Prudhoe Bay Oil Production Optimization: Using Virtual Intelligence Techniques, Stage One: Neural Model Building

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SPE 77659
OUTLINE

- OBJECTIVE
- BACKGROUND
- BUSINESS MOTIVATION
- INTRODUCTION
- METHODOLOGY
- CONCLUSIONS
- FUTURE WORK
OBJECTIVE

● The objective of this study is to develop a tool to assist engineers in maximizing total field oil production by optimizing the gas discharge rates and pressures at the separation facilities.
BACKGROUND

- Prudhoe Bay has approximately 800 producing wells flowing to eight remote, three-phase separation facilities (flow stations and gathering centers).
- High-pressure gas is discharged from these facilities into a cross–country pipeline system flowing to a central compression plant.
BACKGROUND

Simplified Overview of the Gas Transit Line System

- GC2
- GC1/GC1A
- GC3
- CGF/CCP
- FS2
- FS1/FS1A
- FS3

Legend:
- Central Gas Compression Plant
- 3-phase separation facility
- 34" and 60" high pressure gas lines

Scale: 2 Miles

To Gas Reinjection
BACKGROUND

- Fuel gas supply (at the flow stations and gathering centers) and artificial lift gas supply for the lift gas compressors at GC1 are taken off the gas transit line upstream of the compression plant.

- This reduces the feed gas rate and pressure at the inlet to the compression plant.
BACKGROUND

- Gas feeding the central compression plant is processed to produce natural gas liquids and miscible injectant.
- Residue gas from the process is compressed further for reinjection into the reservoir to provide pressure support.
Ambient temperature has a dominant effect on compressor efficiency and hence total gas handling capacity and subsequent oil production.
A significant reduction in gas handling capacity is observed at ambient temperatures above 0 °F.

Gas compression capacity is the major bottleneck to production at Prudhoe Bay and typically field oil rate will be maximized by preferentially producing the lowest GOR wells.
BUSINESS MOTIVATION

- As the ambient temperature increases from 0 and 40 °F, the maximum (or “marginal”) GOR in the field decreases from approximately 35,000 to 28,000 scf/stb.
- A temperature swing from 0 to 40 °F in one day equates to an approximate oil volume reduction of 40,000 bbls, or 1000 bopd per °F rise in temperature.
BUSINESS MOTIVATION

- The reduction in achievable oil rate, per degree Fahrenheit increase in temperature, increases with ambient temperature.
- This is due in part to the increase in slope of the curve of shipped gas versus temperature, and also to the reduction in limiting or “marginal” GOR as gas capacity decreases.
BUSINESS MOTIVATION

- The ability to optimize the facilities in response to ambient temperature swings, compressor failures or planned maintenance is a major business driver for this project.
- Proactive management of gas production also reduces unnecessary emissions.
BUSINESS MOTIVATION

- To maximize total oil rate under a variety of field conditions it is first necessary to understand the relationship between the inlet gas rate and pressure at the central compression plant, and the gas rates and discharge pressures into the gas transit line system at each of the separation facilities.
BUSINESS MOTIVATION

- Gas capacity constraints start to affect oil production at about 0 °F, with increasing impact as the temperature increases.
- The estimated benefit of this tool for optimizing oil rate during temperature swings and equipment maintenance is 1-2 MBOPD for 75% of the year.
INTRODUCTION

- Attempts were made to develop a deterministic model of the gas transit system using commercial pipeline modeling software.
- However, it was extremely difficult to obtain sufficient historical data to validate the model.
- Development of a neural network model was undertaken to determine if this approach would provide a robust description of the observed gas rates and pressures with less stringent data requirements.
INTRODUCTION

- For this initial test it was assumed that there was negligible hysteresis in the system.
- Initial results were very encouraging, suggesting that this is a valid approach, albeit limited to the data range used to train the model.
The methodology is divided into two sections.

1. Data collection
2. Training and verification of neural network models:
   - Central Compression Plant Inlet Model
   - Separation Facility Gas Discharge Models
METHODOLOGY

● Data Collection
  ● The field data necessary to train the neural network models was carefully checked for consistency.
  ● To ensure the data represented consistent field conditions (e.g. similar compressor configurations) and did not include periods where there were major equipment failures or maintenance, the data had to be carefully filtered.
  ● Consequently, the final available dataset was more limited than had been anticipated and the initial neural network model is limited to a fairly narrow range of field conditions.
METHODOLOGY

Data Collection

The data included:

- Gas rate and gas discharge pressure from each of the eight separation facilities
- Fuel gas and lift gas supply rates
- Average hourly temperatures
- Inlet rate and pressure at the central gas compression plant.
METHODOLOGY

