as built data such as pipe sizes (OD and Wall thickness), lengths, elevation profiles, compressor performance data, valve characteristics and pipeline control logic and setpoints.

  2) Gas Properties
      • Gas properties need to be modeled based on accurately analyzed samples. The accuracy of model relies on accurate thermal and physical properties such as density, viscosity, thermal conductivity and specific heat of the gas.

  3) Pipeline Absolute Hydraulics Roughness
      • The major parameter in gas hydraulics model tuning is the pipeline roughness. Ideally, the only parameter to be validated and tuned is the Friction Factor based on the measured pressure loss and pipeline flow rate.
Procedure

• PAPAMETER TUNING PROCEDURE

1. Assumed Pipeline Roughness
2. Time Average Inlet Pressure and User Flow rates Data
3. Gas Pipeline Hydraulics Model
4. Hydraulics Model Output
5. Error Acceptable?
   - No: Adjust Pipeline Roughness
   - Yes: Pipeline Pressure DCS Data
   - Yes: Hydraulics Model Parameter Tuned Pipeline Roughness Verified
Procedure

• MODEL VALIDATION PROCEDURE

1. Tuned Pipeline Roughness and Other Parameters
2. Gas Pipeline Hydraulics Model
3. Hydraulics Model Output

- Error Acceptable?
  - No: Hydraulics Model is not able to predict the gas pipeline performance. Model need to be revised. Deviation of the results need to be identified
  - Yes: Hydraulics Model Validated Successfully by the Data

- Hourly Inlet Pressure and User Flow rates Data
- Hourly Pipeline Gas Pressure and Temperature DCS Data
Procedure

• EXAMPLE
Procedure

- EXAMPLE
Influences and Uncertainty

- Two aspects of uncertainties:
  - 1) Tuned parameter beyond possible range: indicate other factors neglected in the mode
    - E.g. dry black powder
    - For influences that the associated parameters are not easy to be measured or validated, a sensitivity analysis is necessary
  - 2) Randomness and Uncertainty in data and variables
    - Model validation considering randomness and uncertainty due to operation or measurements (Cheng, D. and Acre, M., 2018).
Validation Using MCMC

- User Flow Rates Randomness

<table>
<thead>
<tr>
<th></th>
<th>Inlet</th>
<th>User 1</th>
<th>User 2</th>
<th>User 3</th>
<th>User 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Std Deviation</td>
<td>40.22</td>
<td>4.24</td>
<td>8.79</td>
<td>1.57</td>
<td>34.36</td>
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<td>Min</td>
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<td>52.17</td>
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<td>643.07</td>
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<td>Variance</td>
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<td>17.94</td>
<td>77.34</td>
<td>2.47</td>
<td>1180.41</td>
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</table>
Validation Using MCMC

• Pressure Randomness

<table>
<thead>
<tr>
<th></th>
<th>Inlet</th>
<th>User 1</th>
<th>User 2</th>
<th>User 3</th>
<th>User 4</th>
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</thead>
<tbody>
<tr>
<td>Std Deviation</td>
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<td>Min</td>
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<td>Max</td>
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<td>67.29</td>
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<td>Mean</td>
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<td>66.09</td>
<td>60.54</td>
<td>58.86</td>
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<tr>
<td>Variance</td>
<td>0.59</td>
<td>0.36</td>
<td>0.79</td>
<td>1.32</td>
<td>4.11</td>
</tr>
</tbody>
</table>
Validation Using MCMC

- Markov Chain Monte Carlo method
  - Markov Chain was used to generate the required simulation boundary conditions (inlet pressure and user flow rates)
  - Data generation was based on the probability distribution of the DCS data.
  - A Burn-In MCMC

\[ X_{n+i} = \sigma Z + \mu \]

\( X_{n+i} \) is a random number that will be used in terms of the MCMC to generate the iterations from the original state \( X_{n+1,2,3,...} \) using a linear ramp under a transient simulation, this will generate enough results to compare against the daily average results.
Validation Using MCMC

- Validation Results

<table>
<thead>
<tr>
<th>Total Flow Rate</th>
<th>P User 1</th>
<th>P User 2</th>
<th>P User 3</th>
<th>P User 4</th>
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<tbody>
<tr>
<td><strong>MMCFD</strong></td>
<td>kg/cm²</td>
<td>kg/cm²</td>
<td>kg/cm²</td>
<td>kg/cm²</td>
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<td>Simulation</td>
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<td>63.9</td>
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<td>Data</td>
<td>916.6</td>
<td>66.1</td>
<td>60.5</td>
<td>58.9</td>
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<tr>
<td>% error</td>
<td>9%</td>
<td>6%</td>
<td>6%</td>
<td>4%</td>
</tr>
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</table>
Conclusions

• Practical method to validate the gas pipeline hydraulics model using the DCS data presented
• Application of using the validated model in the assessment and monitoring of pipeline hydraulics performance demonstrated
• Procedures on how to use the method were introduced
• Major factors influencing the results were discussed
Conclusions

• Model validation method using MCMC to consider the data uncertainty introduced
• Work in this area is still ongoing
  • Sensitivity to uncertainty of different factors is under further evaluation
• Markov property shows possibility in developing into a more controllable and efficient way of model validation considering uncertainty and transient pipeline hydraulics