- Data Collection
  - The objective of this study is to optimize the target gas rates at each of the separation facilities in order to maximize oil production from the field.
  - Step One: build a representative model of the entire gas transit pipeline system.
  - Step Two: build an intelligent optimization tool to find the best combination of rate and pressure for each facility to optimize gas production.
METHODOLOGY

● **Data Collection**
  - The neural network model should have two main characteristics:
    - The model must accurately represent this complex dynamic system.
    - The model must provide fast results (close to real-time) once the required information is presented.
METHODOLOGY

- Temperature plays a key role in this operation.
- The data used to build the neural network model was averaged on an hourly basis.
- Data from a total of 46 days was represented in the data set.
- The data starts with the first day of the August and ends with the last day of September 2001.
**METHODOLOGY**

![Graph showing average daily temperature](image)

**Average Daily Temperature**

<table>
<thead>
<tr>
<th>Date</th>
<th>Average Temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/1/2001</td>
<td>20.00</td>
</tr>
<tr>
<td>8/3/2001</td>
<td>25.00</td>
</tr>
<tr>
<td>8/7/2001</td>
<td>30.00</td>
</tr>
<tr>
<td>8/13/2001</td>
<td>35.00</td>
</tr>
<tr>
<td>8/15/2001</td>
<td>40.00</td>
</tr>
<tr>
<td>8/19/2001</td>
<td>45.00</td>
</tr>
<tr>
<td>8/23/2001</td>
<td>50.00</td>
</tr>
<tr>
<td>8/27/2001</td>
<td>55.00</td>
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<tr>
<td>9/2/2001</td>
<td>60.00</td>
</tr>
<tr>
<td>9/6/2001</td>
<td>65.00</td>
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<tr>
<td>9/10/2001</td>
<td>70.00</td>
</tr>
<tr>
<td>9/14/2001</td>
<td>75.00</td>
</tr>
<tr>
<td>9/18/2001</td>
<td>80.00</td>
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<td>9/22/2001</td>
<td>85.00</td>
</tr>
<tr>
<td>9/26/2001</td>
<td>90.00</td>
</tr>
<tr>
<td>9/29/2001</td>
<td>95.00</td>
</tr>
</tbody>
</table>
METHODOLOGY

- The average daily temperature may be misleading in demonstrating the temperature swings within a single day.
- The model will be dealing with average temperature on an hourly basis rather than a daily basis.
METHODOLOGY

Hourly Temperature Change in One Day

<table>
<thead>
<tr>
<th>Time (Hours)</th>
<th>Temperature (Fahrenheit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/9/01 21:36</td>
<td>37</td>
</tr>
<tr>
<td>9/9/01 0:28</td>
<td>38</td>
</tr>
<tr>
<td>9/9/01 3:21</td>
<td>39</td>
</tr>
<tr>
<td>9/9/01 6:14</td>
<td>40</td>
</tr>
<tr>
<td>9/10/01 9:07</td>
<td>41</td>
</tr>
<tr>
<td>9/10/01 12:00</td>
<td>42</td>
</tr>
<tr>
<td>9/10/01 14:52</td>
<td>43</td>
</tr>
<tr>
<td>9/10/01 17:45</td>
<td>44</td>
</tr>
<tr>
<td>9/10/01 20:38</td>
<td>45</td>
</tr>
<tr>
<td>9/10/01 23:31</td>
<td>46</td>
</tr>
</tbody>
</table>
METHODOLOGY

- Central Compression Plant Inlet Model

Ranges of the parameters that were used during the development of the network models

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Average</th>
<th>Max</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Temperature</td>
<td>20.23</td>
<td>35.85</td>
<td>57.33</td>
<td>6.44</td>
</tr>
<tr>
<td><strong>GAS DISCHARGE RATES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Fuel Gas</td>
<td>38.92</td>
<td>46.61</td>
<td>53.46</td>
<td>2.79</td>
</tr>
<tr>
<td>Gas-Lift Gas at GC1</td>
<td>401.23</td>
<td>809.30</td>
<td>923.09</td>
<td>152.29</td>
</tr>
<tr>
<td>FS1</td>
<td>895.75</td>
<td>1,137.61</td>
<td>1,304.96</td>
<td>76.10</td>
</tr>
<tr>
<td>FS2</td>
<td>428.09</td>
<td>704.69</td>
<td>769.89</td>
<td>63.35</td>
</tr>
<tr>
<td>FS3</td>
<td>382.06</td>
<td>786.61</td>
<td>1,066.79</td>
<td>164.15</td>
</tr>
<tr>
<td>FS1A</td>
<td>907.18</td>
<td>1,273.55</td>
<td>1,530.64</td>
<td>136.96</td>
</tr>
<tr>
<td>GC1</td>
<td>456.85</td>
<td>964.30</td>
<td>1,127.55</td>
<td>214.05</td>
</tr>
<tr>
<td>GC2</td>
<td>807.91</td>
<td>998.21</td>
<td>1,080.00</td>
<td>55.59</td>
</tr>
<tr>
<td>GC3</td>
<td>490.54</td>
<td>1,011.01</td>
<td>1,131.89</td>
<td>112.26</td>
</tr>
<tr>
<td>GC1A</td>
<td>944.00</td>
<td>1,353.91</td>
<td>1,438.83</td>
<td>73.24</td>
</tr>
<tr>
<td><strong>GAS DISCHARGE PRESSURES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed Gas Rate to CCP</td>
<td>6,473.64</td>
<td>7,370.93</td>
<td>7,832.34</td>
<td>234.48</td>
</tr>
<tr>
<td><strong>GAS PRESSURES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS1</td>
<td>592.47</td>
<td>603.46</td>
<td>624.02</td>
<td>7.39</td>
</tr>
<tr>
<td>FS2</td>
<td>563.67</td>
<td>626.76</td>
<td>650.03</td>
<td>11.43</td>
</tr>
<tr>
<td>FS3</td>
<td>625.98</td>
<td>640.73</td>
<td>669.42</td>
<td>10.64</td>
</tr>
<tr>
<td>FS1A</td>
<td>560.75</td>
<td>602.37</td>
<td>625.66</td>
<td>10.47</td>
</tr>
<tr>
<td>GC1</td>
<td>574.95</td>
<td>611.38</td>
<td>634.87</td>
<td>11.54</td>
</tr>
<tr>
<td>GC2</td>
<td>578.68</td>
<td>610.47</td>
<td>634.62</td>
<td>12.16</td>
</tr>
<tr>
<td>GC3</td>
<td>581.66</td>
<td>600.94</td>
<td>622.99</td>
<td>9.66</td>
</tr>
<tr>
<td>GC1A</td>
<td>572.04</td>
<td>601.64</td>
<td>627.60</td>
<td>13.20</td>
</tr>
<tr>
<td>Inlet Pressure to CCP</td>
<td>536.03</td>
<td>559.82</td>
<td>588.60</td>
<td>10.81</td>
</tr>
</tbody>
</table>

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**METHODOLOGY**

- **Central Compression Plant Inlet Model**
  - The spread of the data for each of the neural network models (based on the average daily temperature)

<table>
<thead>
<tr>
<th>Temperature Range in the Dataset</th>
</tr>
</thead>
<tbody>
<tr>
<td>52 51 50 49 48 47 46 45 44 43 42 41 40 39 38 37 36 35 34 33 32 31 30 29 28 27 26 25 24 23</td>
</tr>
</tbody>
</table>

- **Network #1**
  - Training
  - Calibration
  - Verification

- **Network #2**
  - Training
  - Calibration
  - Verification

- **Network #3**
  - Training
  - Calibration
  - Verification
METHODOLOGY

- **Central Compression Plant Inlet Model**

<table>
<thead>
<tr>
<th></th>
<th>Training</th>
<th>Calibration</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Output:</strong></td>
<td>Rate</td>
<td>Pressure</td>
<td>Rate</td>
</tr>
<tr>
<td><strong>Cases:</strong></td>
<td>660</td>
<td>210</td>
<td>118</td>
</tr>
<tr>
<td><strong>R squared:</strong></td>
<td>0.9968</td>
<td>0.9975</td>
<td>0.9919</td>
</tr>
<tr>
<td><strong>Network 1</strong></td>
<td>693</td>
<td>192</td>
<td>103</td>
</tr>
<tr>
<td><strong>R squared:</strong></td>
<td>0.9972</td>
<td>0.9987</td>
<td>0.9827</td>
</tr>
<tr>
<td><strong>Network 2</strong></td>
<td>645</td>
<td>143</td>
<td>94</td>
</tr>
<tr>
<td><strong>R squared:</strong></td>
<td>0.996</td>
<td>0.9977</td>
<td>0.9862</td>
</tr>
</tbody>
</table>
METHODOLOGY

- Central Compression Plant Inlet Model

![Diagram showing a graph with network rates and actual rates. The graph includes data points labeled as 'Training', 'Calibration', and 'Validation'.]
METHODOLOGY

- Central Compression Plant Inlet Model

![Graph showing comparison between Network #1 Compressor Inlet Suction Pressure and Actual FSIM Pressure]
METHODOLOGY

- Central Compression Plant Inlet Model
METHODOLOGY

- **Central Compression Plant Inlet Model**
METHODOLOGY

- Central Compression Plant Inlet Model
METHODOLOGY

- **Central Compression Plant Inlet Model**

![Graph showing Compressor Inlet Suction Pressure - Network #3 with data points for Training, Calibration, and Verification.](image)
METHODOLOGY

- **Separation Facility Gas Discharge Models**
  - A second set of neural networks was developed to model the gas discharge rates and pressures at each of the eight separation facilities.
METHODOLOGY

- **Separation Facility Gas Discharge Models**
  - Since this is a dynamic problem where rate and pressure at each of the facilities depends on the rate and pressure at each of the other facilities as well as the corresponding rate and pressure at the inlet to the Central Compression Plant, the network model built for each of the facilities serve as a pressure-rate check for the optimization process.
METHODOLOGY

- *Separation Facility Gas Discharge Models*
  - This is to ensure that the pressure rate combinations suggested by the optimization routine for each facility does not exceed the local gas capacity or pressure limits.
**METHODOLOGY**

- *Separation Facility Gas Discharge Model*

<table>
<thead>
<tr>
<th></th>
<th>Training</th>
<th>Calibration</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cases:</td>
<td>693</td>
<td>197</td>
<td>98</td>
</tr>
<tr>
<td>R squared for FS1</td>
<td>0.952</td>
<td>0.938</td>
<td>0.922</td>
</tr>
<tr>
<td>R squared for FS2</td>
<td>0.933</td>
<td>0.918</td>
<td>0.909</td>
</tr>
<tr>
<td>R squared for FS3</td>
<td>0.983</td>
<td>0.966</td>
<td>0.975</td>
</tr>
<tr>
<td>R squared for FS1A</td>
<td>0.948</td>
<td>0.948</td>
<td>0.938</td>
</tr>
<tr>
<td>R squared for GC1</td>
<td>0.963</td>
<td>0.954</td>
<td>0.969</td>
</tr>
<tr>
<td>R squared for GC2</td>
<td>0.907</td>
<td>0.911</td>
<td>0.906</td>
</tr>
<tr>
<td>R squared for GC3</td>
<td>0.958</td>
<td>0.949</td>
<td>0.953</td>
</tr>
<tr>
<td>R squared for GC1A</td>
<td>0.932</td>
<td>0.940</td>
<td>0.927</td>
</tr>
</tbody>
</table>
METHODOLOGY

- **Separation Facility Gas Discharge Model**
  - These models are not built based on theoretical understanding of the system, rather by building representative functions that can approximate the data present in the dataset.
  - The nature of the data being studied in this study is discrete.
  - These snap shots in time do not cover all the possible situations that might occur.
METHODOLOGY

- **Separation Facility Gas Discharge Model**
  - Therefore, in some instances it is possible that the data present in the data set does not fully represent all the possible cases.
  - In such cases, one must expect to see an *atypical* behavior of a Pressure-Rate curve that may or may not fit our theoretical understanding of the process.
METHODOLOGY

- **Separation Facility Gas Discharge Mode**

![Graph showing PS1 Pressure-Flow Characteristics at Different Compressor Inlet Suction Pressures](image-url)
METHODOLOGY

- Separation Facility Gas Discharge Mode
METHODOLOGY

- Separation Facility Gas Discharge Mode
METHODOLOGY

- **Separation Facility Gas Discharge Mode**

![Graph showing FS1A Pressure-Rate Curves for Different Compressor Inlet Suction Pressures](image)

- **Temp. = 50 Degrees**
METHODOLOGY

- **Separation Facility Gas Discharge Mode**

![GC1 Pressure-Rate Curves for Different Compressor Inlet Suction Pressures](chart)

**Temp. = 50 Degrees**
METHODOLOGY

- **Separation Facility Gas Discharge Mode**

![GC2 Pressure Rate Curves for Different Compressor Inlet Suction Pressures](chart)

Temp. = 50 Degrees

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METHODOLOGY

- Separation Facility Gas Discharge Mode
METHODOLOGY

- Separation Facility Gas Discharge Mode
CONCLUSIONS

- It is possible to represent the gas transit line system at Prudhoe Bay by a group of neural network models.
- However, additional data is required to retrain the network models for larger range of conditions.
FUTURE WORK

- A rigorous data collection process to obtain data for a broader range of conditions to retrain the network model.
- Validate a deterministic pipeline model of the gas transit line system, which has been built using commercial pipeline simulation software.
- Once validated, this model will be used to generate additional data to train the neural network models.
- This will allow a wider range of sensitivities to be performed to generate potential solutions to the optimization problem.
ACKNOWLEDGEMENT

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